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The *Fermi*-LAT and H.E.S.S. views of the supernova remnant W49B

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Abstract

The supernova remnant (SNR) W49B originated from a core-collapse supernova that occurred between one and four thousand years ago, and subsequently evolved into a mixed-morphology remnant, which is interacting with molecular clouds (MC). SNR/MC associations are particularly interesting for probing the acceleration of hadrons in SNRs and consequently the origin of Galactic cosmic rays. The molecular material in the vicinity of the source acts as an efficient target material for accelerated particles, leading to an enhanced γ-ray emission, making these kinds of sources of particular interest for γ ray observatories. W49B has been detected in γ-rays at high energies and very high energies with the *Fermi* Large Area Telescope (*Fermi*-LAT) and the High Energy Stereoscopic System (H.E.S.S.), respectively. The latest results obtained on W49B with these instruments are presented in this contribution. In particular, the spectrum shows a break at low energies, similar to previous observations by the *Fermi*-LAT in other SNRs and interpreted as the signature of a pion-decay γ-ray emission. The implications of these results on the population of particles at the origin of the γ-ray emission are discussed.

Keywords: W49B, Supernova remnant, Cosmic-rays, ISM

1. Introduction

Supernova remnants (SNRs) and the strong shocks associated with them, are very good candidates for accelerating hadronic Galactic cosmic rays to at least 10^{15} eV through the diffusive shock acceleration mechanism [e.g. 1]. Since the accelerated particles at the SNR shock front radiate γ-rays in the high energy (HE; 0.1 – 100 GeV) and very-high energy (VHE; $E >$ 100 GeV) domain, observations of such objects in these energy bands are of particular interest to validate this hypothesis. Depending on the nature of the accelerated particles (electrons or protons/nuclei), their spectral γ-ray signature can be different. In particular, in the case of accelerated protons, or more generally hadrons, their interaction with the matter surrounding the astrophysical object produce neutral pions which rapidly decay in gamma rays. In this case, the expected gamma-ray spectrum has a very peculiar feature: a steep rise below $\sim$ 200 MeV, often referred to as the pion-decay bump.

Located at a distance of $\sim$ 10 kpc [2] from the sun, in the Aquila constellation, W49B (also known as SNR G43.3–0.2) is an object particularly interesting for the search of Galactic cosmic-ray accelerators. It is a rather young SNR ($1-4$ kyr) [3, 4, 5], and its shock front is interacting with dense (10^3 particles/cm3) molecular material [6]. The molecular cloud (MC) poses a dense target for hadronic interaction and, if hadrons are accelerated at the shock front, the γ-ray emission from neutral pion decay is expected to be strongly enhanced. Such an SNR/MC association is therefore a good laboratory to test acceleration of protons and nuclei in SNRs.

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A growing number of SNRs interacting with molecular clouds (SNR/MC) are being revealed in the GeV and TeV γ-ray domain. This includes W44 [7], W28 [8, 9], CTB 37A [10, 11] and IC 443 [12, 13, 14]. For three of them (IC 443 and W44 [15], and W51C [16]), the characteristic pion-bump spectral feature has been recently detected at high energies with the *Fermi*-LAT.

The detection of W49B at HE was reported by the *Fermi*-LAT in 2010 [17] with 17 months of data. In this contribution, the detection of a source coincident with the SNR W49B in the VHE γ-ray domain with H.E.S.S. is reported and the analysis of the *Fermi*-LAT data is applied to 5 years of data using an updated calibration and updated source and background models.

All the results presented in this contribution are discussed in details in the dedicated publication [18].

2. Data analysis

2.1. H.E.S.S.

H.E.S.S. is an array of five imaging Cherenkov telescopes located in the Khomas Highland in Namibia (23°16′18″ S, 16°30′01″ E), at an altitude of 1800 m above sea level [19]. The fifth telescope was added in July 2012 but observations with the upgraded system are not used in this work. The data set presented in this contribution comprises 75 hours (live time) of observations towards the W49 region taken from 2004 to 2013 with a mean pointing offset of 1.1° and a mean zenith angle of 37°. The data were analysed using the Model Analysis [20] and its "Standard cuts". This set of cuts includes a minimum charge in the shower images of 60 photoelectrons resulting, for this data set, in an energy threshold of 290 GeV. The results presented in this contribution have been cross-checked with the analysis methods described in [21] and [22] and yield compatible results.

The signal was extracted from a circular region with a radius of 0.1° around the position of W49B (the position of the maximum of the emission in X-rays determined by [4]) : $(\ell = 43.275°, b = -0.190°)$. The correlated excess map[1] displayed in Fig. 1 shows a significant excess of VHE γ-rays at the position of W49B, with a peak significance of 12.9σ [Eq. 17 of 24]. The VHE γ-ray emission towards W49B is found to be point-like with a best-fit position of $(\ell = 43.260° \pm 0.005°_{stat}, b = -0.190° \pm 0.005°_{stat})$ with a systematic error of ±0.006° on each axis. As can be seen in Fig. 2, the obtained position is compatible with the center of the SNR observed in radio and X-rays [e.g. 25].

[1]Computed using the ring background subtraction method [23].

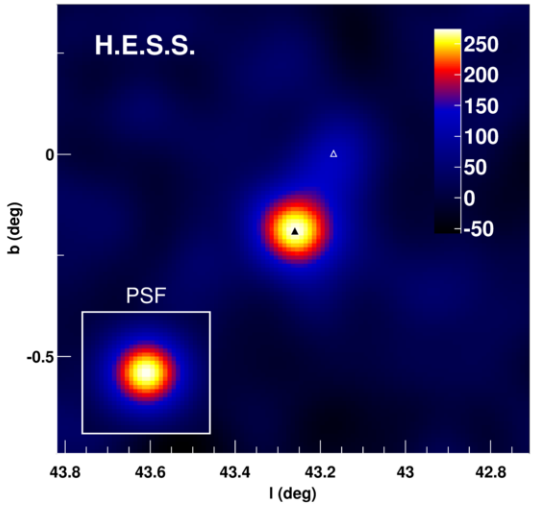

Figure 1: γ-ray excess map of the W49 region obtained with H.E.S.S. The map is smoothed with a Gaussian of width 0.06°, corresponding to the 68% radius containment of the H.E.S.S. point spread function (PSF; shown in the inset). The black triangle denotes the position of the supernova remnant W49B [28]. The white triangle denotes the position of the nearby star-forming region W49A [29]. This figure is reproduced from [18].

The spectrum of the VHE emission coincident with W49B is derived at the best-fit position, using the reflected background subtraction method [23]. The differential energy spectrum is derived above 290 GeV using a forward folding method described in [26]. The data are well described (χ^2/ndf = 60.6/61) by a power-law model $dN/dE = \Phi_0 (E/1\ \mathrm{TeV})^{-\Gamma}$ with a flux normalisation at 1 TeV of $\Phi_0 = \left(3.15 \pm 0.46_{\rm stat} \pm 0.63_{\rm sys}\right) \times 10^{-13}\ \mathrm{cm^{-2}\ s^{-1}\ TeV^{-1}}$ and a spectral index of $\Gamma = 3.14 \pm 0.24_{\rm stat} \pm 0.10_{\rm sys}$ (see Fig. 3). The integrated flux above 1 TeV is $F(E > 1\ \mathrm{TeV}) = \left(1.47 \pm 0.38_{\rm stat} \pm 0.29_{\rm sys}\right) \times 10^{-13}\ \mathrm{cm^{-2}\ s^{-1}}$, corresponding to 0.65% of the Crab Nebula flux above the same energy [27]. Two other spectral shapes were tested (log parabolic power-law and power-law with exponential cutoff) but they do not fit the data significantly better.

2.2. Fermi-LAT

The LAT onboard the *Fermi* satellite detects γ-ray photons by conversion into electron-positron pairs in the energy range between 20 MeV to higher than 300 GeV, as described by [31]. The following analysis was performed using 5 years of *Fermi*-LAT data collected pri-