Frascati Physics Series Vol. VVV (2007) pp.1-9
SCIENCE WITH THE NEW GENERATION OF HIGH ENERGY EXPERIMENTS
Frascati, 18-20 June, 2007

OBSERVATIONS OF VERY HIGH ENERGY GAMMA-RAY GALACTIC SOURCES WITH H.E.S.S.

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Abstract

The H.E.S.S array of imaging Cerenkov telescopes has discovered a number of previously unknown gamma-ray sources at very high energy (VHE) and has provided exciting results from the Galactic plane survey. In this communication a selected sample of highlights are presented.

1 The H.E.S.S. telescope system

The H.E.S.S. array, a system of four large (13 m diameter) imaging atmospheric Cerenkov telescopes, is operated since December 2003 by an international collaboration of about 100 physicists. Located in the Khomas highland of Namibia, the H.E.S.S. system covers a 5^o field of view, with a sensitivity which allows to detect sources with a flux of 1% of the Crab Nebula in 25 h of observation and an energy threshold between 100 and 700 GeV increasing with the observation zenith angle. The four telescopes provide multiple images of gamma-ray induced air showers in the Cerenkov light emitted by the shower particles, enabling the stereoscopic reconstruction of the shower geometry and the shower energy. The estimated energy resolution is 15% and 0.1^o is the angular resolution for individual gamma-ray corresponding to $1'$ location position of a VHE gamma-ray source. A personal selection of the highlights from H.E.S.S. is imposed by the lack of space: most recent published results from the galactic plane survey and dedicated source observations together with a summary on the studies of shell-type supernova remnants and pulsar wind nebulae will be the main topics of this letter.

2 The H.E.S.S. galactic plane survey

The Galactic plane survey was conducted in the summer of 2004 covering the region of -30^o to 30^o galactic longitude and -2.5^o to 2.5^o in galactic latitude, resulting in 15 new VHE gamma ray sources plus three previously known. Searching for counterparts in radio- and X-ray catalogs they resulted to be related to SNR, a significant fraction to PWNe and at least three "Dark accelerators" without counterpart known. A new observation campaign was conducted during the years 2005-2007 with the scanned region now reaching from -80^o to 60^o galactic longitude. The number of new sources is more than 15 with 6 new "Dark accelerators", others sources incrementing the known classes and some new results. Details on published results on the two campaigns can be found in [1] and [2] respectively.

2.1 HESS J1023-575

The discovery [3] of the source HESS J1023-575 is one of the most relevant highlight of the 2006 data taking: a clue to the investigation on the cosmic-rays origin. The detection of VHE gamma-ray emission associated with the young stellar cluster Westerlund 2 in the HII complex RCW 49 provides evidence that particle acceleration to extreme energies is associated with this region, a luminous massive star formation region already well studied at various wavelengths. The source (Fig. 1) has been observed for a total 14 h of data for a corresponding statistical significance of more than 9 σ and clearly extended beyond the nominal PSF. The differential energy spectrum, extended about two order of magnitude in energy and with a minimum threshold of 380 GeV, can be described by a power law with index 2.53 ± 0.16 and an integral flux of $1.3 \pm 0.3 \times 10^{-11}$ cm^{-2} s^{-1}. A variety of potential emission scenarios are suggested [4] for the interpretation of HESS J1023-575, a new type of astronomical object, profoundly distinguished from other source findings made

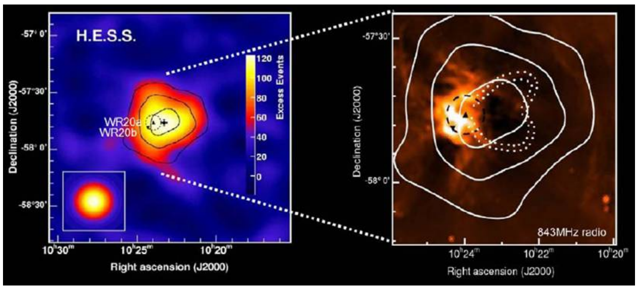

Figure 1: Left: H.E.S.S. gamma-ray sky map of the Westerlund 2 region. The WR stars WR20a and WR20b are marked as filled triangles, while the dashed circle is the extension of the luminous stellar cluster Westerlund2. Right: HESS J1023 5, 7, and 9 σ significance contours overlaid on a radio image.

during Galactic Plane Scan observations. Further investigation with H.E.S.S. will allow to discriminate among alternative interpretations.

3 Study of the shell-type supernova remnants (SNRs)

Two supernova shells already detected as gamma sources by CANGAROO, RX J1713.7-3946 [5] and RX J0852.0-4622 ("Vela Junior") [6](Fig. 2), are now firmly established VHE gamma-ray emitters and morphologically resolved by H.E.S.S.. The energy spectra follow a power law with index of about 2.3, constant across the entire remnants. For both sources, the gamma-ray shell intensity observed with H.E.S.S. is highly correlated with the X-rays one. This correlation would be natural if a common population of primary electrons were responsible for both emission regimes. Assuming that X-rays represents synchrotron radiation and that the gamma rays are generated in Inverse Compton scattering, as it is shown in Fig. 3, simple electronic models assuming an electron injection index of 2.5 and with a local magnetic field of B $\sim$ 10 μG, which accommodates both levels of spectra, fail to consistently fit the multi-wavelength data (e.g.: over shooting the radio flux [8]). In contrast models assuming higher magnetic field and adding gamma-rays from proton-interactions, achieve a good description of wide-band spectra [7]. This interpretation would support the hadronic origin of gamma rays even if a conclusive evidence is still lacking. The currently modest number of shell SNR resolved in VHE has been increased by the recent observation of RCW 86, a supernova remnant with a barrel-shaped shell, visible in X-rays, radio and optical waves. Hints for gamma-ray emission were seen with CANGAROO-II instrument, but no firm detection was claimed. A clear gamma-ray signal with more than 9 σ has

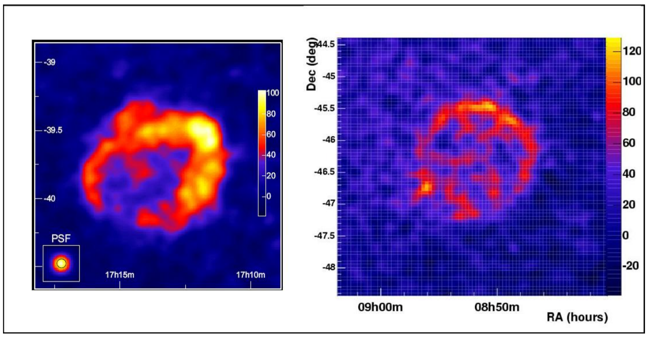

Figure 2: Shell supernova remnants seen in gamma rays by H.E.S.S.: RX J1713.7-3946 (*left*) and RX J0852.0-4622 (*right*).

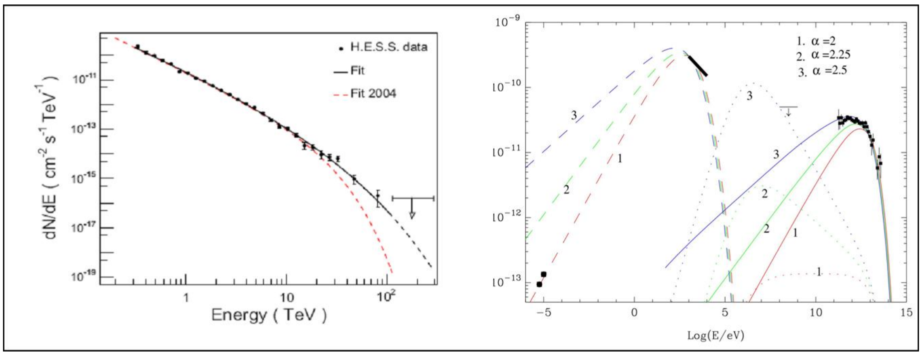

Figure 3: RX J1713.7-3946: energy spectrum (*left*); wide band spectra (together with X-rays, radio data and H.E.S.S. gamma rays measurements) for a magnetic field $\sim 10\ \mu$G and an electron injection index of 2.0, 2.25 and 2.5 (*right*).

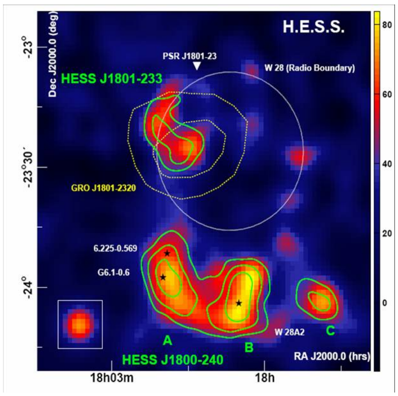

Figure 4: W 28 VHE gamma-rays excess map with 4, 5 and 6σ contour levels for HESS J1801-233 and HESS J1801-240 A, B and C sources.

been detected by H.E.S.S.. A detailed analysis is in progress and preliminary results [9] have shown: a flux 5-10% of the Crab nebula, a 2.3-2.5 spectral index and a shell type morphology.

3.1 HESS J1800-240 and HESS J1801-233

An other composite or mixed-morphology SNR, which is an ideal target for VHE observations, is W 28 (G6.4-0.1). The old-age W 28 SNR is thought to have entered its radiative phase of evolution. The shell-like radio emission peaks at the northern and northeastern boundaries where interaction with molecular cloud is established. The X-ray emission, which overall is well-explained by a thermal model, peaks in the SNR center but has local enhancements in the northeastern SNR/molecular cloud interaction region. On the south boundary several HII regions, including ultra-compact HII region W 28A2 are found. H.E.S.S. observations of W 28 have revealed VHE gamma-ray emission situated at its northeastern (HESS J1801-233) and southern boundaries (HESS J1801-240 with components A, B and C) (Fig. 4) [10]. A multi-wavelength analysis of W 28 has revealed a dense molecular cloud enveloping the southern region, and EGRET MeV/GeV emission centered on HESS J1801-233 and the northeastern interaction region. Overall, these results suggest that old-age SNRs are capable of multi-TeV particle accelerators and candidate hadrons diffusive shock accelerators.

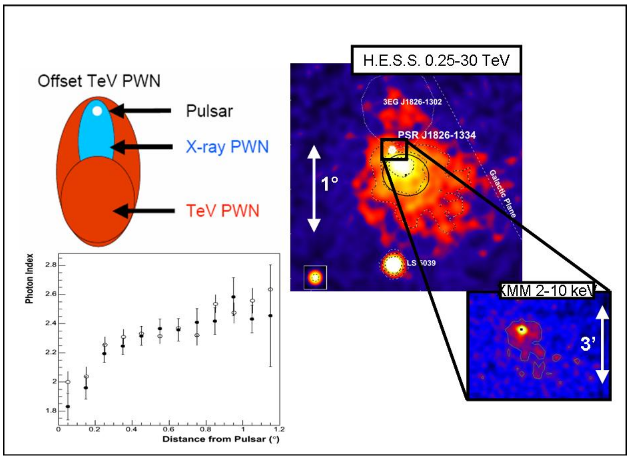

Figure 5: HESS J1825-137, a PWN candidate manifesting an offset from the associated pulsar position, a steepening of the power-law spectral index with increasing distance from the pulsar and a larger extension than in X-ray.

4 Study of the Pulsar Wind Nebulae

Pulsar Wind Nebulae (PWN) are responsible for a significant fraction of the new VHE Galactic sources observed by H.E.S.S.. The purpose of the PWN study is a diagnostic of the spatial and spectral distribution of the high energy electrons responsible of the TeV gamma-ray production dominated by the Inverse Compton scattering off the well-known cosmic microwave background. HESS J1825-137 is a particularly interesting PWN candidate: it is a strong source extended over a fraction of degree [11]. It was detected during the first Galactic plane survey and then further observed. It is located south of the pulsar PSR B1823-13 which exhibits an X-ray nebula trailing extended over ∼5' in the direction of the VHE source but then much smaller in size. A natural explanation is that the X-ray generating electrons (via interaction with the nebula magnetic field ∼10 μG) have higher energies than those responsible via Inverse Compton scattering for the VHE gamma rays. The higher energy X-ray electrons cool faster and have a shorted range. More importantly, for the first time observations have revealed the energy dependent morphology of the source. This manifests itself as a steepening of the power-law spectral index with increasing distance from the pulsar, as would be expected from the radiative losses of high-energy electrons injected by the pulsar (see Fig. 5).

Among the number of PWNe detected by H.E.S.S. and apart from the almost point-like Crab nebula, extensively studied through different consecutive

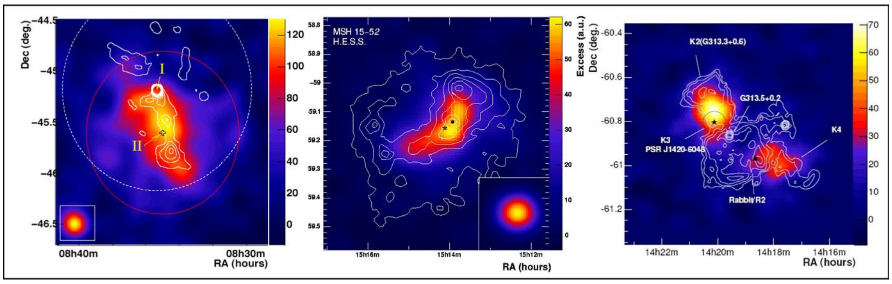

Figure 6: Smoothed gamma-ray excess map (from left to right) from Vela X, MSH 15-52 and the two sources in the Kookaburra region. White contours are X-ray corresponding to count rates contour lines.

observation campaigns [12], Vela X associated with the Vela pulsar (Fig. 6) is likely the most extended one (about a degree south of the pulsar) and significantly old (age ∼11 kyr). The energy spectrum is very hard reaching 50 TeV. The radio, X-rays and VHE gamma-rays emission regions of Vela X are markedly offset from the pulsar position. This may be due to the supernova explosion occurring in an inhomogeneous medium, and the resulting asymmetric reverse shock displacing the PWN in the direction away from the higher density medium. The displacement of the nebulae from the pulsar positions is a surprising constant of almost of extended PWN candidate sources. It is also the case of MSH 15-52, associated with the pulsar PSR B1509-58 inside the G 320.4-1.0 / RCW 89 shell. This elongated and single-sided nebula was revealed by H.E.S.S. as aligned in the same direction of the jet-like high-resolution X-ray Chandra image. More recently, studies of the "Kookaburra" region revealed two new TeV gamma-ray sources, one most likely associated with the pulsar PSR J1420-6048, the other one with the "Rabbit" feature presumably resulting from another pulsar. Both sources have relatively hard spectra index around 2.2, both are extended on the scale of about 10 pc and both are displaced by a similar amount from their pulsars.
Re-observations of the mentioned extended PWNe have been recently accomplished and analysis are in progress to further infer about the spectral and spatial distribution of the energetic electrons within the leptonic interpretation of the VHE emission.

A systematic search for gamma-ray counterparts of known pulsars is addressed by the possibility that all pulsars have associated VHE gamma rays nebulae. Such a research has produced a bunch of new PWN candidates: e.g.: HESS J1718-385 and HESS J1809-193 (Fig. 7) [13]. They show that among pulsars with a spin-down energy flux above 10^{35}ergs/s/kpc^2, a large fraction is

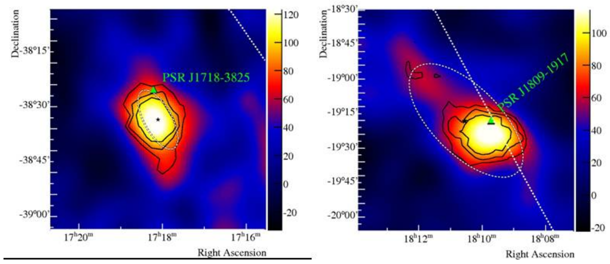

Figure 7: Two new PWNe candidates, HESS J1718-385 and HESS J1809-193, observed during the Galactic sky survey.

visible as gamma-ray emitters, converting about 1% of their spin-down energy into 1-10 TeV gamma rays. This implies that about 10% of pulsar spin-down energy is fed into high-energy electrons. More observations of these sources and corresponding multi-wavelength investigations would provide important progress in the physics of PWNe.

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