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New Companions for the lonely Crab? VHE emission from young pulsar wind nebulæ revealed by H.E.S.S.

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Abstract: The deeper and more extended survey of the central parts of the Galactic Plane by H.E.S.S. during 2005-2007 has revealed a number of new point-like, as well as, extended sources. Two point-like sources can be associated to two remarkable objects around "Crab-like" young and energetic pulsars in our Galaxy : G21.5-0.9 and Kes 75. The characteristics of each of the sources are presented and possible interpretations are briefly discussed.

Introduction

The standard candle of VHE astronomy, the Crab Nebula, has served for decades as a yardstick in almost all wavelengths, and yet it is a very peculiar object, harbouring the most energetic and one of the youngest pulsars of our Galaxy. Since the early days, where the similarities of the historical trio Crab/3C 58/G 21.5-0.9 were under debate [1], radio and X-ray astronomy have provided a wealth of information by detecting and characterizing nebulae around rotation-powered pulsars. In the VHE domain, H.E.S.S. has revealed more than a dozen pulsar wind nebulae (PWN), either firmly established as such or compelling candidates [2], almost all of which are middle-aged (at least few kyrs up to $\sim$100 kyrs, except MSH 15-52) and exhibit an offset between the pulsar position and the nebula center. We report here on the VHE emission discovery of two remarkable objects, G 21.5-0.9 and Kes75, which also harbor very young and energetic pulsars and which on some aspects, especially their plerionic nebular emission due to an energetic pulsar, can be considered as Crab-like.

G21.5-0.9 [3], recently revealed as a composite SNR consisting of a centrally peaked PWN and a $4'$ shell [4, 5], was previously classified as one of the about ten Crab-like SNR [6]. Its flat spectrum PWN is polarised in radio [7] with a spectral break above 500 GHz [8]. The non-thermal X-ray PWN with radius $\sim 40''$ shows significant evidence of cooling [9], with the power-law photon index steepening from 1.43$\pm$0.02 near the pulsar to 2.13$\pm$0.06 at the edge of the PWN. There appears to be a synchrotron X-ray halo at a radius of $140''$ from the pulsar which could originate in the shell [4, 5], with a contribution of scattering off dust grains as proposed by Bocchino et al. [4]. The 61.8 ms pulsar PSR J1833-1034, with a spin-down power of $\dot{E} = 3.3 \times 10^{37}$erg/s and a characteristic age of 4.9 kyr was discovered only recently through its faint radio pulsed emission [10, 11]. Given the derived distance of 4.7$\pm$0.4 kpc, the age of G 21.5-0.9 was revised downwards by a factor of $\sim$10 to force consistency with the freely expanding SNR shell [11]. PSR J1833-1034 in G 21.5-0.9 is the second most energetic pulsar known in the Galaxy.

Kes 75 (SNR G29.70.3) is also a prototypical example of a composite remnant for which the distance of 19 kpc was estimated through neutral hydrogen absorption measurements [12]. Its $3.5'$ ra-

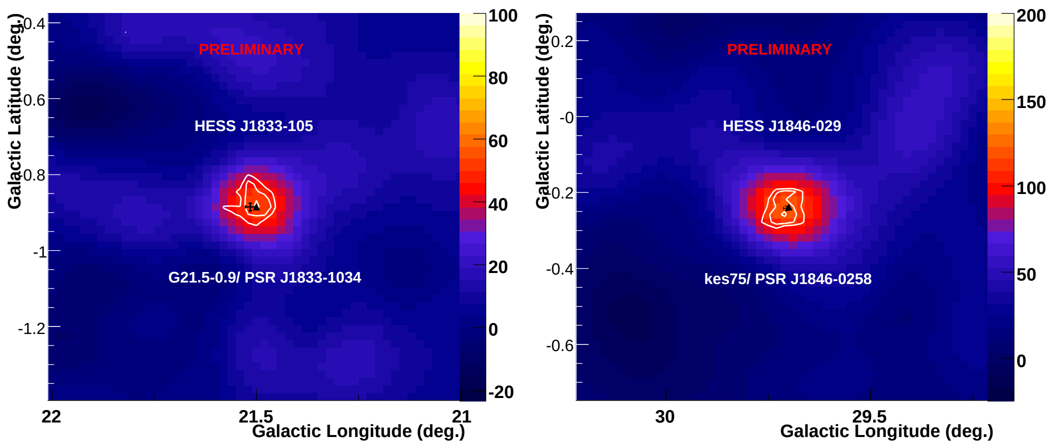

Figure 1: Smoothed excess maps ($\sigma = 0.08°$) of the $0.5° \times 0.5°$ field of view around the positions of HESS J1833-105 (left) and HESS J1846-029 (right). The white contours show the pre-trials significance levels for 4, 5, 6 σ, and 7, 8, 9 σ, respectively. The black triangle marks the position of the pulsars. The best-fit positions of the two sources are marked with an error cross (for HESS J1846-029 the latter overlaps with the triangle).

dio shell surrounds a flat-spectrum highly polarized radio core, and harbors, at its center, the 325 ms X-ray Pulsar, PSR J1846-258 [13]. The latter has the shortest known characteristic age $\tau_c =$ 723 yr and a large inferred magnetar-like magnetic field of B= 4.9×10^{13}G. The pulsar lies within a $25'' \times 20''$ X-ray nebula which exhibits an photon index of 1.92±0.04, but no evidence of cooling as a function of the distance to the pulsar. Like in G 21.5-0.9 there is an X-ray halo, in this case due mostly to dust scattering, but a non-thermal contribution from electrons accelerated in the shell remains possible [14].

Observations, Analysis & Results

Results presented in this section should be considered as preliminary.

The first H.E.S.S. observations of G 21.5-0.9 and Kes 75 were performed during 2004 and 2005 as part of the systematic survey of the inner Galactic plane within the longitude range $l \in [-30°, +30°]$ and latitude band $b \in [-3°, +3°]$. Kes 75, at the edge of the first survey, was covered in the extension to $l \in [+30°, +60°]$ of the survey in the years 2005-2007. The data obtained through the systematic survey was completed with followup observations of promising candidates in wobble mode, hence the two sources are offset at various angular distances with respect to the center of the field of view. The total quality-selected and dead-time corrected data-set includes 19.7 hours of data on G 21.5-0.9 and 24.1 hours on Kes 75, with average offsets of 1.33° and 1.1°, for each source, respectively.

The standard scheme for the reconstruction of events was applied to the data [15]. Cuts on the scaled width and length of images (optimised on γ-ray simulations and off-source data) were used to suppress the hadronic background. As described e.g. in [16], sky-maps and morphological analyses are made with a tight cut on the image size of 200 p.e. (photoelectrons) to achieve a maximum signal-to-noise ratio and a narrow PSF (point spread function). For the spectral analysis, the image size cut is loosened to 80 p.e. in order to cover the maximum energy range. The background estimation for each position in the two-dimensional sky map is made in the same way as for search of extended sources [17], i.e. computed from a ring with a radius of 1.0°. For a point-like source

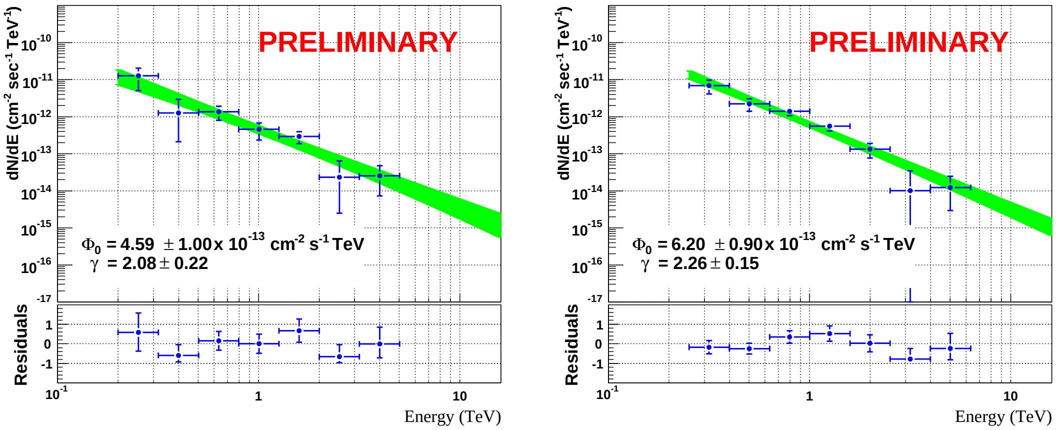

Figure 2: Differential energy spectra above for HESS J1833-105 (left) and HESS J1846-029 (right). The shaded area shows the 1 σ confidence region for the fit parameters.

this radius yields seven times a larger area for the background estimation than the on-source region. The background used for the derivation of the spectrum, is evaluated from circular regions in the field of view with the same radius and same offset from the pointing direction as that of the source region. Finally, to avoid contamination of the background, events coming from known sources were excluded.

Fig. 1 shows the Gaussian-smoothed excess maps for HESS J1833-105 and HESS J1846-029 where the white contours mark the pre-trials significance levels. Both sources were first discovered as hotspots within the analysis scheme described above and then confirmed through additional followup data at pre-trials significance of 6.4 and 9.9 standard deviations, respectively. A conservative estimate of the trials yields post-trials significance of 4.0 σ and 8.3 σ for HESS J1833-105 and HESS J1846-029, respectively.

The extension and the position of the sources were evaluated by adjusting to the images a symmetrical two-dimensional Gaussian function, convolved with the instrument PSF ($5'$ for this analysis). The best-fit positions lie at $18^{h}33^{m}32.5^{s}\pm0.9^{s}, -10d33'19''\pm55''$ and $18^{h}46^{m}24.1^{s}\pm0.5^{s}, -02d58'53''\pm34''$. The intrinsic extensions are compatible with a point-like source for both sources and their positions are in a quite good agreement with the pulsars associated to each supernova remnant, i.e. PSR J1833-1036 ($18^{h}33^{m}33.57^{s}, -10d34'7.5''$) and PSR J1846-0258 ($18^{h}46^{m}24.5^{s}, -02d58'28''$).

The energy spectra of the two sources are derived using the forward-folding maximum likelihood fit of a power-law [18]. The fluxes are at a level of $\sim$2% of that of the Crab Nebula and the spectra are rather hard (Fig. 2): the photon indices are $2.08\pm0.22_{\rm stat}$ and $2.26\pm0.15_{\rm stat}$ for HESS J1833-105 and HESS J1846-029, respectively, with a systematic error of ±0.1.

Discussion

It is remarkable that de Jager et al. [19] predicted that plerionic VHE γ-rays from G21.5-0.9 would be detectable at a level of 4×10^{-13} cm^{-2} s^{-1} at 1 TeV with an electron spectral index of $\sim$2.8, which would give a photon index near 2.0 at VHE energies (after including KN effects given the contributions from dust and CMBR). Their prediction was based on an assumed equipartition field strength of 22 μG which is close to the value of $\sim$15μG implied from γ-ray observations reported here (assuming IC scattering on CMB photons only, and using the ratio of the X-ray to the γ-ray luminosities: $L_{\rm X}/L_\gamma \sim 30$). The equipartition field strength was afterwards increased to 0.3 mG following the revision of the maximum spectral range of the radio PWN to 500 GHz [8, 11]. However, the detection of VHE γ-rays by H.E.S.S. from PWN tends to confirm the suggestion of Chevalier [20] that some PWN may be particle dominated, so that the true PWN field strength may be significantly lower than equipartition for some objects. In the case of Kes 75, $L_{\rm X}/L_{\gamma}$ ~10 yields also a lower than equipartition nebular magnetic field strength of ~10 μG. It should be noted that Kes 75 shows the highest conversion efficiency in X-rays ($\sim$ 15%) as compared to other "Crab-like" pulsars ($\sim$ 3% and ~ 0.6% for the Crab and G 21.5-0.9, respectively) and a 100 times larger γ-ray efficiency (~2%) than the Crab and G 21.5-0.9 which are similar in that respect (~0.02%). However, the latter object's $L_{\rm X}/L_{\gamma} \sim 30$ is 4 times smaller than that of the Crab Nebula $L_{\rm X}/L_{\gamma} \sim 120$. These numbers together with the spin parameters and high surface magnetic field in the case of PSR J1846-0258, show that these objects, although "Crab-like" in some aspects, do possess peculiar properities.

Given the evidence for synchrotron emission in the SNR shell, an alternative interpretation of the VHE emissions of G 21.5-0.9 and Kes75 would be radiation from particles accelerated at the non-relativistic forward shock of the freely expanding SNR. However the required field strength in the shell to explain the H.E.S.S. detection in terms of IC scattering should be much lower than 10 μG, value which may be unreasonably low for typical expanding SNR shells. Deeper observations of both sources could help to constrain the size of the VHE emission region and to ascertain whether it is compatible with this scenario.

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