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# HESS J1632-478: An energetic relic

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**Summary.** — HESS J1632-478 is an extended and still unidentified TeV source in the galactic plane. In order to identify the source of the very high energy emission and to constrain its spectral energy distribution, we used a deep observation of the field obtained with XMM-Newton together with data from Molonglo, Spitzer and Fermi to detect counterparts at other wavelengths. The spectral energy density features two large prominent bumps with the synchrotron emission peaking in the ultraviolet and the external inverse Compton emission peaking in the TeV. HESS J1632-478 is an energetic pulsar wind nebula with an age of the order of $10^4$ years. Its bolometric (mostly GeV-TeV) luminosity reaches 10% of the current pulsar spin down power. The synchrotron nebula has a size of 1 pc and contains an unresolved point-like X-ray source, probably the pulsar with its wind termination shock.

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PACS 97.60.Gb – Pulsars.
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## 1. – Introduction

HESS J1632-478 has been discovered as a diffuse very high energy (VHE) $\gamma$-ray source during the 2004-2006 survey of the inner Galaxy [1] performed with the High Energy Stereoscopic System Cherenkov Telescope Array [2] H.E.S.S.

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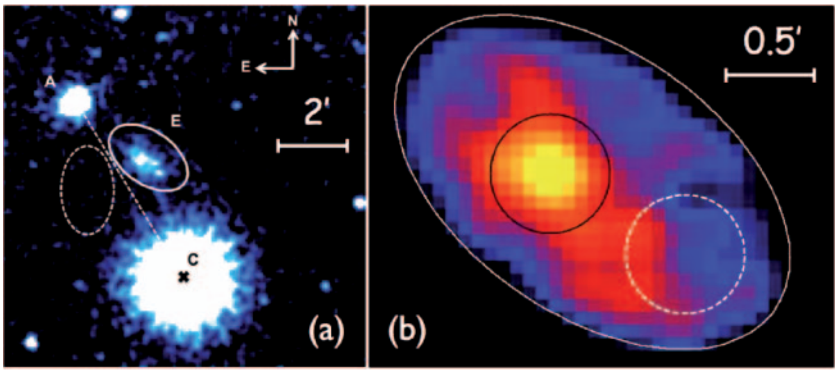


Fig. 1. – a) XMM-Newton MOS mosaic image in the energy band 0.2–12 keV. Ellipses indicate the source (solid) and the background (dashed) extraction region for the extended source. b) The enlarged image extracted from the MOS1 camera shows the extraction region for the point-like (black) and extended (white) sources, respectively.

Though many galactic VHE sources are recognized to be supernova remnants, pulsars and pulsar wind nebulae, a small number of them still lack a clear identification. HESS J1632-478 is one of them, even if tentatives to explain its nature have already been presented [1, 3]. A detailed VHE spectral and positional analysis of HESS J1632-478 has been reported in [1], based on 4.5 hours of H.E.S.S. observations. The source best-fit position is RA = 16h 32m 09s DEC = –47h 49m 12s (J2000), placing it in the direction of the near 3 kpc arm tangent in the galactic plane. The TeV source is extended with a semi-major axis of $(12 \pm 3)'$, forming an angle of $21 \pm 13°$ with respect to the positive galactic longitude axis.

To understand HESS J1632-478, we collected multi-wavelength data from Fermi, XMM-Newton, Spitzer and Molonglo, to construct its spectral energy distribution and discuss the emission mechanisms.

## 2. – Observations

In the period from August to September 2008, XMM-Newton performed 9 observations of a field centered close to HESS J1632-478, collecting data for a total of 92 ks. Standard data reduction procedures were applied using XMM Science Analysis Software (SAS v.9) and selected for the energy ranges 0.2–12 keV for MOS and 0.2–15 keV for pn. Periods with enhanced background due to soft proton flares were disregarded in the analysis, resulting in a total filtered exposures of 87 ks and 62 ks for the MOS and pn cameras, respectively. Merging together all the observations we obtained the mosaic image in fig. 1a, where the extended source is highlighted with the white continuous ellipse.

Zooming inside this ellipse (fig. 1b) it is shown an unresolved point-like component with a black continuous line. The point and extended sources have a significances of 15 and 18 $\sigma$, respectively. We fitted both the point-like and the extended source spectra with an absorbed power-law model with $\Gamma_{\rm point} = 2.6^{+1.3}_{-0.8}$ and $\Gamma_{\rm ext} = 3.4^{+0.6}_{-0.8}$ [4].

We analysed also the radio energy band using the 2nd Molonglo Galactic Plane Survey (MGPS-2) at 843 MHz [5]. Integrating the excess counts based on a conservative detection threshold of the MGPS-2 survey yields to an upper limit for the flux density of 25 mJy. This radio excess corresponds well to the position and size of the extended

X-ray source. In the infrared energy band between 3.6 and 8 $\mu$m we have taken into account the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire [6] GLIMPSE and we did not find any sign for diffuse infrared emission corresponding to the X-ray and radio counterparts. We extracted a flux density upper limit of $\sim 25$ mJy at 3.6 $\mu$m. We looked for possible high energy counterpart in the Fermi-LAT first year Catalogue [7], and found two unidentified GeV sources in the neighborhood of HESS J1632-478. Both these sources are flagged with the letter "c", indicating that they are to be considered as potentially confused with galactic diffuse background or perhaps spurious detection. It is therefore very unclear if any of these Fermi sources could be a counterpart of HESS J1632-478. The HESS ellipse is extended with a semi-major axis of $(12 \pm 3)'$ and it is parallel to the line joining the two Fermi sources, lying close to the extremity of that ellipse. If the two Fermi sources are real and radiate in the TeVs, the extension and inclination of HESS J1632-478 could be significantly affected by confusion. The VHE spectrum, between 0.2 and 4.5 TeV, can be fitted with a power-law model, yielding a photon index $\Gamma = 2.12 \pm 0.20$ and a flux above 200 GeV of $(28.7 \pm 5.3) \times 10^{12}$ ph cm$^2$ s$^1$ [1].

## 3. – Modelling

The XMM-Newton and H.E.S.S. spectra indicate the presence of two spectral bumps matching the expected synchrotron and inverse Compton emission of a Pulsar Wind Nebula. We used a phenomenological description of the electron energy distribution [8,9] used to model the SED of a sample of PWNs:

$$n(\gamma) = \begin{cases} K\left(\frac{\gamma}{\gamma_c}\right)\exp\left[\frac{\gamma}{\gamma_c}\right] = n_0(\gamma) & \gamma \le \gamma_1, \\ n_0(\gamma) + K_1\left(\frac{\gamma}{\gamma_c}\right)^{-\alpha}\exp\left[\frac{\gamma}{\gamma_{c1}}\right] & \gamma > \gamma_1, \end{cases} \tag{1}$$

where $\gamma_c$ is the Lorentz factor of the electrons at the termination shock and we fixed [8] $\gamma_1 = 7\gamma_c$. The resulting SED was obtained using a well-tested code [10] and is reported in fig. 2. We reproduced both the synchrotron self-Compton and the external Compton emission, assuming a one-zone (post terminal shock) homogeneous emitting region [4].

## 4. – Conclusion

We observed the unidentified TeV source HESS J1632-478 with XMM-Newton and looked for counterparts in the GeV, infrared and radio bands. An extended faint X-ray source is detected close to the centroid of the H.E.S.S. ellipse. A radio excess corresponding to the X-ray source is found in the Molonglo sky survey. Upper limits have been derived from Spitzer and Parkes data. The GeV image obtained by Fermi shows two close-by sources, but none of them corresponds to the X-ray source. The flux density emitted by HESS J1632-478 at very high energies is at least 20 times larger than observed at the other wavebands probed. The source shape and spectral energy distribution suggests a pulsar wind nebula and can be used to constrain a one-zone model for the post terminal shock region of the pulsar wind nebula. The assumed relativistic electron distribution is Maxwellian ($\gamma \sim 10^5$) with a non-thermal tail extending to $\gamma \sim 10^8$. The synchrotron nebula is faint because of the low magnetic field (3 $\mu$G). The point-like X-ray source, detected in the synchrotron nebula, is probably the signature of the pulsar and of the termination shock. The ratio of the $\gamma$-ray and X-ray fluxes suggests a pulsar age of $\sim 10^4$ years [11].

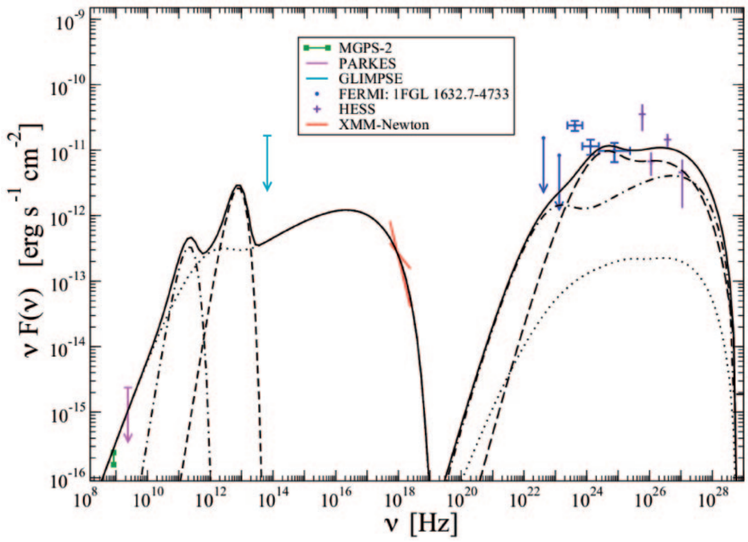


Fig. 2. – The continuous line indicates the prediction of the model used to represent the emission. At low energy the dotted line represents the synchrotron emission from the electron distribution described by eq. (1), the dot-dashed and the dashed lines show the CMB and IR dust photons components, respectively. At high energy, the dotted line represents the SSC component, the dot-dashed and the dashed lines show the external Compton emission on the CMB and dust photons components, respectively [4]. Errors on the VHE spectrum are only statistical.

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