

Extending the H.E.S.S. Galactic Plane Survey

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Abstract. The High Energy Stereoscopic System (H.E.S.S.), located in the Khomas Highlands of Namibia, is an array of four imaging atmospheric-Cherenkov telescopes designed to detect γ -rays in the very-high-energy (VHE; $E > 100$ GeV) domain. It is an ideal instrument for surveying the Galactic plane in search of new sources of VHE γ -rays, due to its location in the Southern Hemisphere, its excellent sensitivity, and its large field-of-view. The H.E.S.S. Galactic Plane Survey (GPS) began in 2004 and initial observations of the Galactic plane resulted in the discovery of numerous VHE γ -ray emitters. This original H.E.S.S. GPS covered the inner Galaxy within $\pm 30^\circ$ in longitude and $\pm 3^\circ$ in latitude, with respect to the Galactic center. In the last four years, the longitudinal extent of the survey has more than doubled, now including the region $l = 275^\circ - 60^\circ$, and the exposure in the inner Galaxy has also been significantly increased. These efforts have consequently led to the discovery of many previously-unknown VHE γ -ray sources with high statistical significance. We report on the current status of this ongoing, extended H.E.S.S. GPS, present the latest images of the survey region, and highlight the most recent discoveries.

Keywords: H.E.S.S., Galactic Plane Survey, VHE gamma-rays

I. INTRODUCTION

The current generation of imaging atmospheric-Cherenkov telescopes (IACTs) has opened a new astronomical window on the Universe in the very-high-energy (VHE; $E > 100$ GeV) domain. Twenty years after the detection of the first TeV γ -ray source, the Crab nebula [1], approximately 100 VHE γ -ray sources have now been discovered¹ [2]. Over two-thirds of these sources are located in our Galaxy, of which most were discovered by the IACT array H.E.S.S. (High Energy Stereoscopic System) during its ongoing Galactic Plane Survey (GPS). VHE γ -rays carry information about the most extreme environments in the local Universe, and although a significant fraction of the Galactic VHE γ -ray sources do not appear to have obvious counterparts at other wavelengths [3] [4], the majority of them are associated with the violent, late phases of stellar evolution, e.g. supernova remnants (SNRs), pulsar wind nebulae (PWNe) of high spin-down luminosity pulsars,

and massive Wolf-Rayet (WR) stars in stellar clusters. Since all of these astronomical objects are known to cluster along the Galactic plane, a comprehensive and systematic survey of this region is an obvious approach for discovering new sources of VHE γ -rays.

II. THE H.E.S.S. TELESCOPE ARRAY

H.E.S.S. is comprised of four, identical, 12-m diameter IACTs located at an altitude of 1800 m above sea level in the Khomas Highlands of Namibia [5]. Its location in the Southern Hemisphere affords it an excellent view of the inner Galaxy compared to most of the other IACTs, which are located in the Northern Hemisphere. Each of H.E.S.S.'s four telescopes is equipped with a camera containing 960 photomultiplier tubes and a tessellated mirror with a combined area of 107 m² [6]. The optical design allows for a comparatively large, 5° field-of-view (FoV), the largest of all the IACTs currently in operation. The H.E.S.S. array has an angular resolution of $\sim 0.1^\circ$ and an energy resolution of $\sim 15\%$. Its unprecedented sensitivity to γ -rays above ~ 100 GeV enables H.E.S.S. to detect a point source with a flux $\sim 1\%$ of the Crab nebula with a statistical significance of 5σ in just 25 hours of observations [5]. This high sensitivity, coupled with a large FoV, permits H.E.S.S. to effectively survey large areas of the Galaxy within a reasonable amount of time.

III. THE H.E.S.S. GALACTIC PLANE SURVEY

A. The Original Survey in 2004

The H.E.S.S. Galactic Plane Survey began in 2004 and has been a major component of the H.E.S.S. observation program ever since. The original GPS [12], conducted during 2004, covered the region $l \pm 30^\circ$ in longitude and $b \pm 3^\circ$ in latitude, with respect to the Galactic center (GC). This large area (360 sq. deg.) corresponds roughly to the inner part of the Galaxy, from the Norma spiral arm tangent at $l \approx 327^\circ$ to the Scutum-Crux spiral arm tangent at $l \approx 31^\circ$ [9]. Observations of 28-min duration each were taken at pointing positions separated in Galactic longitude by $\sim 0.7^\circ$. The systematic pointings were distributed in three strips in Galactic latitude, at $b = -1^\circ, 0^\circ$ and $+1^\circ$, covering a $\sim 6^\circ$ -wide region along the Galactic plane. In this *scan* mode, 95 h of data were initially taken. Promising VHE γ -ray source candidates were then re-observed with dedicated *pointed* observations, comprising an additional 30 h of data. Finally, known or presumed VHE γ -ray sources were observed, including the GC [10] and the shell-type SNR RX J1713.7–3946 [11]. In total, the original

¹See TeVCat, an online TeV γ -ray catalog, at <http://tevcat.uchicago.edu>.

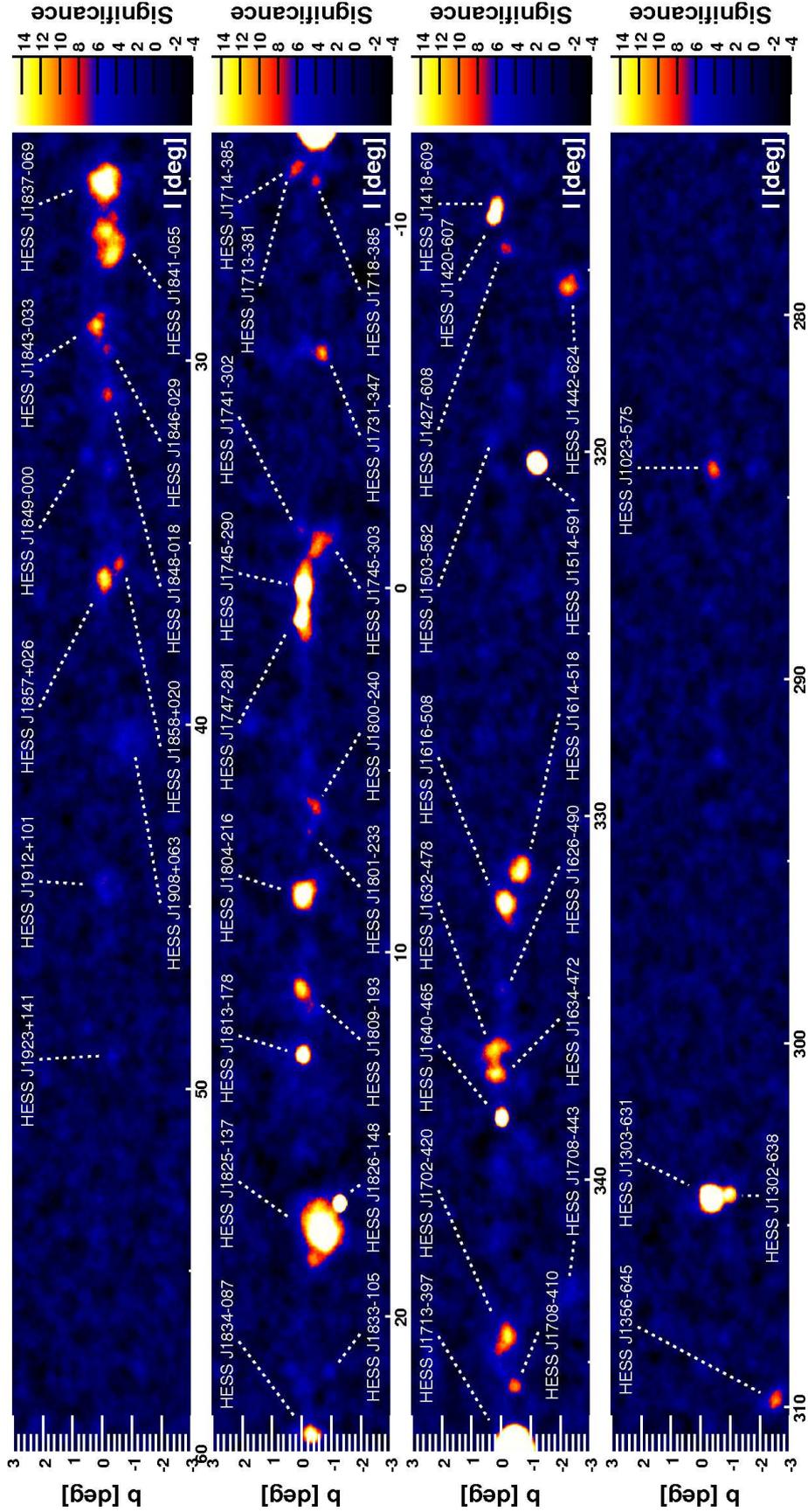


Fig. 1. Image showing the pre-trials statistical significance in the H.E.S.S. Galactic Plane Survey region in four panels. HESS J1507–622 is not shown, since it is located -3.5° off-plane. The recently-discovered VHE γ -ray emission from Westerlund 1 is also not labeled. The significance is truncated above 15σ to increase visibility, and the color transition (from blue to red) is set at 7.4σ pre-trials significance, which corresponds to 5σ post-trials significance. See section III-B for more information.

H.E.S.S. GPS dataset included ~ 230 h of observations after data quality selection.

The first phase of the H.E.S.S. GPS resulted in the discovery of eight, previously-unknown sources of VHE γ -rays with a statistical significance greater than 6σ , after accounting for all trials involved in that initial survey (post-trials) [8]. Additionally, six likely sources were detected with post-trials significances above 4σ [12], all of which were subsequently confirmed with deeper observations.

B. Extending the Survey in 2005–2009

In the last four years, the H.E.S.S. GPS has been extended in Galactic longitude and now includes the 145° -wide region $l \sim 275^\circ - 60^\circ$ [7]. The Survey now reaches two additional spiral arm tangents, Sagittarius-Carina at $l \approx 51^\circ$ and Crux-Scutum at $l \approx 310^\circ$ [9], and beyond, for a total area of 870 sq. deg. In addition to expanding the surveyed region, the overall exposure along the Galactic plane has also increased significantly. The total exposure of the GPS dataset has increased by a factor of 6 from the initial ~ 230 h of observations to over 1400 h. Approximately 450 h of data were taken in *survey* mode, and an additional ~ 950 h of data are a result of *pointed* observations.

The latest image of the pre-trials statistical significance in the extended H.E.S.S. GPS region is presented in Fig. 1. The image was created using calibrated, quality-selected data from observations during the period March 2004 to October 2008. The on-source counts (signal plus background) were summed from a circle of radius 0.22° centered on each grid point. The background was then estimated from a ring with a mean radius of 1.2° and an area ~ 7 times as large as the on-source region, also centered on each grid point. A grid spacing of 0.02° was used to produce the image. The γ -hadron separation was performed using *hard* cuts (which require a minimum of 200 p.e. for each Cherenkov image). Further details on the H.E.S.S. *standard analysis* can be found in [5]. The minimum energy threshold and the effective exposure—and, therefore, the sensitivity—vary considerably throughout this image. Efforts are currently underway to increase the uniformity of the exposure across the survey region.

The Galactic plane is clearly visible at VHE γ -ray energies, with the vast majority of VHE γ -ray sources distributed at low Galactic latitudes. Figure 2 shows the distribution of the H.E.S.S. GPS sources in Galactic latitude. The distribution has a mean of $b = -0.26^\circ$ and an rms of 0.40° , not counting the four outliers at $b < 2.0^\circ$. This implies the Galactic plane as seen in VHE γ -rays has a thickness of ~ 70 – 120 pc in the inner Galaxy, compatible with the distribution of a presumed parent population of SNRs and pulsars. However, given the non-uniform sensitivity of the H.E.S.S. GPS, this analysis is still preliminary.

The official H.E.S.S. Source Catalog is available on-

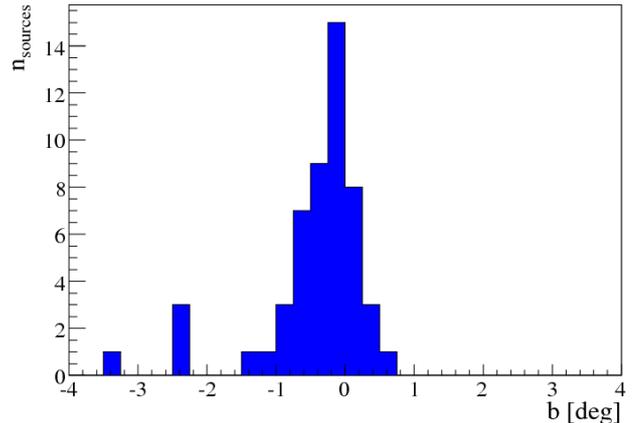


Fig. 2. Distribution of the Galactic latitude b of all the VHE γ -ray sources in the extended H.E.S.S. GPS region. The distribution has a mean $b = -0.26^\circ$ and an rms of 0.40° , not counting the four outliers at very low Galactic latitude.

line² and includes all of the VHE γ -ray sources (Galactic and extragalactic) which were detected by H.E.S.S. and subsequently published in refereed journals.

IV. RECENT DISCOVERIES OF VHE γ -RAY SOURCES

H.E.S.S. is continually surveying the Galaxy for VHE γ -ray source candidates and then following up on these source candidates with dedicated, *pointed* observations. Some of the more recent H.E.S.S. discoveries are highlighted below:

- **HESS J1923+141:** This new source is located in the complex W 51 region, which hosts many high-energy phenomena, among them the SNR W 51C (G49.2–0.7). This partial shell-type SNR is interacting with a nearby giant molecular cloud (GMC), as evidenced by the presence of two OH(1720 MHz) masers; in this scenario, VHE γ -rays could be produced by π^0 decay after hadronic interactions in the GMC. Competing scenarios involve leptonic interactions associated with a PWN candidate in the region, and, alternatively, an active star-forming region within the GMC. See [14] for more information.
- **HESS J1741–302:** This very faint VHE γ -ray source was detected after deep observations of the GC region. The plausible counterparts are currently being studied; they include cosmic ray interaction with MCs as well as a weak, offset PWN scenario. See [4] for more information.
- **HESS J1708–443:** One of the latest H.E.S.S. discoveries in the Galactic plane is in the vicinity of the energetic pulsar PSR B1706–44 and SNR G343.1–2.3. It is an extended source of VHE γ -rays and has a relatively hard spectrum ($\Gamma = 2.0 \pm 0.1_{\text{stat}} \pm 0.2_{\text{sys}}$). The H.E.S.S. source could be associated with a relic PWN of the pulsar or with the SNR itself, two scenarios still under investigation. See [13] for more information.

²See <http://www.mpi-hd.mpg.de/hfm/HESS/pages/home/sources>

- **HESS J1507–622:** This recently-discovered VHE γ -ray emitter is unique due to its location relatively far from the Galactic plane, at a Galactic latitude $b \sim -3.5^\circ$. It is currently unidentified (or *dark*), i.e. there are no plausible, lower-energy counterparts nearby, despite a comprehensive multi-wavelength search. See [4] for more information.
- **Westerlund 1 region:** H.E.S.S. has also recently announced the discovery of VHE γ -ray emission from the region of Westerlund 1, a massive young stellar cluster which is rich in WR stars. See [15] for more information.

V. SUMMARY

When the H.E.S.S. Galactic Plane Survey began in 2004, there were only three known sources of VHE γ -rays in our Galaxy. The ongoing and extended Survey now covers most of the Galactic plane as seen from the Southern Hemisphere, specifically the region of Galactic longitude $l \sim 275^\circ - 60^\circ$ and latitude $b = \pm 3^\circ$. More than 1400 h of observations have now been taken in this region; these data come from a combination of systematic, *scan-mode* observations, re-observations of promising VHE γ -ray source candidates, and dedicated observations of known or presumed VHE γ -ray emitters. As of May 2009, H.E.S.S. has detected a total of 52 Galactic sources of VHE γ -rays in or near the survey region. While many of these sources are still unidentified or *dark*, the majority are thought to be associated with some of the most energetic phenomena in our Galaxy, in particular pulsar wind nebulae and supernova remnants.

VI. ACKNOWLEDGMENTS

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