

Discovery of the VHE gamma-ray source HESS J1641–463

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For the H.E.S.S. Collaboration

A new TeV source, HESS J1641–463, has been serendipitously discovered in the Galactic plane by the High Energy Stereoscopic System (H.E.S.S.) at a significance level of 8.6 standard deviations. The observations of HESS J1641–463 were performed between 2004 and 2011 and the source has a moderate flux level of 1.7% of the Crab Nebula flux at $E > 1$ TeV. HESS J1641–463 has a rather hard photon index of $1.99 \pm 0.13_{\text{stat}} \pm 0.20_{\text{sys}}$. HESS J1641–463 is positionally coincident with the radio supernova remnant SNR G338.5+0.1, but no clear X-ray counterpart has been found in archival Chandra observations of the region. Different possible VHE production scenarios will be discussed in this contribution.

1. H.E.S.S. analysis and results

H.E.S.S. is an array of five imaging Cherenkov telescopes situated in the Khomas Highland in Namibia at an altitude of 1800 m above sea level (see e.g. Bernlöhr et al. [2003], Funk et al. [2004]). In the initial phase of the H.E.S.S. project (*Phase I*), the array was composed of four 13 m diameter Cherenkov telescopes, whereas in *Phase II* a single huge dish with about 600 m² mirror area was added at the center of the array, increasing the energy coverage, sensitivity and angular resolution of the instrument [Giebels 2012]. Due to the accumulation of exposure with H.E.S.S. in the Galactic plane, complex VHE (Very High Energy; $E > 100$ TeV) gamma-ray sources are better resolved and frequently new structures appear. This is the case for a new source, dubbed HESS J1641–463, that has been discovered near the strong gamma-ray source HESS J1640-465 [Aharonian et al. 2005]. Observations have been performed between 2004 and 2011 with H.E.S.S. *Phase I* for a total acceptance-corrected livetime of 72 h. The standard H.E.S.S. run selection procedure has been used to select observations taken under good weather conditions, and data have been analyzed with the Hillas analysis technique [Aharonian et al. 2006], resulting in the detection of a new source with a significance of 8.6σ above 4 TeV (see Fig. 1), [Li & Ma 1983]. The significance of the detection corresponds to an excess of 68 counts at the source best fit position, the total number of ON- and OFF-source events being $N_{\text{ON}} = 107$ and $N_{\text{OFF}} = 757$, respectively, with

an on/off sampling area factor of $\alpha = 0.05$.

The emission of HESS J1640–465/HESS J1641–463 has been modeled with a double Gaussian function convolved with the instrument point spread function (PSF), showing a clear increase of the second source with increasing energy (see Fig. 2). The preliminary best-fit position of HESS J1641–463 is found to be at RA: $16^{\text{h}} 41^{\text{m}} 1.7^{\text{s}} \pm 3.1^{\text{s}}_{\text{stat}} \pm 1.9^{\text{s}}_{\text{sys}}$, DEC = $46^{\circ} 18' 11'' \pm 35''_{\text{stat}} \pm 20''_{\text{sys}}$ (J2000).

The time-averaged differential VHE γ -ray spectrum of the source, has been derived using the forward-folding technique described in Piron et al. [2001]. The spectrum is well fitted by a power-law function with a photon index of $1.99 \pm 0.13_{\text{stat}} \pm 0.20_{\text{sys}}$ for the energy range from 0.64 to 30 TeV ($\chi/\text{d.o.f.}$ equivalent value of 9.08/7 corresponding to a p-value of 25%). The flux density of HESS J1641–463 is $1.9 \pm 0.2_{\text{stat}} \times 10^{-12}$ erg cm⁻² s⁻¹ above 1 TeV, corresponding to a 1.7% of the Crab nebula flux at this energy. The spectral index of HESS J1641–463 is one of the hardest found so far in a VHE γ -ray source.

No significant variability in the VHE γ -ray emission could be established for HESS J1641–463. The integral flux is found to be constant within errors over the H.E.S.S. dataset. A fit of the period-by-period light curve for energies above threshold with a constant value yields a $\chi^2/\text{dof} = 11.7/14$, with a p-value of 67%. No variability can be seen either in other time binnings tested (from year-by-year to run-by-run testing).

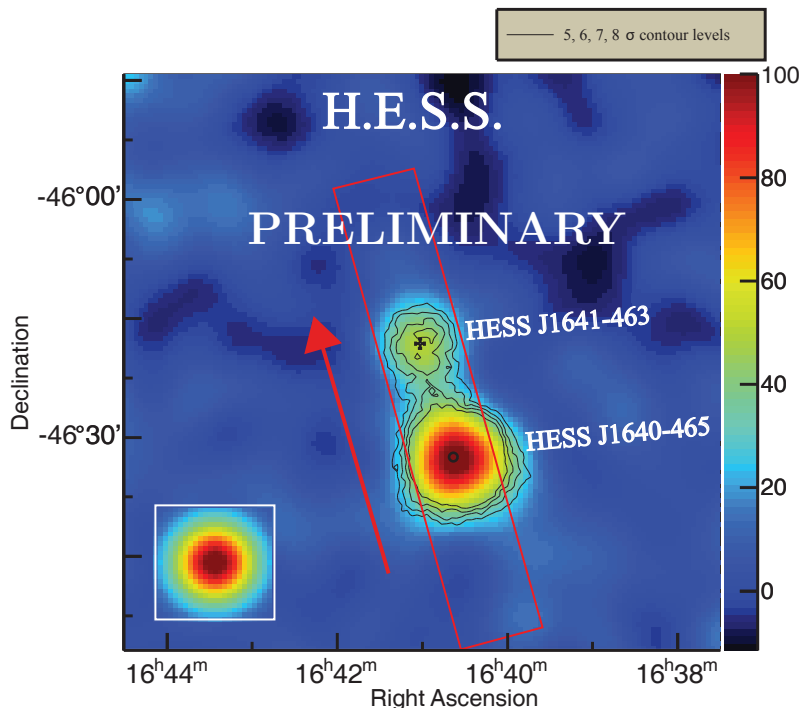


Figure 1: Smoothed map (smoothing radius 0.05°) of excess events with energies $E > 4$ TeV for the region around HESS J1641–463. The black solid contours indicate the significance of the emission at the 5σ , 6σ , 7σ and 8σ levels. the box and arrow indicate the area and direction for the extraction of the profiles shown in Fig. 2. The inset illustrates the PSF of the instrument.

2. Searching for a MWL counterpart

HESS J1641–463 is found within the bounds of the Supernova Remnant (SNR) G338.5+0.1 [Green 2009], see Fig. 3. According to the Green Catalogue of SNR [Green 2009], SNR G338.5+0.1 has a roughly circular morphology, and shows a flux density at 1 GHz of 12 Jy and an angular size of 0.15° . The distance to the SNR is estimated to be ~ 11 kpc [Koches & Dougherty 2007], indicating that it has a physical size of about 30 pc. No X-ray source or massive star counterpart is found in the different catalogues within 0.03° of the best fit position of HESS J1641–463. No Fermi LAT source is located in the area, besides the nearby 2FGL J1640.5-4633, associated with HESS J1640–465 [Slane 2010].

Two archival *Chandra* observations, both obtained with the Advanced CCD Imaging Spectrometer (ACIS) detector, cover the region of interest (ROI) (Tab I). These archival data have been re-calibrated and analyzed with CIAO 4.4 and CALDB 4.4.7 versions. The area at a distance smaller than 0.1° to the best fit position of HESS J1641–463 has been scanned with the CIAO `wavdetect`, `celldetect` and `vtpdetect` tools, revealing the presence of 25 faint X-ray sources in the region. In order to reduce the sample of revealed sources, a filter has been applied by requesting a $S/N > 3$, and a positive hardness ratio

of counts with energies in the range of 2–10 keV over counts with 0.3–2 keV. After these selection criteria, the sample is reduced to 12 sources, and from these, two are located within 0.03° of the best-fit position of HESS J1641–463 (see Fig. 4 and tab 2.). The flux densities of these faint sources have been calculated with the CIAO command `calc_energy_flux` for the 0.3–10 keV energy range (see Tab. II).

In order to investigate a possible variability in the emission of the found X-ray sources, a one-sample Kolmogorov-Smirnov (KS) test has been used to calculate the probability, P_{KS} , for the null hypothesis of a uniform flux for each found X-ray source (see Fig. 4). For all the sources, $P_{KS} > 0.1$ and therefore no variability was found in the emission of any of them.

3. Discussion

The fact that HESS J1641–463 is found within the bounds of a radio SNR immediately suggests the possibility of the detection of a new VHE SNR. However, the existing X-ray observations do not provide additional support to this scenario due to the lack of detection of an extended X-ray feature at the position of HESS J1641–463. In addition, the larger extension of SNR G338.5+0.1 as compared to HESS J1641–463, and the relatively old age of the SNR inferred from

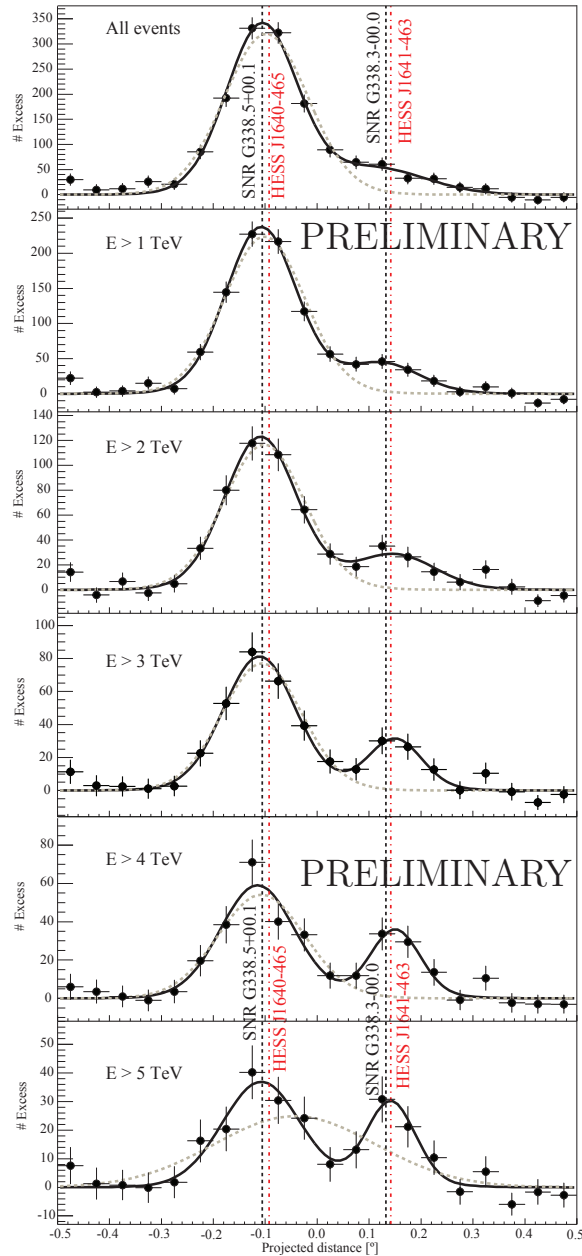


Figure 2: Distribution of gamma-ray flux along the slice indicated in Fig. 1. Full lines model a double Gaussian convolved with the instrument PSF, (compared with a single Gaussian indicated with the dashed line). Vertical lines show the position of SNR 338.0+0.0, SNR G338.5+0.1, HESS J1641–463 and HESS J1640–465.

its physical size of ~ 30 pc suggests that the emission might not be necessarily connected with the SNR but rather with a Pulsar Wind Nebula (PWN) at its center, driven by an yet undetected pulsar. From energy considerations, any of the faint X-ray sources of the area near HESS J1641–463 can be its counterpart in the PWN scenario. In particular, the flux density level of the nearest found X-ray source, (source L) is a factor ~ 15 less energetic when compared with the energy flux density of HESS J1641–463 at

the VHE energies. Yet, several associations of “dark” TeV sources and weak X-ray synchrotron PWN have been established, were ratios of TeV/keV energy flux much larger have been observed (e.g. HESS J1303-631 [Abramowski et al 2012]).

Another possibility could be that HESS J1641–463 is a binary system, similar to HESS J0632+057 [Hinton et al. 2009]. Hard spectral indexes ($\Gamma \sim 1.2 - 2$) are found in those systems, similar to those measured in HESS J1641–463. In a γ -ray binary sce-

Table I X-ray observations.

| Obs ID | Original target | Exposure time | Mode | Chips with ROI |
|--------|-----------------|---------------|--------|----------------|
| 11008 | Mercer 81 | 40.0 ks | VFaint | I2 and I3 |
| 12508 | Norma | 18.8 ks | VFaint | S3 |

Table II X-ray sources within the possible extension of HESS J1641–463.

| Source ID | RA (J2000) | Dec (J2000) | Net counts | Flux density erg cm ⁻² s ⁻¹ |
|-----------|------------|-------------|------------|---|
| L | 16:40:58.9 | -46:17:02.8 | 15.2±5.1 | 1.5 10 ⁻¹³ |
| G | 16:40:57.2 | -46:19:30.7 | 20.7±5.0 | 4.2 10 ⁻¹⁴ |

nario, however, a certain degree of flux variability in both X-rays and TeV γ -rays is expected, although this variability could appear in a relatively large range of time-scales. In this regard, the lack of such variability features does not permit to further constrain the γ -ray binary scenario based on the temporal distribution of the TeV datasets. A flux of $\sim 10^{-14}$ erg cm⁻² s⁻¹ may be expected from an X-ray faint binary system similar to HESS J0632+057 if located at the estimated distance of SNR G338.5+0.1 (11 kpc). Massive stars that could be tracers of the location of a γ -ray binary position were investigated, but none were found. However, the lack of an obvious optical counterpart could be explained due to the high optical extinction expected given both the large distance and the position of the source, close to the Galactic plane.

4. Conclusions

The excellent capabilities of H.E.S.S. have enabled the serendipitous discover a new TeV source showing one of the hardest spectral indices found so far. The inspection of astronomical catalogues and archival X-ray observations do not provide an obvious counterpart to the VHE source but reveal two potential, but weak, X-ray counterparts. The spectral and morphological characteristics of HESS J1641–463, as well as its location induce to think it could be most likely a SNR or a PWN, but other source types like a binary cannot be excluded with the existing data and therefore the source remains unidentified. Further observations, in particular with high resolution X-ray instruments, are encouraged for the proper identification of this new VHE source.

Acknowledgments

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This research has made use of *Chandra* Archival data, as well as the *Chandra* Source Catalog, provided by the *Chandra* X-ray Center (CXC) as part of the *Chandra* Data Archive. This research has made use of software provided by the *Chandra* X-ray Center (CXC) in the application packages CIAO, ChIPS, and Sherpa. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

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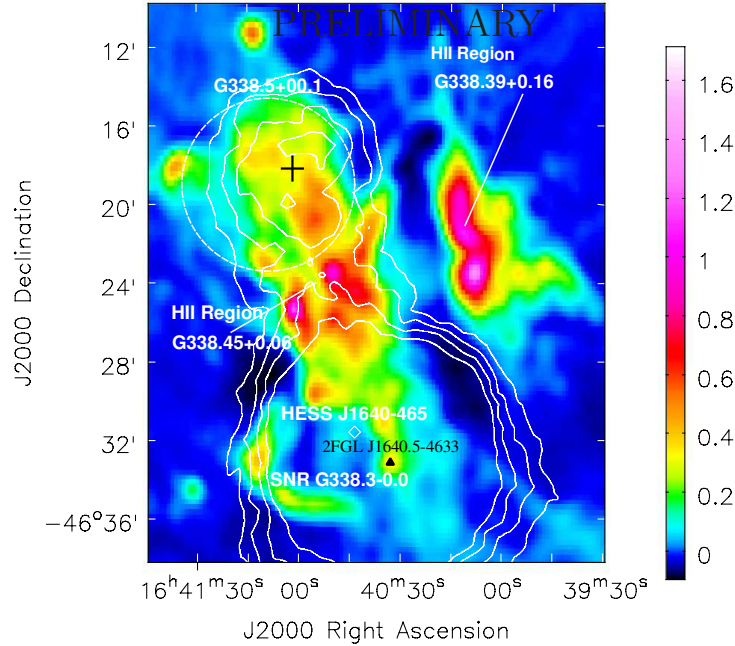


Figure 3: Radio view (MOST 843 MHz) of the region of interest. The catalog position and extension of the SNR is indicated as a dashed white circle. The solid contours indicate the significance of the emission at $E > 4$ TeV at the 5σ , 6σ , 7σ and 8σ levels. The black cross indicates the best fit position of HESS J1641-463, and the black triangle the location of 2FGL J1640.5-4633.

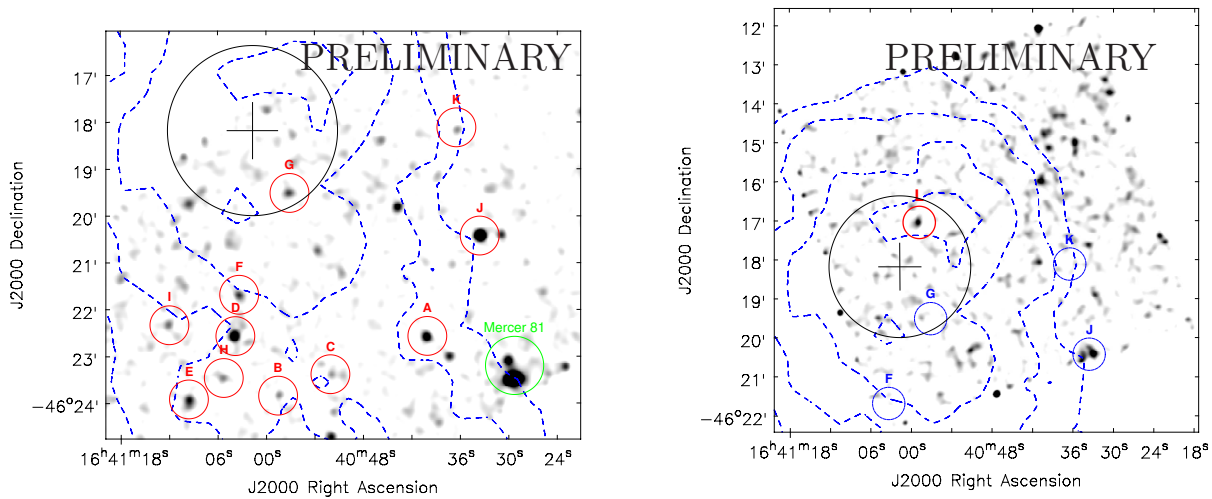


Figure 4: Exposure corrected, smoothed (10 arcsec) image from Chandra Obs 11008 (left) and 12508 (right) of the area near HESS J1641-463 (the black cross indicating the best fit, the black circle a region of 0.03° radius around it, and the dashed contours the significance of the emission at $E > 4$ TeV at the 5σ to 8σ levels). The small circles indicate the detected faint X-ray sources.