The H.E.S.S. Galactic Plane Survey - maps, source catalog and source population

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Abstract: The H.E.S.S. Galactic Plane Survey (HGPS), the first comprehensive survey of the inner Galaxy at TeV energies, has led to the discovery of an unexpectedly large and diverse population of over 60 sources of TeV gamma rays within its current range of l = 250 to 65 degrees in longitude and |b| < 3.5 degrees in latitude. The data set of the HGPS comprises ~2800 hours of high-quality data, taken in the years 2004 to 2013. The sensitivity for the detection of point-like sources is at the level of 2% Crab or better in the HGPS region. The population of TeV gamma-ray emitters is dominated by the pulsar wind nebula and supernova remnant source classes, although nearly a third of the sources remain unidentified or ambiguous. We are presenting the latest HGPS significance and sensitivity maps, as well as a work on the HGPS source catalog, based on a uniform re-analysis of the full data set collected in the last decade. We will also give a brief overview of the H.E.S.S. Galactic source population.

Keywords: very-high-energy gamma rays, Galactic, H.E.S.S., survey

1 Introduction

The High Energy Stereoscopic System (H.E.S.S. [1]) is ideally suited for undertaking a deep survey of our Galaxy, due to its high sensitivity, comparatively large field-of-view (FoV) of 5°, and its angular resolution of ~0.1° [2]. Its location in the Khomas highlands of Namibia provides it a prime view of the inner Galaxy. Here we report on the status and latest results of the H.E.S.S. Galactic Plane Survey (HGPS), the deepest and most comprehensive survey of the inner Galaxy undertaken in very-high-energy (VHE, E>0.1 TeV) γ-rays so far. The latest significance map is shown, alongside a short introduction to advanced methods for the suppression of cosmic-ray background. A software pipeline to detect and model sources of VHE γ-rays in the HGPS data set and construct a catalog is introduced.

The VHE γ-ray source population is dominated by objects that are linked to the final stages in stellar evolution, namely: pulsar wind nebulae (PWNe) and supernova remnants (SNRs). For a large number of sources, however, no plausible counterpart at other wavelengths has been found yet, or the physical origin of the detected emission remains unclear. An overview of the H.E.S.S. Galactic source population, and some of its properties is given.

2 Maps and source catalog

The inner Galaxy has now been observed for ~2800 hr using a variety of observation strategies [3,4] from 2004 to 2012. The main goal has always been to discover new VHE γ-ray sources and enable studies of populations of Galactic source classes as a consequence.

After calibration and quality selection [2], a multivariate analysis technique [5] based on shower and image shape parameters is used to discriminate γ-ray-like events from cosmic-ray-induced showers. A minimum image amplitude of 160 photo electrons is required.

To produce maps, the remaining background is estimated by the ring background technique [6], where, for each map position, the background is estimated from a ring centered on this position. It is vital to exclude regions with known γ-ray emission from areas in which the background is being calculated. A procedure has been developed to generate these exclusion regions automatically. The resulting exclusion maps cover areas of the sky that are comparatively large on the scale of the size of the FoV. Therefore, the ring background technique was modified to allow the ring radius to adaptively enlarge when a large fraction of the ring area overlaps with an excluded region, until an appropriate ring of the same thickness is reached. Further details on these two procedures can be found in [7]. The significance value for each position is then calculated [8] by summing the candidate events within a fixed and predefined radius of e.g. 0.1°, suitable for point-like sources, and comparing to the estimated background level at that position. Fig. 1 shows the latest significance map obtained for the survey region using these methods and the latest data.

The current H.E.S.S. sensitivity to VHE γ-ray sources (here, for point-like sources and assuming a power-law spectrum with index 2.3) is below 2% Crab for practically all of the longitude range l = 283° to 59° at latitude b = −0.3° (the mean for known Galactic H.E.S.S. sources) [7].

Using the HGPS maps as input, we have been developing a software pipeline to generate a source catalog. The aim is to have detection criteria as well as morphological and spectral analyses which are as uniform as possible. Such a catalog greatly facilitates population studies of Galactic source classes as well as measurements of Galactic diffuse

1. The H.E.S.S. software hap, version hap-13-06, was used.
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Figure 1: Significance map for the H.E.S.S. Galactic Plane Survey. The pre-trials significance for a correlation radius of 0.1 deg is shown. The colour transition from blue to red corresponds to \( \sim 5\sigma \) post-trials significance. The significance has been calculated for regions on the sky where the sensitivity of H.E.S.S. for point sources (5\( \sigma \) pre-trials, and assuming the spectral shape of a power law with index 2.3) is better than 10% Crab. Identifiers for sources that have been described in publications or announced at conferences are included.

3 Galactic source population

Currently, more than 140 sources are listed in the online VHE \( \gamma \)-ray catalogue TeVCat\(^4\) of which nearly 70 sources were detected by H.E.S.S. in the Galactic plane. The dominant source populations are PWNe and SNRs, but a large fraction are still unidentified (Fig. 2 data from TeVCat).

To construct the catalog, we use a likelihood fit of the H.E.S.S. event (count) map, taking the exposure and point spread function as well as the estimated background into account (see \[7\] for more details on the HGPS catalog production). The measurement of spectra of catalog sources is done independently from the maps, by defining source regions that contain most of the emission from a given source using the reflected background method \[6\].

2. \text{http://fermi.gsfc.nasa.gov}
3. \text{http://www.hawc-observatory.org}
4. \text{http://tevcat.uchicago.edu}
Figure 2: Galactic H.E.S.S. sources, status February 2013 (classifications taken from TeVCat). Pulsar wind nebulae (PWN, orange) are the largest source class with $\sim 35\%$, followed by supernova remnants, either interacting with a molecular cloud (SNR MC, yellow, $\sim 13\%$) or exhibiting emission from their shell (SNR Shell, light green, $\sim 8\%$). Besides a few massive stellar clusters (dark red, $\sim 6\%$) and some binary systems (light blue, $\sim 4\%$) a large part of the H.E.S.S. source population remains unidentified (dark blue, $\sim 31\%$). ’Other’ (dark green) comprises the globular cluster Terzan 5 and the high-frequency peaked BL Lac object HESS J1943+213.

example, the VHE $\gamma$-ray integral flux as a function of the source radius is shown in Fig. 3. It reveals that the sample is likely incomplete, with a reduced sensitivity to large and faint sources.

The question of the completeness of the H.E.S.S. source sample can also be evaluated in terms of spatial coverage of the Galaxy. Figure 4a shows a face-on view of our Galaxy, in which detected sources are plotted at their estimated distances. This clearly shows that only a small fraction of the Galaxy is observed (roughly 50% of the Galaxy for 10% Crab luminosity). An important caveat to the displayed horizons is that they are computed based on the sensitivity of the HGPS and do not take into account the screening effect that known sources have in obscuring or confusing potential emission along the line-of-sight but behind that source. Moreover, the horizons are currently calculated only for the simplified hypothesis of point-like sources. As seen in Fig. 4b, the sensitivity decreases as the source size increases, which would yield a closer horizon in the case of an extended source.

4 Outlook

After nearly a decade of data taking, H.E.S.S. is ending its surveying program of the Galactic Plane. The additional of a large fifth Cherenkov telescope in the centre of the H.E.S.S. array marks the beginning of H.E.S.S. Phase II and will concentrate on deeper observations with much improved intensity and spatial resolution but smaller FoV. Here, we have presented an update on the HGPS status and a brief overview of the H.E.S.S. Galactic source population, including some of its limitations. In the near future, we aim to present the entire data set of the HGPS, in the form of high-level maps and a source catalog accessible to the community.

With this large data set, extensive population studies in the VHE range become possible for the first time, as will be reported in this conference in a contribution by S. Klepser et al., "A Population of Teraelectronvolt Pulsar Wind Nebulae in the H.E.S.S. Galactic Plane Survey" (ID 591) and in a contribution by J. Hahn et al., "Study of the Very High Energy emission from Supernova Remnants with H.E.S.S." (ID 1048). Besides population studies other interesting topics can be explored in this data set, e.g. the diffuse emission in the Galactic plane, on which K. Egberts et al. will report: "Diffuse TeV Gamma-Ray Emission in the H.E.S.S. Galactic Plane Survey" (ID 744). In-depth studies of the Galactic centre will be presented by A. Viana et al., "Spectral morphology of the inner 50 pc of the Galactic Center region in very-high-energy gamma-rays with H.E.S.S." (ID 901).

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References

Figure 3: H.E.S.S. Galactic sources: Integrated flux in the $1 - 10$ TeV (cm$^{-2}$ s$^{-1}$) energy band versus source radius (arcmin). The blue line depicts an estimate of the radius-dependant sensitivity of H.E.S.S. SNRs are marked in yellow, PWNe in red, and all other classes (including those unidentified or confused) in black. (Data taken from TeVCat.)

Figure 4: Face-on view of our Galaxy, with the spiral arms [9] drawn as solid grey lines. The H.E.S.S. horizons for 1% and 10% of the Crab Nebula luminosity above 1 TeV (ph s$^{-1}$), for a 5-$\sigma$ point-like source, are depicted by the blue curves. Superimposed are the H.E.S.S. Galactic sources with known distances, as listed in TeVCat. Colours as in Fig. 3.