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X-ray observations of unidentified H.E.S.S. γ-ray sources

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Abstract. In a survey of the inner part of the Galaxy, performed with the H.E.S.S. Instrument (High energy stereoscopic system) in 2004 and 2005, a large number of new unidentified very high energy (VHE) γ-ray sources above an energy of 100 GeV was discovered. Often the γ-ray spectra in these sources reach energies of up to $\sim$ 10 TeV. These are the highest energy particles ever attributed to single astrophysical objects. While a few of these sources can be identified at other wavebands, most of these sources remain unidentified so far. A positive identification of these new γ-ray sources with a counterpart object at other wavebands requires a) a positional coincidence between the two sources, b) a viable γ-ray emission mechanism and c) a consistent multiwavelength behaviour of the two sources. X-ray observations with satellites such as XMM-Newton, Chandra or Suzaku provide one of the best channels to studying these enigmatic γ-ray sources at other wavebands, since they combine high angular resolution and sensitivity with the ability to access non-thermal electrons through their synchrotron emission. We therefore have started a dedicated programme to investigate VHE γ-ray sources with high-sensitivity X-ray instruments.

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While some of the new VHE γ-ray sources detected in the Inner Galaxy can be attributed to Supernova remnants (SNRs), Pulsar Wind Nebulae (PWNe) or microquasars, most of them remain unidentified at other wavebands. This could be either caused by the sources not emitting in other wavebands (so-called “dark accelerators”), or simply by the fact that there have been thus far no sensitive observations of the source regions in other wavebands. The detection of γ-rays from an astrophysical object confronts us with an inherent ambiguity about the γ-ray production processes. The acceleration of both hadrons or leptons in astrophysical sources inevitably leads to the production of γ-rays, by a) the decay of π^0s produced in hadronic interactions, b) Inverse Compton scattering background radiation fields or c) non-thermal Bremsstrahlung both of energetic electrons. X-ray observations break this degeneracy by providing a measurement of the electron population in the source through the measurement of the synchrotron emission in magnetic fields. The following sections will give an overview over two VHE γ-ray sources observed with *XMM-Newton* in the keV-energy range and the lessons that can be learnt from these studies.

HESS J1813–178 – γ-ray emission from a shell-type SNR or a PWN?

In the original H.E.S.S. publication HESS J1813–178 classified as *unidentified* at other wavelengths [1, 2]. However, shortly after the H.E.S.S. discovery, two publications claimed the positional coincidence of this source with a) an unpublished hard ASCA X-ray-source [3] b) an INTEGRAL hard X-ray source continuing the ASCA spectrum [4] and c) an unpublished 20 cm VLA radio source [3]. While H.E.S.S, ASCA, and INTEGRAL have comparable angular resolutions and were not able to resolve the object, the arcsecond-resolution of VLA revealed a shell-like morphology with a non-thermal radio spectrum, suggestive of a shell-type Supernova remnant. The H.E.S.S. collaboration observed this object with *XMM-Newton* to further investigate the X-ray properties of the source with high angular resolution. The results (see Figure 1) show highly absorbed non-thermal X-ray synchrotron emission not from a shell, but rather from a compact object with an extended tail towards the north-east, located in the centre of the radio shell. This central object shows morphological and spectral resemblance to a PWN and the whole object can therefore possibly be considered *composite SNR*. High angular resolution *Chandra*-data of this region (see Gotthelf et al., these proceedings) reveal a similar picture, resolving a central point-source with a extended tail of emission towards the north-east. The position of this X-ray source (AX J1813–178) is located well within the extension of 2.2’ of HESS J1813–178 as shown in Figure 1.

To estimate whether the shell of the SNR could be responsible for the γ-ray emission the “Gaussian equivalent width” of the SNR has been determined to be $\sigma_{\mathrm{SNR}} \approx 1.8'$, compatible with the measured rms extension $2.16' \pm 0.36'$ of the VHE γ-ray emission region. Both the SNR shell as well as the X-ray PWN must therefore be regarded as

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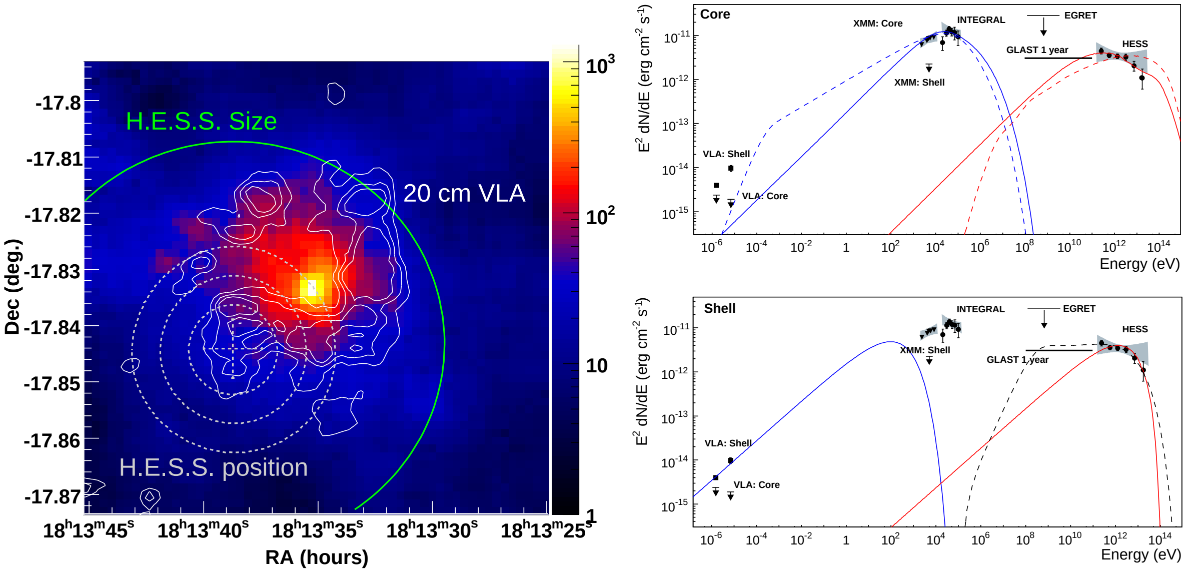

FIGURE 1. **Left:** *XMM-Newton* counts map above 4.5 keV of the region surrounding HESS J1813–178 (colour contours). Overlaid is the VLA 20 cm shell-like emission (white contours) [3]. Also shown are the positional contours (1, 2, 3 σ error) of the best fit position of HESS J1813–178 (dashed circles) and the extension (solid green), covering both the radio and X-ray emitting region completely. **Right** Spectral energy distribution for HESS J1813–178 for two different scenarios: γ-ray emission connected to the compact central PWN (top) or connected to the shell-like emission of the radio SNR (bottom).

possible candidates for the origin of the γ-ray emission. Figure 1 (left) shows the two scenarios in which the γ-rays are connected to the X-ray PWN (top) and to the shell of the SNR (right). Both option provide valid models and as a result, it has to be concluded that even with superior angular resolution as provided with the VLA and *XMM-Newton*, the origin of the γ-ray emission cannot be unambiguously established. The radio and X-ray observations indicate that G 12.82–0.02 is a composite supernova remnant with a bright X-ray core and a radio shell. The size of the γ-ray source measured by H.E.S.S. appears to be consistent with an origin of high energy emission in the SNR shell, but a common origin of the X-ray and γ-ray emission in a central PWN cannot be excluded as a larger spatial extent of the γ-ray source with respect to the X-ray source could occur in such cases (see for example the case of HESS J1825–137 [5]), due to the energy dependent cooling of electrons.

HESS J1640–465 – Different source ages?

HESS J1640–465 was also first detected by H.E.S.S. in the survey of the inner Galaxy [1, 2] in 2004. It was found to show compelling positional coincidence with the shell-type Supernova remnant (SNR) G338.3–0.0[6]. This broken-shell SNR with a diameter of 8’ was detected in the 843 MHz radio survey using the Molonglo Observatory Synthesis Telescope (MOST) [7] but is not particularly well studied by radio telescopes [6]. At γ-ray energies above 100 MeV the unidentified EGRET source 3EG J1639–4702 [8], is found spatially compatible with HESS J1640–465 at an angular distance of 34’. The X-ray *XMM-Newton* observations reveal an extended hard-spectrum non-thermal X-ray source in the centre of the SNR, coincident with the best fit position of the VHE γ-ray sources and as in the case of HESS J1813–178 completely enclosed in the γ-ray emission region. This X-ray source resembles in morphology and spectral properties typical Pulsar Wind Nebulae.

Asymmetric “trails” in PWN can be generated either a) through an asymmetric density distribution of the surrounding medium, preventing the expansion of the PWN on one side as e.g. seen in Vela X, b) dynamically by a supersonic motion of the pulsar with respect to the ISM, generating a bow-shock and a “cometary trail” The hypothesis that the X-ray source is a PWN (stemming from the hard energy spectrum and the morphology) is strengthened further by the location of this object within the boundaries of the shell-type radio SNR G 338.3–0.0. As in the case of HESS J1813–178 the parent population responsible for the γ-ray emission cannot be distinguished from the multi-frequency modelling. Both the shell of the SNR and a central PWN are viable VHE γ-ray emitters and the two emission scenarios

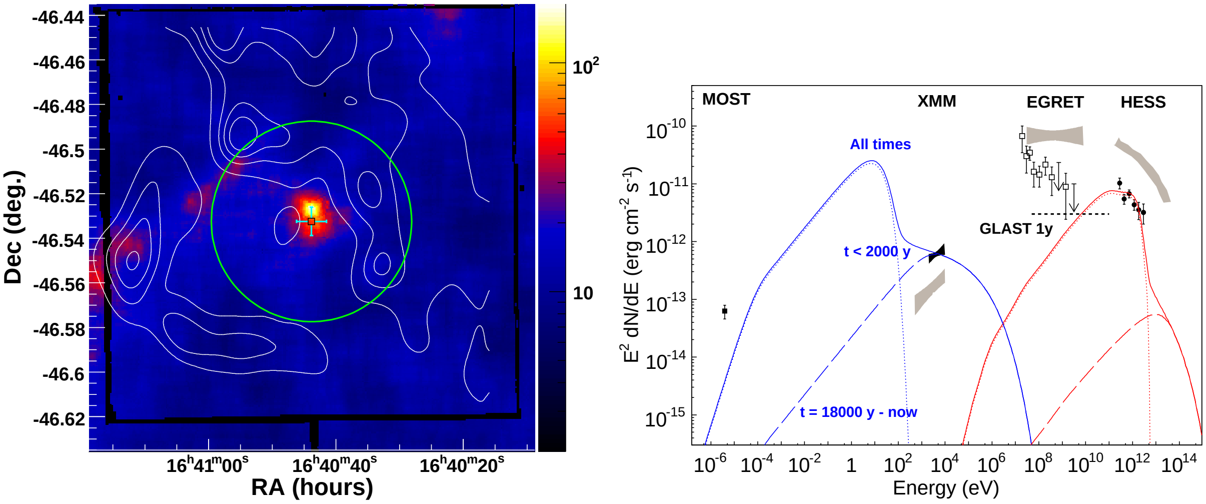

FIGURE 2. **Right:** *XMM-Newton* counts map above 2 keV of the region surrounding HESS J1640–465 (colour contours). Overlaid is the Molonglo 843 MHz shell-like emission (white contours) [7]. The black square along with the solid cyan lines denote the best fit position (and 1σ error) of the VHE γ-ray source HESS J1640-465, the dashed cyan circle indicates the rms extension of the γ-ray emission. **Right** Spectral energy distribution for HESS J1640-465 in a leptonic scenario in which the X-rays are connected to the VHE γ-rays.

cannot be distinguished at this point (similar to the case of HESS J1813–178). If the VHE γ-ray are generated by inverse Compton emission associated with the PWN, the spectral energy distribution shows an interesting similarity to another VHE γ-ray PWN, namely HESS J1825–137 [5]. As for that object, the low ratio of the X-ray power to the VHE γ-ray power suggests a time dependent rate of injection for the relativistic electrons responsible for the X-ray emission and an older (and more numerous) population of electrons producing the VHE γ-ray emission.

Summary and conclusion

The detection of the extended X-ray source in the centre of radio Supernova remnants *following* the detection of a VHE γ-ray source demonstrates that X-ray follow-up observations of VHE γ-ray are well motivated and provide important insights into the nature of these objects. High angular resolution X-ray observation on these two objects show that even with the relatively good angular resolution of instruments such as H.E.S.S., it is still very hard to identify γ-ray sources through observations in other wavebands. This statement is particularly true for objects located in the Galactic plane (due to source confusion) that do not show characteristic time-variability or periodicity. These observations also show, that the identification of such sources for the GLAST-LAT sources will not be easy, since GLAST sources will in addition have to be distinguished from the diffuse Galactic γ-ray background. The results also show, that X-ray and radio observations are a powerful tool to identify γ-ray sources in other wavebands due to their access to non-thermal particle populations. γ-ray observations seem to be well suited to find SNRs, that are otherwise very hard to detect due to obscuration by gas and dust.

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