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On the GeV-TeV connection of Galactic Gamma-Ray Sources
II. VHE gamma-ray sources without EGRET-detected counterparts and vice versa

O. REIMER[1], S. FUNK[2], D.F. TORRES[3], AND J.A. HINTON[4]
[1] *Stanford University, HEPL & KIPAC, Stanford, CA 94305-4085, USA*
[2] *Kavli Institute for Particle Astrophysics and Cosmology, SLAC, Menlo Park, CA-94025, 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*
olr@stanford.edu; funk@slac.stanford.edu; dtorres@ieec.uab.es; jah@ast.leeds.ac.uk

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 experiment EGRET revealed a population of gamma-ray sources clustering along the Galactic Plane. Here we investigate those gamma-ray sources, which currently lack a connection in their proximate energy band. We conclude on similarities and differences among the EGRET resp. VHE gamma-ray sources, and complement the discussion with consistently determined upper limits in the adjacent energy regime. An interpretation will invoke the characteristics of known object classes at high-energy gamma-rays, and both observational and theoretical arguments to explain situations where no counterpart can be expected in one or the other energy regimes.

Introduction

In a companion paper [1] the general aim and methodology was introduced to investigate gamma-ray sources detected in the H.E.S.S. Galactic Plane Scan (GPS) [2, 3] which connect to gamma-ray sources discovered by EGRET at energies above 100 MeV [4]. Besides these connect-cases based on spatial coincidence and spectral match, it is furthermore interesting to investigate the remainder, where either a VHE source does not seems to have a GeV-counterpart, or an EGRET source is not anymore detectable at VHE energies. Once again we restrict ourself in this investigation to a region in the ranges of $|l| < 30°$ and $|b| < 3°$. Both aspects of such assessments need to be seen in connection with the instrumental capability to actually detect a counterpart in the proximate energy band. Based on the simplifying assumption of equal energy flux at high-energy gamma-rays, the case of EGRET sources not having a H.E.S.S. detected counterpart appears to be the more appealing one given that the mismatch of the rather different instrumental capabilities argues generally in favor of tighter constraints being set by the more sensitive experiment. On the other hand, the introduced methodology is easily applied to those cases where a H.E.S.S. detection is confronted to a non-detection at GeV energies, but the discussion widens according to the lesser constraints. We discuss the non-connect cases according to the following aspects: (1) the less sensitive EGRET instrument has effectively no realistic chance to detect a GeV counterpart based on a naive extrapolation of the low end of a H.E.S.S. source spectrum; (2) an extrapolation from the EGRET spectrum anticipates a H.E.S.S. detection; (3) higher order spectral fits on the EGRET data indicate limitations of a naive power-law extrapolation. In order to investigate these aspects we consistently determined upper limits at energies above 1 GeV in cases of reported VHE sources, or upper limits at 1 TeV in cases of detected EGRET sources in the GPS region, when the criterion for a connect case (nominal H.E.S.S. source location inside a EGRET 99%-confidence contour) was not fulfilled. Table 1 lists the respective EGRET and H.E.S.S sources in the GPS region subject of this investigation.

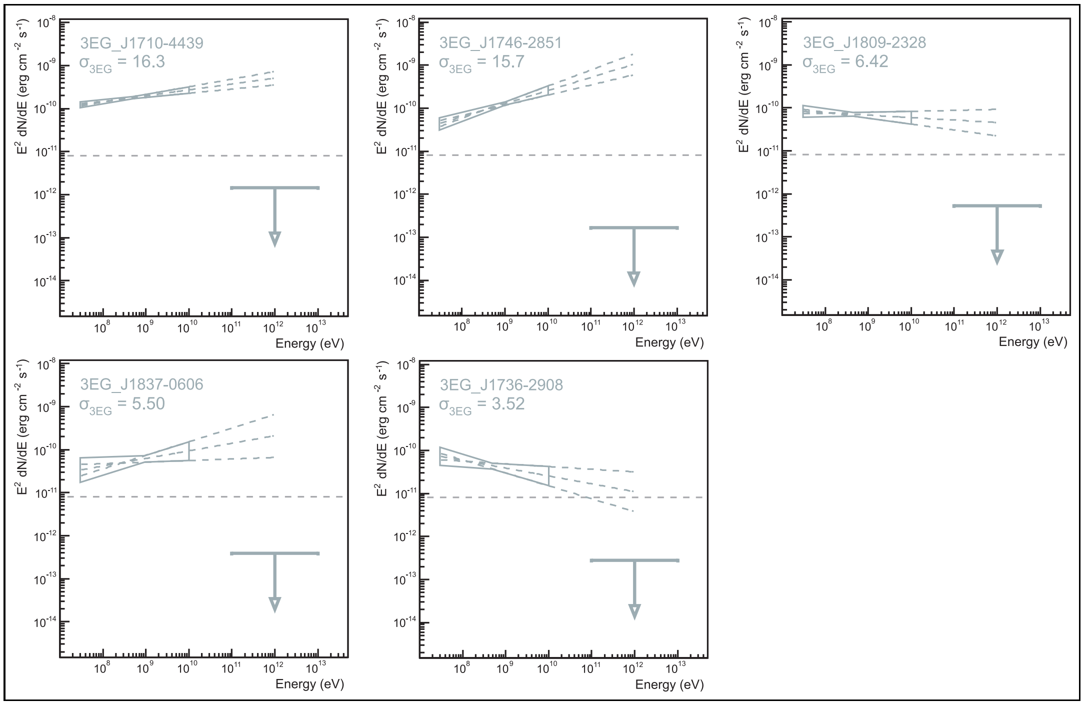

Figure 1: Spectral energy distribution at E > 30 MeV for the cases where a simple power-law extrapolation from the EGRET measured spectrum violates the H.E.S.S. upper limit. This figure depicts the most constrained cases by means of the parameter $\sigma_{\rm 3EG}$, ranging from left top to bottom middle. It is interesting to note that for three cases, a PSR or PWN nature of the EGRET source is established or suggested, and for those two found most incompatible among this five source sample the EGRET data itself indicate a spectral cutoff at GeV energies already.

EGRET sources without corresponding H.E.S.S. counterpart

In this section we examine those cases where no H.E.S.S. source was reported at any location inside a 99%-confidence contour of a cataloged EGRET source. This sample consist of 11 EGRET sources, with E > 100 MeV fluxes ranging between 0.4 and 3.1 $\times 10^{-6}$ cm^{-2} s^{-1}. The index of the power-law fit to the EGRET data ranges between $\sim$1.75 and 3.2. 2σ upper limits on the VHE emission at the nominal position of an EGRET source were determined at an energy of 1 TeV by scaling the H.E.S.S. sensitivity for achieving a 5σ point source detection at 1% of the Crab in 25 h to the actual exposures as published for the H.E.S.S. GPS region [3]. Spectral consistency with the determined VHE upper limit is tested by extrapolating a power-law from EGRET to 1 TeV. The nominal spectral index was systematically varied around the pivot point of the butterfly representation of an EGRET spectrum until the extrapolation intercept an energy of 1 TeV, $\Gamma_{\rm match}$. The deviation is measured in units of $\sigma_{\rm 3EG}$, which is obtained as of $\sigma_{\rm 3EG} = (\Gamma_{\rm match} - \Gamma_{\rm 3EG})/(\Delta\Gamma_{\rm 3EG})$ (where $\Gamma_{\rm 3EG}$ and $\Delta\Gamma_{\rm 3EG}$ are the EGRET index and its error from the third EGRET catalogue). We find that in six cases any conclusion concerning spectral compatibility remains indifferent when compared to the respective H.E.S.S. upper limit ($\sigma_{\rm 3EG} < 1.5$), which includes mainly the EGRET sources with steep spectrum. For five sources a H.E.S.S. detection would have been expected based on our assumption, but none was reported (Fig. 1). In particular the hard spectrum EGRET sources 3EG J1710–4439, 3EG J1746–

EGRET Source	H.E.S.S. Source
3EG J1655–4554	HESS J1614–518
3EG J1710–4439	HESS J1616–508
3EG J1718–3313	HESS J1632–478
3EG J1734–3232	HESS J1634–472
3EG J1736–2908	HESS J1702–420
3EG J1746–2851	HESS J1708–410
3EG J1809–2328	HESS J1713–395
3EG J1812–1316	HESS J1718–385
3EG J1823–1314	HESS J1745–290
3EG J1837–0423	HESS J1747–281
3EG J1837–0606	HESS J1800–240
	HESS J1804–216
	HESS J1809–193
	HESS J1813–178
	HESS J1834–087
	HESS J1837–069

Table 1: EGRET and H.E.S.S. sources considered as non-connect cases in this study.

2851, 3EG J1809–2328, and 3EG J1837–0606 are incompatible at a level exceeding $\sigma_{\rm 3EG} > 5$. Interestingly, at least three among them are more or less certain of Pulsar nature: 3EG J1710–4439 was unambiguously identified with PSR 1706–44 [5], 3EG J1837–0606 was suggested as counterpart of PSR J1837–0604 [6], and 3EG J1809–2328 to be of PWN nature [7]. The Galactic Center source stays in an own category in terms of variety of possible emission scenarios. However, when we look into higher-order spectral fits on these sources, we find that there is already indication for spectral cutoffs [8, 9] in the EGRET spectra of 3EG J1710–4439 and 3EG J1746–2851, both in fact the two sources with the highest incompatibility measure $\sigma_{\rm 3EG}$ in our sample. In that respect we can substantiate our findings of required spectral changes (softening/cutoff) in order to correspond to a H.E.S.S. upper limit into observational constraints at both the GeV and the TeV energies: The indicated cutoff in the EGRET spectrum corresponds nicely to the expected spectral changes in respect of the constraining VHE limit based on power-law extrapolation.

H.E.S.S. sources without corresponding EGRET counterpart

In this paragraph we examine the H.E.S.S. sources which are outside cataloged EGRET sources. We consistently determine flux upper limits from the EGRET data at the nominal H.E.S.S. location at energies above 1 GeV by means of the EGRET likelihood technique [10].Both detected GeV sources above a 4 σ detection threshold, and the galactic diffuse emission were modeled, and the underlying exposure corresponds to the first four years of the EGRET data taking. The determination of spectral incompatibility is now reversed by extrapolating H.E.S.S. measured VHE spectra to lower energies until they intersect the EGRET upper limit at 1 GeV. The measure $\sigma_{\rm H.E.S.S.}$ is determined in a similar way as $\sigma_{\rm 3EG}$. In order to avoid biases by extrapolating from H.E.S.S. spectra with apparent cutoffs, those were only fitted from $\rm E_{thres}$ to 1 TeV. Accordingly, $\sigma_{\rm H.E.S.S.}$ describes how well the extrapolated H.E.S.S. spectrum can be accommodated by the determined EGRET upper limit. In stark contrast to the results discussed in the previous section, there are generally no constraints to be made out when comparing H.E.S.S. detections with EGRET upper limits based on our assumption of power-law extrapolation. The main reason for that can be seen in the lack of instrumental sensitivity at GeV energies, in particular when observing in regions of pronounced diffuse γ-ray emission like the central Galactic strip. All values of $\sigma_{\rm H.E.S.S.}$ are less then 1, implying the EGRET upper limit is not violated. The most interesting case is that of HESS J1713–395, which was analyzed at GeV energies under the assumption that the emission from the source 3EG J1714–3857 is not associated with SNR RX J1713.7–3949 (according to the argumentation in [11]). Here the single power-law extrapolation is at level with the EGRET upper limit $\sigma_{\rm H.E.S.S.} = 1$. However, this situation will immediately change considering the expected sensitivity of the Gamma-Ray Large Area Telescope (GLAST). The increased sensitivity by GLAST will predictably elevate such investigation to a level where results will have consequences for the shape of a common emission component at low to high GeV energies. At this stage, we can only

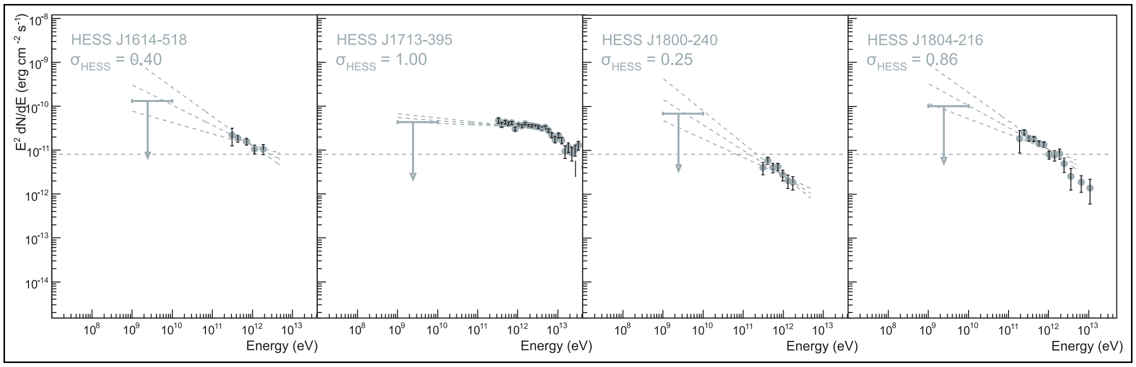

Figure 2: Spectral energy distribution at E $>$ 1 GeV for the cases where a simple power-law extrapolation from the H.E.S.S. measured spectrum intersects at about the level of the EGRET flux limit.

compare the number of six connect cases among the H.E.S.S. and EGRET source in the GPS region with the 16 H.E.S.S. sources where no constraining upper limit at GeVs could be derived. Concluding, we expect that the majority of GLAST source detections in the central Galactic strip will not outshine the population of currently known H.E.S.S. sources in terms of energy flux. It remains to be seen if GLAST will pick up emission at comparable or lower energy flux or the peak in νFν is indeed at VHE energies. A particular problem to such assessment lies in the fact that source extension at GeV energies is not comparably good studied as nowadays possible from VHE γ-ray observations. If source extension will be a common phenomenon in Galactic GeV astrophysics, the sensitivity comparison needs to invoke analysis on extension scales of comparable size or according to a specific emission scenario.

Summary

An immediate conclusion of our study is the finding that EGRET sources in the Galactic Plane are not necessarily a good general prior for subsequent detection of a VHE γ-ray source. Among other possibilities, associations with neutron stars may account for cutoffs at low GeV energies which diminish chances of their VHE detection at comparable energy flux level, or even prevent it. Even less stringent is any expectation of a GeV source when a VHE γ-ray source has been reported from the present generation of VHE γ-ray telescopes given the sensitivity of pair conversion telescopes prior to GLAST.

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