ICRC'07 Mérida, México

On the GeV-TeV Connection of gamma-ray sources, I. VHE gamma-ray sources and their EGRET counterparts

S. FUNK[1], O. REIMER[2], D. F. TORRES[3] AND J. A. HINTON[4]
[1]*Kavli Institute for Particle Astrophysics and Cosmology, SLAC, Menlo Park, CA-94025, USA*
[2]*Stanford University, HEPL & KIPAC, Stanford, CA 94305-4085, USA*
[3]*ICREA & Institut de Ciencies de l'Espai (IEEC-CSIC), 08193 Barcelona, Spain*
[4] *School of Physics and Astronomy, University of Leeds, Leeds LS2 9JT, UK*
Stefan.Funk@slac.stanford.edu

Abstract: Recent observations by atmospheric Cherenkov telescopes such as H.E.S.S. and MAGIC have revealed a large number of new sources of very-high-energy (VHE) gamma-rays above 100 GeV mostly concentrated along the Galactic plane. At lower energies (100 MeV – 10 GeV) the satellite-based instrument EGRET revealed a population of sources clustering along the Galactic Plane. Given their adjacent energy bands a systematic investigation of a correlation seems appropriate. While a large number of sources are only detected in one energy band, several sources can be connected, such as (amongst others) the source in the Kookaburra region (HESS J1420–607/3EG J1420–6038). In this paper we describe the common properties of the sources detected in both energy regimes.

Introduction

The recent years have changed our image of the VHE gamma-ray sky above 100 GeV through the detection of a wealth of sources mostly using ground-based Imaging Atmospheric Cherenkov telescopes such as H.E.S.S., MAGIC or VERITAS. The photon energies connected to these sources are so far characterising the end of the electromagnetic spectrum for astrophysical sources. One immediate question arising from this fact is the connection to sources at lower energies. The adjacent energy band has been studied by the EGRET telescope aboard Compton Gamma-Ray Observatory with an energetic coverage between 30 MeV and 10 GeV [1]. In this paper we will assess the connection between EGRET sources and H.E.S.S. sources in a systematic way focusing on the region that was covered in the H.E.S.S. Galactic plane survey (GPS) [2, 3] in the ranges Galactic longitude $\pm 30^\circ$, Galactic latitude $\pm 3^\circ$. This survey (along with pointed observations in this region) resulted in 22 sources (14 in the Galactic plane survey, LS 5039, Galactic Centre, RX J1713.7–3946, G0.9+0.1, two in the W 28-region, and the two new pulsar wind nebulae (PWNe) HESS J1718–385 and HESS J1809–193) most of them previously unknown VHE gamma-ray emitters.

The third EGRET catalogue [1] represents the companion catalogue at an energy threshold of 100 MeV (with best sensitivity between 150 and 400 MeV, depending on the gamma-ray source spectrum). It lists a similar number of 17 sources within the GPS region. Even though this is the nearest energy band to the VHE gamma-ray band, assuming an EGRET source is detected all the way up to ~ 10 GeV, this still leaves an energetic gap of roughly a decade before the H.E.S.S. energy range sets in. The upcoming GLAST-LAT satellite is expected to bridge this gap between ~ 10 GeV and ~ 100 GeV. Comparing instrumental parameters of H.E.S.S. and EGRET there is a clear mismatch both in angular resolution as well as in sensitivity. In a ~ 5 hour observation (as a typical value in the GPS region) H.E.S.S. is about a factor of $\sim 50-80$ more sensitive (in terms of energy flux $E^2 dN/dE$) than EGRET was along the Galactic Plane above 1 GeV for the exposure accumulated between 1991 and 1995 (corresponding to the third EGRET catalogue). Assuming a similar energy flux output in

ICRC 2007 Proceedings - Pre-Conference Edition

the two different bands this mismatch implies at first sight that H.E.S.S. sources are not necessarily detectable by EGRET. On the other hand (again under the assumption of equal energy flux output) H.E.S.S. should be able to detect the majority of the EGRET sources. In reality this naive expectation can be wrong in Galactic gamma-ray sources for various reasons: EGRET sources might indeed not emit the same energy flux in the H.E.S.S. band but rather show cutoffs in the energy range between EGRET and H.E.S.S. (as e.g. known for pulsars). H.E.S.S.-like instruments are typically only sensitive to emission on scales smaller than $\sim 1^\circ$. If some of the EGRET sources were extended beyond 1° without a dominant central excess mimicking a point-source behaviour (which is not precluded by the EGRET measurements), H.E.S.S. might not be able to see them. Nevertheless, it is interesting to study the connection between GeV and TeV emitters and we here we present a study of both the positional and the spectral correlation between sources. This paper describes the sources where a connection between the GeV and the TeV gamma-ray emission can be made, whereas an upcoming publication will also describes the cases where a non-connection is established.

Positional coincidences

Comparing the EGRET sources to the H.E.S.S. sources within the survey region a distinct lack of positional coincidences between the two populations is noticeable. Only a minor fraction of the H.E.S.S. sources coincide within the considerably larger location uncertainty contours of EGRET sources. Any systematic assessment of positional matches between EGRET and H.E.S.S. sources will be dominated by the EGRET localisation error on the position. Using the 95%-confidence contour on the EGRET source positions 3 H.E.S.S. sources are found in positional coincidences with EGRET sources in the GPS region. Extending the error on the source position criterion to the EGRET 99%-confidence contours yields an additional 3 H.E.S.S. sources that line up with EGRET sources. Table 1 summarises the H.E.S.S. sources within the EGRET confidence contours.

EGRET Source	H.E.S.S. Source	
	Within 95% Containment	Within 99% Containment
J1639–4702	J1640–465	1640–465
J1714–3857	J1713–381	1713–381
J1744–3011	J1745–303	1745–303
J1800–2338		1800–233
J1824–1514		1826–138
J1826–1302		1825–137

Table 1: Positionally coincident EGRET and H.E.S.S. sources for different criteria.

From the total sky coverage by EGRET sources within the GPS region of 4.4×10^{-4}sr (determined from the 95% positional confidence contour), corresponding to 4% of the total area of the GPS, a spatial coincidence by chance is expected for ~ 1 source given the size of the H.E.S.S. sample. While other prominent positional coincidences of Galactic H.E.S.S. source with EGRET sources outside the GPS exist (e.g. in the Kookaburra region [4, 5], in the Monoceros Supernova remnant (SNR) [6] or in the Crab [7]), these will not be considered here but systematically explored in an upcoming publication. It is interesting to note that Kookaburra is the only source in which the H.E.S.S. source (HESS J1420–607) is located within the 68% confidence limit of an EGRET source (3EG J1420–6038). In this region a recent re-analysis of the EGRET data yields the interesting conclusion that the dominant GeV source is positionally coincident with HESS J1420–607. This source is however confused with a less intense gamma-ray source at the location of a second VHE gamma-ray source HESS J1418–609 (often referred to as the “Rabbit”) which is detected at approximately 1/3 of the GeV flux of the dominant source [5]. Summarising this section, it is noteworthy that rather few positional coincidences between EGRET and H.E.S.S. sources exist. This might be partially caused by the different energy flux sensitivities of the two instruments. Deriving predictions from this study towards the upcoming GLAST satellite measuring in the EGRET range is beyond the scope of this proceedings paper and will soon be presented elsewhere. Two important

ICRC 2007 Proceedings - Pre-Conference Edition

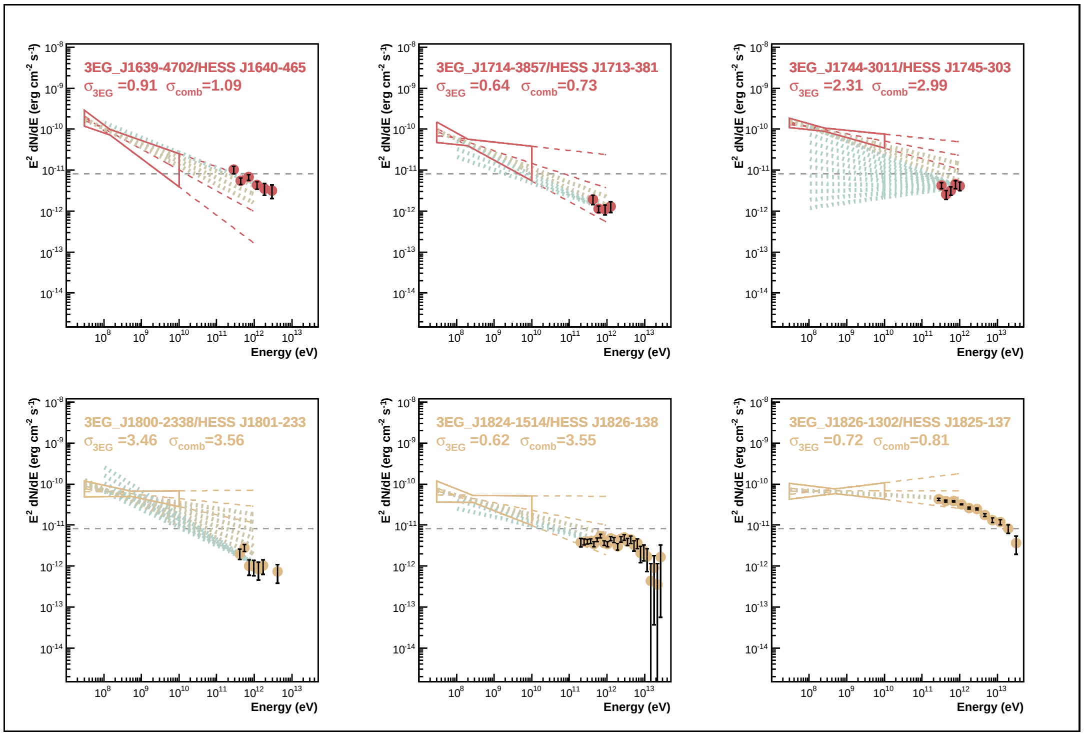

Figure 1: Spectra for the source in which a positional coincidence between EGRET and H.E.S.S. sources is given. The red plots show sources for which the H.E.S.S. source is located within the 95% confidence level whereas the orange plots show those within the 99% confidence contour (as give in Table 1)

fact should, however, briefly be noted in this regard: a) the fact that H.E.S.S. does not detect most of the EGRET sources and that b) the brightest Galactic H.E.S.S. sources (such as RX J1713.7–3946) are only marginally detectable by GLAST as shown in detailed simulations using reasonable estimations of the LAT instrument response functions as well as the gamma-ray emission in these sources (see Funk et al, these proceedings), indicates that H.E.S.S. detected Galactic VHE gamma-ray sources will not be the most prominent sources in the GLAST-LAT era.

Spectral match

For the connecting sources reported in the previous section, a test of the spectral match based on the simple assumption of a power-law fit between the EGRET and the HESS-range has been performed. To assess the spectral match the quantity $\sigma_{\rm comb}$ has been defined in the following way: $\sigma_{\rm comb} = \sqrt{(\sigma^2_{\rm 3EG} + \sigma^2_{\rm H.E.S.S.})}$. To determine $\sigma_{\rm 3EG}$, the index of the EGRET source has been varied (around the pivot point of the butterfly) until the extrapolation to 1 TeV matches the H.E.S.S. flux at that energy. This index is called $\Gamma_{\rm match}$ and $\sigma_{\rm 3EG} = (\Gamma_{\rm match} - \Gamma_{\rm 3EG})/(\Delta\Gamma_{\rm 3EG})$ (where $\Gamma_{\rm 3EG}$ and $\Delta\Gamma_{\rm 3EG}$ are the EGRET index and its error from the third EGRET catalogue). In short $\sigma_{\rm 3EG}$ is a quantity that describes by how much the EGRET index has to be changed (in comparison to the error on this index) to match the H.E.S.S. spectrum at 1 TeV. In the same way $\sigma_{\rm H.E.S.S.}$, is determined by changing the H.E.S.S. index until the flux matches the EGRET flux at 1 GeV (to avoid biases through spectral cutoffs in the H.E.S.S. data the spectra were fitted only below 1 TeV). These two quantities are finally added in quadrature to yield the final $\sigma_{\rm comb}$, describing how well the two spectra can be connected by a linear extrapolation. This same procedure can also be performed in the case where there is no connection between two sources but only an upper limit on the emission in either the EGRET or the H.E.S.S. band (with the obvious difference that only one of the extrapolation onto that limit can be performed) as will be shown elsewhere. It is interesting to note that while the spread in $\sigma_{\rm comb}$ for the cases where there is only an upper limit in one of the two bands is rather large (values between 0 and 15), for the cases discussed here $\sigma_{\rm comb}$ is always below 4. This points to the interesting fact that for the cases in which a positional match is found, a rather good spectral match (in terms of a powerlaw extrapolation) is also given. A statistical assessment of these properties is beyond the scope of this proceedings paper but will be presented in an upcoming publication.

Source classes

A detailed multi-frequency study has been performed or is ongoing for most of the 6 H.E.S.S. sources described here [3, 8, 9, 10]. Discussing them individually is beyond the scope of this work. It is however interesting to note, that almost all Galactic VHE gamma-ray source classes are represented amongst the counterparts to the H.E.S.S. sources. HESS J1640–465 can either be associated with a shell-type radio SNR or a central X-ray PWN [8], HESS J1826–138 is a gamma-ray binary (LS 5039), HESS J1825–137 is probably the best example for an offset PWN (see Funk et al, these proceedings) and others such as HESS J1745–303 is not yet identified. If these connections are proved to be real (as e.g. through GLAST measurements), this would open up several new source classes as Galactic GeV emitters, a band in which currently only pulsars are firmly established as source classes due to their characteristic timing emission properties.

Summary

For the first time a systematic study of the connection between EGRET and H.E.S.S.-sources has been performed in the H.E.S.S. Galactic plane survey region. We have investigated both the positional and the spectral matches between the EGRET and the H.E.S.S. source populations within this inner Galaxy. Our studies shows that even though the H.E.S.S. energy flux sensitivity is more than an order of magnitude larger than the EGRET one, the number of apparently connected GeV and TeV sources is rather small. This might for example be due to spectral features such as cutoffs for the GeV sources. For the sources that do show a connection, the spectral match between EGRET and H.E.S.S. in terms of a naive powerlaw extrapolation seems to work rather well.

References

[1] Hartman, R. C., et al., 1999, ApJS, 123, 79
[2] Aharonian, F. A., et al. (*H.E.S.S. Collaboration*) 2005, Science 307, 1938
[3] Aharonian, F. A., et al. (*H.E.S.S. Collaboration*) 2006, ApJ 636, 777
[4] Aharonian, F. A., et al. (*H.E.S.S. Collaboration*), 2006, A&A 456, 245
[5] Reimer, O., & Funk, S., 2006, in press, Ap&SS (astro-ph/0611653)
[6] Aharonian, F., et al.,(*H.E.S.S. Collaboration*), 2007, submitted to A&A (astro-ph/0704.0171)
[7] Aharonian, F., et al., (*H.E.S.S. Collaboration*), 2006, A&A 457, 899
[8] Funk, S., et al., 2007, ApJ 662, 517
[9] Aharonian, F., et al., (*H.E.S.S. Collaboration*), 2006, A&A 460, 365
[10] Aharonian, F., et al., (*H.E.S.S. Collaboration*), 2006, A&A 460, 743