PROCEEDINGS OF SCIENCE

Detection of extended VHE γ-ray emission from the vicinity of Westerlund 1

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Westerlund 1 (Wd 1) is best known for being the most massive stellar cluster in the Galaxy, harbouring the richest population (≥ 24) of stars in the Wolf-Rayet phase. The dissipated power in the form of kinetic energy in stellar winds and expanding supernova (SN) shells has been estimated to reach $L \approx 3 \times 10^{39}$ erg s^{-1}. A fraction of the kinetic energy is available to accelerate particles to very-high energies, e.g. at the boundaries of wind-blown bubbles, in colliding wind zones in binary systems, or in the framework of collective wind or wind/SN ejecta scenarios. Owing to these particle acceleration scenarios, Wd 1 has become a promising target for VHE γ-ray observations. Here we present spectral and morphological results of H.E.S.S. observations of Wd 1 performed from 2004 to 2008 and discuss the origin of the detected, degree-scale VHE γ-ray emission in the context of different particle acceleration mechanisms.

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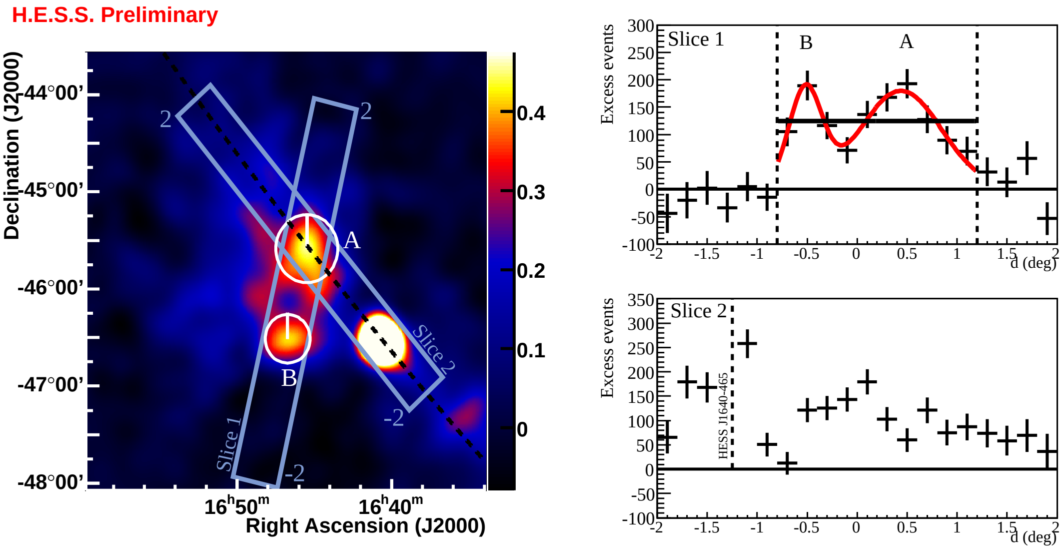

Figure 1: *Left:* H.E.S.S. excess map (in γ-ray events per arcmin^2). *Right, top:* Distribution of VHE γ-ray excess events in Slice 1. The results of a fit of a constant and of two sources with Gaussian shape are indicated as black and red line, respectively. *Right, bottom:* Same as top, but oriented along the Galactic plane (which is indicated by the dashed black line on the left).

1. Introduction

In the Galactic plane survey (GPS), which was performed by the H.E.S.S. Collaboration in the last years (see e.g. [1]), a large number of γ-ray emitters were detected in the very-high-energy (VHE; $E \geq 100$ GeV) domain. A significant fraction of these astrophysical objects are connected to the late phases of stellar evolution, like supernova remnants (SNRs) or pulsar wind nebulae (PWNe). However, some of the VHE γ-ray sources seem to be related to the birthplaces of these objects themselves, namely massive star-forming regions and massive stellar clusters.

The detection of VHE γ-ray emission from the region surrounding Wd 1 was initially reported in [2]. In the following, we present spectral and morphological results of H.E.S.S. observations of Wd 1 and briefly discuss the origin of the detected, degree-scale VHE γ-ray emission in the context of different particle acceleration mechanisms.

2. H.E.S.S. results

The region around Wd 1 was observed between 2004 and 2008 for 45.1 hours, of which 33.8 pass standard data quality selection [3]. The two-dimensional Gaussian fit gives a best fit position of RA/Dec = $16^{\mathrm{h}}46^{\mathrm{m}}50^{\mathrm{s}} \pm 27^{\mathrm{s}}$, $-45°49'12'' \pm 7''$. Within statistical errors, the centre of gravity of HESS J1646–458 is consistent with the nominal Wd 1 cluster position.

The sky image shows a complex structure greater than 2° across which seems to suggest multiple, distinct emission regions. A fit of two separate sources with Gaussian shape as shown in Fig. 1 seems to support this hypothesis as it results in a χ^2 of 2.0 for 4 degrees of freedom with a probability of 74%. However, the probability that the emission is explained by a single Gaussian profile or a constant value is found to be 0.2% and 0.1%, respectively. The data set has also been

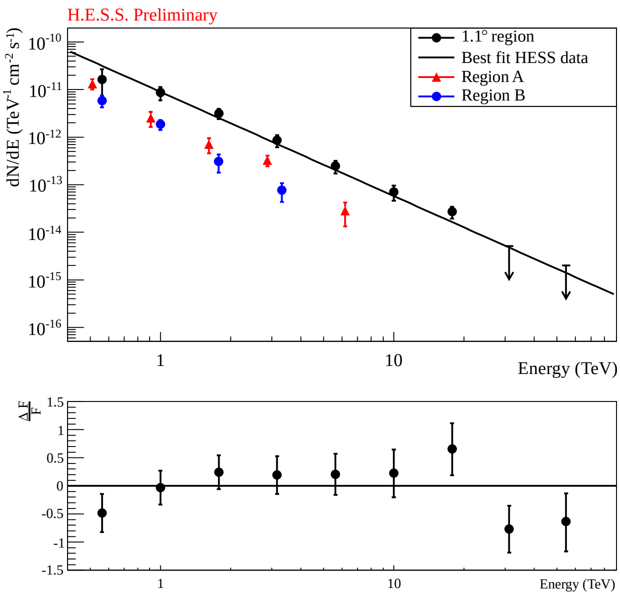

Figure 2: Preliminary differential VHE γ-ray energy spectrum of HESS J1646–458. Also shown are spectra obtained for region *A* and *B*. Arrows indicate 2σ upper limits for spectral bins which are compatible with a zero flux within 1σ.

divided in two energy bands (>1 TeV and <1 TeV) and a χ^2 test has been used to test for a common underlying distribution implying a probability of 6.5%. With the available statistics it is at the moment neither possible to establish a multi-source origin of the emission nor is it possible to rule out a single-source origin.

The spectrum obtained for the whole emission region is well described by a power law with photon index $\Gamma = 2.19 \pm 0.08_{\mathrm{stat}} \pm 0.20_{\mathrm{sys}}$ and differential flux normalisation at 1 TeV $\Phi_0 = (9.0 \pm 1.4_{\mathrm{stat}} \pm 1.8_{\mathrm{sys}}) \times 10^{-12}\,\mathrm{TeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. The χ^2/ndf for the power law fit is 9.9/7 with a probability of 19%. This translates into a VHE γ-ray luminosity at 4 kpc distance of $L_{0.1-100\,\mathrm{TeV}} \approx 2 \times 10^{35}$ erg s^{-1}. The energy spectra for regions *A* and *B* are also determined and show, within statistical errors, no change in photon index between the three studied regions ($\Gamma_A = 2.11 \pm 0.12_{\mathrm{stat}} \pm 0.20_{\mathrm{sys}}$ and $\Gamma_B = 2.29 \pm 0.17_{\mathrm{stat}} \pm 0.20_{\mathrm{sys}}$).

3. Possible counterparts

Among catalogued astrophysical objects within the degree-scale extended VHE γ-ray emission region, the four most promising are discussed in the following:

Low-mass X-ray binary 4U 1642–45: The position of 4U 1642–45 close to the centre of region *A* makes this binary an interesting object to consider. Additionally, this low-mass X-ray binary is with about 10^{38} erg s^{-1} an X-ray bright source. However, known VHE γ-ray binaries are commonly high-mass X-ray binaries and appear point-like to H.E.S.S. Assuming a similar source size in order of the H.E.S.S. PSF, region *A* and therefore also HESS J1646–458 are apparently too large for a common VHE γ-ray binary scenario.

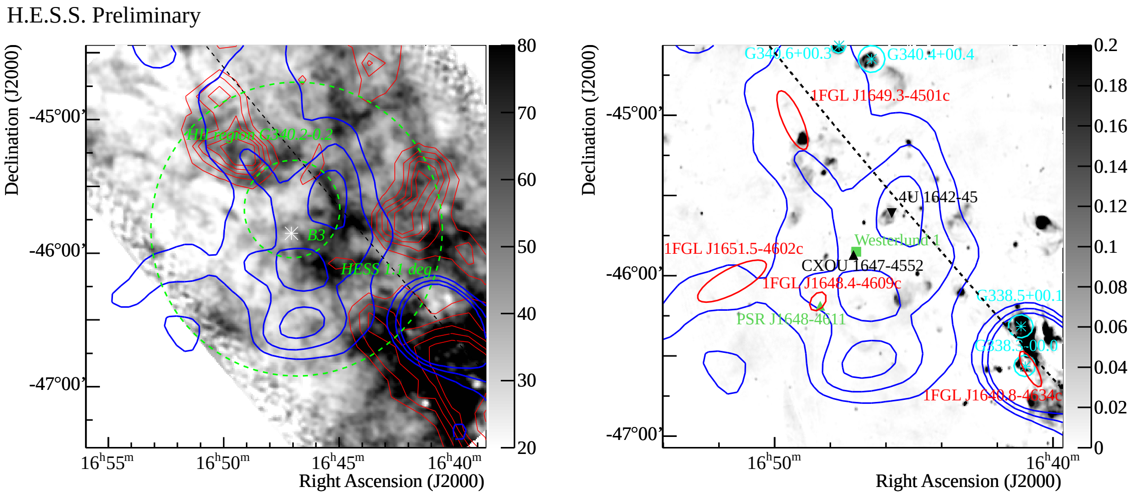

Figure 3: *Left:* HI 21 cm line emission map at -55 km s^{-1} between 20 and 80 K [4] with red CO contours and blue HESS J1646–458 excess contours overlaid. The estimated position of the HI void *B3* is marked by the small green dashed circle [5]. The large green dashed circle depicts the TeV spectral reconstruction region. *Right:* H.E.S.S. smoothed VHE γ-ray excess contours overlaid on the Molonglo 843 MHz map ([6], grey scale, in Jy). Overlaid are SNRs [7], pulsars with spin-down flux $\dot{E}/d^2 > 5 \times 10^{33}$ erg s^{-1} kpc^{-2} [8] and γ-ray sources from the *Fermi* 1-year catalogue [9]. Also shown as black upright triangle is the magnetar CXOU 1647–4552 [10].

Magnetar CXOU J164710.2–455217: As a member of Wd 1, this magnetar is located within the statistical errors of the best-fit position of HESS J1646–458. *Chandra* observations have led to an upper limit of 3×10^{33} erg s^{-1} on the spin-down power, comparable to its X-ray luminosity. This could be a hint that the X-ray emission from the magnetar is due to non-spin-down processes, e.g. magnetic dissipation or reconnection. Among established VHE γ-ray source classes, magnetars are not to be found although they are promising objects for further studies.

Pulsar PSR J1648–4611: PSR J1648–4611 is spatially coincident with the *Fermi*–LAT source 1FGL J1648.4–4609c (the designator *c* indicates potential confusion with diffuse emssion or a spurious detection) which could be indicative for a PWN scenario as found for other H.E.S.S. sources. Moreover, 1FGL J1648.4–4609c showed preliminary evidence of pulsed emission [11]. At the distance of the pulsar (5.7 kpc), HESS J1646–458 would have a physical diameter of ~ 200 pc. Its age of $\sim 10^5$ yrs implies that the current spin-down power ($\sim 10^{35}$ erg s^1) was higher at earlier stages of the pulsars life. Therefore, at these stages, the pulsar could have contributed to the emission of HESS J1646–458 or the subregions *A* or *B*.

Stellar cluster Westerlund 1: The stellar winds of the large amount of massive stars (e.g. Wolf-Rayet stars and OB hyper- and supergiants) within Wd 1 together with the SNe over the last 5 Myrs provide an average power of $\sim 10^{39}$ erg s^{-1}, i.e. sufficient to explain the observed VHE γ-ray luminosity of $L_{0.1-100\ \mathrm{TeV}}$. For this massive cluster ($\sim 10^5\ M_\odot$), there are several possible sites of particle acceleration onto the VHE regime. One could be the dense wind-wind interaction zones of stellar binary systems (e.g. [12, 13]) as Wd 1 exhibits a high binary fraction. Moreover, the interactions of a supersonic collective cluster wind with the ambient medium (e.g. [14]) and/or the interaction of SNe (about $\sim$ 80 to 150 are expected to have occured [15]) with the cluster environment can contribute as well. At the cluster distance ($\sim$ 4 kpc), the diameter of HESS J1646–458 corresponds to a physical size of 160 pc.

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