H.E.S.S. observations towards the massive stellar cluster Westerlund 1

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***Abstract*. Westerlund 1 is known as the most massive stellar cluster in our galaxy, harboring the presently known richest population ($\geq$ 24) of stars in the Wolf-Rayet (WR) phase. The dissipated power in the form of kinetic energy in stellar winds and expanding supernova (SN) shells might reach $L_{\rm SN} \approx 3 \times 10^{39}$ ergs s^{-1} in this system. 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. Motivated by the detection of very-high-energy (VHE) γ-ray emission towards Westerlund 2 and assuming similar particle acceleration mechanisms at work, Westerlund 1 is an even more promising target for VHE γ-ray observations given that massive star content and distance are more favorable for detectable VHE γ-ray emission compared to Westerlund 2. Here we present results of H.E.S.S. observations of Westerlund 1 performed from 2004 to 2008.**

***Keywords*: VHE γ-rays, Westerlund 1, H.E.S.S.**

I. Introduction

During the Galactic plane scan (GPS) performed by the H.E.S.S. Collaboration from 2004 to 2008 [1], [2], [3] a large number of astrophysical objects arose in VHE γ-rays. A significant fraction of those are connected to late phases of stellar evolution, like supernova remnants (SNRs) or pulsar wind nebulae (PWNe). However, some of the VHE γ-ray emitters seem to be connected to the birthplaces of these objects, namely massive star forming regions and massive stellar clusters.

Here we discuss possible acceleration mechanisms which are at work in massive stellar clusters, introduce the most massive stellar cluster in our galaxy, Westerlund 1 and finally present new results of H.E.S.S. observations and the detection of VHE γ-ray emission towards Westerlund 1.

II. Acceleration mechanisms in massive stellar clusters

A. Colliding wind binaries

Many stellar clusters harbor massive stars which are in many cases bound in multiple star systems (mostly double, but also triple, quadruple systems, etc. are known). In a double system, e.g., the strong and fast winds of the two stars collide and form a wind collision region, in which particles can be accelerated to high energies. In an electromagnetic scenario, γ-rays up to GeV energies can be produced through inverse Compton scattering of relativistic electrons in the dense stellar radiation field (e.g. [4], [5], [6], [7]). On the other hand relativistic nucleons can inelastically scatter on particles in the dense stellar wind, producing neutral pions which subsequently decay into VHE γ-rays [8].

B. Collective stellar winds

The interaction of the strong supersonic stellar winds of massive stars in a stellar cluster results in the formation of a wind-blown bubble which is filled with a hot and tenous plasma (e.g. [9]). In the interaction regions of multiple wind-blown bubbles strong turbulence and MHD waves are formed, and turbulent diffuse particle acceleration can occur (e.g. [10], [11], [12], [13]).

C. Supernovae in stellar clusters

Stars with masses $M \geq 8 M_{\odot}$ undergo supernova explosions after a few Myrs at the end of their lives. Therefore, an additional contribution of kinetic energy for particle acceleration to very high energies is available. Since these SNe explode in the wind-blown bubble produced by the collective stellar winds, its SNR shell will expand faster due to the lower density in the surrounding medium and in a medium with higher sound speed due to the higher temperature in the bubble. Under these conditions particle acceleration may be more efficient compared to SNe which occur isolated in the ISM [14]. Furthermore, the maximum reachable energy of particles may be higher in that case.

III. The massive stellar cluster Westerlund 1

The highly reddened stellar cluster Westerlund 1, detected in 1961 [15], is located at a distance of 4 to 5 kpc [16], [17], [18], has an estimated age of 5×10^6 yrs and an estimated total mass of 6×10^4 $M_\odot$. Its total stellar luminosity reaches $L_* \approx 10^7$ $L_\odot$ [17] where the projected stellar number density implies a core size of 0.5 pc (20"). X-ray observations have revealed a magnetar candidate with period $P = 10.6$ s which implies a massive progenitor of mass > 40 $M_\odot$ which is associated with Wd 1 [19]. Westerlund 1 is currently the record holder in terms of its rich population of stars in the Wolf-Rayet (WR) phase. At least 24 WR stars are known of which 60-70 % are expected to be in binary systems [20]. Moreover, more than 80 blue super-giants, 3 red super-giants, one luminous blue variable and 6 (out of 12 in the whole galaxy) yellow hyper-giants are found to be coincident with Westerlund 1. (summarized in [21]).

The dissipated power in the form of kinetic energy in the wind of the WR stars alone is $L_{\rm W} \approx 10^{39}$ ergs s^{-1}. Given the fact that the most massive stars have already evolved into supernovae (SN), an additional contribution of kinetic energy provided by the expanding SN shells of $L_{\rm SN} \approx 3 \times 10^{39}$ ergs s^{-1} can be expected for an assumed supernova rate of 10^{-4} yr^{-1} [21]. There is however no observational evidence for SN shells in Westerlund 1 [22]. We note that such shells may be rather faint due to their expansion into the very low density ISM within the cluster volume [11]. Wd 1 is an interesting object as a very high luminosity in the form of kinetic energy must be dissipated to the surrounding medium. Chandra observations have revealed extended diffuse (of the order of arc minutes) emission which deviates from the typical thermal emission that can be seen from many other stellar associations. With increasing distance to the cluster core, the hard non-thermal emission dominates and line-emission disappears. The total luminosity observed in X-rays amounts to $L_x = 3 \times 10^{34}$ ergs s^{-1} [21]. The same authors discuss various possibilities to explain the "missing energy" in this powerful system, among others, acceleration of cosmic rays have been suggested [23].

IV. H.E.S.S. observations of Westerlund 1

The region around Westerlund 1 was observed by H.E.S.S. between 2004 and 2007 during the Galactic plane scan and in dedicated observations for 14 hours under good weather conditions (according to the run quality selection [24]) with the full array at zenith angles below 55°. Between May and August 2008 Westerlund 1 was observed again, resulting in another 22 hours of

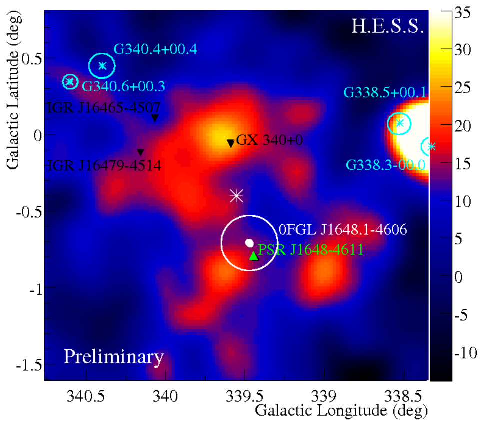

Fig. 1: The Westerlund 1 region in VHE γ-rays as seen by H.E.S.S. after integrating events within an oversampling radius of 0.22 degrees. Overlaid are known pulsars from the ATNF catalogue (green, upright triangle), SNRs from Greens catalogue (cyan circles), INTEGRAL sources (black, reversed triangles) and a source detected by Fermi-LAT (white dot). The white star marks the position of Westerlund 1.

good quality data and a total data set of 34 hrs live-time [1]. Preliminary H.E.S.S. results of these observations unveil an extended emission region of VHE γ-rays with a total significance of $> 15\sigma$, within the 85% containment radius of 1° around the nominal position of Westerlund 1. A total of 2300 γ-ray like events above the analysis threshold of 680 GeV are detected within 1° around the Westerlund 1 position. Fig. 1 shows the preliminary gaussian smoothed (σ=0.13) γ-ray excess map. Additionally, the radial profile of the uncorrelated excess map starting at the position of Westerlund 1 and going outwards to 1.2° is shown in Fig. 2. The emission appears to be rather flat up to radii of 0.9° and the fit of a constant results in a χ^2/ndf of 14.6/8. The VHE γ-ray emission from the stellar cluster itself is at the 2-3σ level and compatible with the overall picture of flat emission.

Also shown in Fig. 1 are potential counterparts for the VHE γ-ray emission. Among the established classes of counterparts like SNRs and PWNe only PSR J1648–4611 is found coincident with some part of the emission region. With an $\dot{E}/d^2$ of $(6.2 - 8.2) \times 10^{33}$ergs s^{-1} kpc^{-2}, depending on the distance estimate of 5.71 kpc [25] and 4.96 kpc [26], the energy of the pulsar would be sufficient to explain at least a part of the observed VHE γ-ray emission. Recently, high energy emission was detected by the LAT instrument on board of the Fermi satellite coincident with the pulsar position. Nevertheless, no significant periodicity could be detected yet [27]. Furthermore, the Low Mass X-Ray Binary (LMXB) GX 340+0 and two INTEGRAL sources are

[1] observation time, corrected for the dead-time of the system

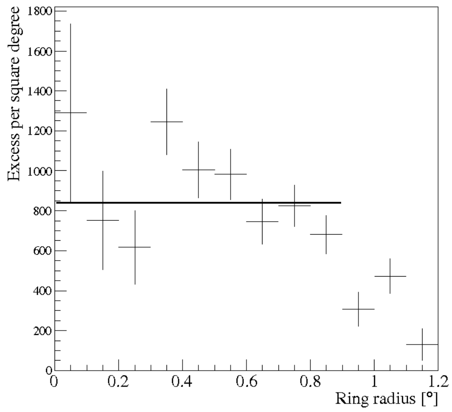

Fig. 2: Preliminary radial profile as obtained from the uncorrelated excess map, starting at the nominal position of Westerlund 1 (white star in Fig. 1) and going outwards to 1.2°.

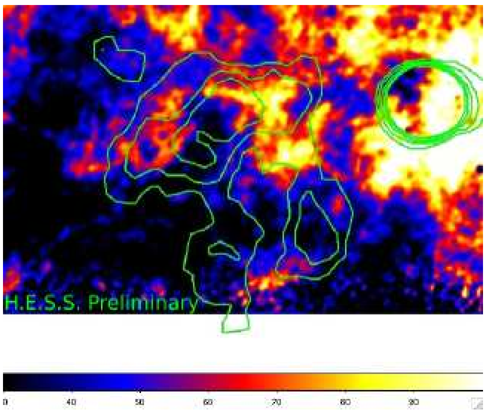

Fig. 3: Preliminiary H.E.S.S. significance contours from 4 to 8 σ overlaid on the HI channel map at a velocity of -55 km/s [28].

coincident with the VHE γ-ray emission as well.

The analysis of the HI data shows two small expanding bubbles with dynamical ages of $\sim$0.6 Myrs and one large interstellar bubble with a size of 50 pc size and a dynamical age of 2.5 Myrs at a distance of 3.9 ± 0.7 kpc [18]. Fig. 3 shows preliminary H.E.S.S. significance contours overlaid on the HI channel map at -55 km/s [28]. The comparison between the two wavelength bands suggests a correlation between neutral hydrogen and VHE γ-rays. The spectral and morphological analysis is ongoing and will help to understand the acceleration mechanisms and the nature of the observed VHE γ-ray emission. If a physical connection between the observed VHE γ-ray emission and Westerlund 1 can be established, we might be able to conclude about intrinsic differences between these prime objects in an emerging new class of VHE-emitting objects.

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