Exploring the population of Galactic very-high-energy $\gamma$-ray sources

Constantin Steppa\textsuperscript{a,\,*} and Kathrin Egberts\textsuperscript{a} on behalf of the CTA Consortium  
(a complete list of authors can be found at the end of the proceedings)

\textsuperscript{a}Institut für Physik und Astronomie, Universität Potsdam,  
Karl-Liebknecht-Str. 24/25, Potsdam, Germany  
E-mail: steppa@uni-potsdam.de, kathrin.egberts@uni-potsdam.de

At very high energies (VHE), the emission of $\gamma$ rays is dominated by discrete sources. Due to the limited resolution and sensitivity of current-generation instruments, only a small fraction of the total Galactic population of VHE $\gamma$-ray sources has been detected significantly. The larger part of the population can be expected to contribute as a diffuse signal alongside emission originating from propagating cosmic rays. Without quantifying the source population, it is not possible to disentangle these two components. Based on the H.E.S.S. Galactic plane survey, a numerical approach has been taken to develop a model of the population of Galactic VHE $\gamma$-ray sources, which is shown to account accurately for the observational bias. We present estimates of the absolute number of sources in the Galactic Plane and their contribution to the total VHE $\gamma$-ray emission for five different spatial source distributions. Prospects for CTA and its ability to constrain the model are discussed. Finally, first results of an extension of our modelling approach using machine learning to extract more information from the available data set are presented.
Exploring the population of Galactic very-high-energy $\gamma$-ray sources
C. Steppa & K. Egberts

1. Introduction

In the last decades, we have continuously expanded our horizon for the very high-energy universe. Yet, with about 150 VHE $\gamma$-ray sources discovered, we have uncovered only a small fraction of the population of Galactic sources. This small sample is not representative of the entire population, as it has a strong inherent observational bias. The composition of this sample is the result of the complex interplay between global source distributions, such as source position, luminosity or physical extent, and instrumental selection effects. In this contribution we describe a model of the population of Galactic VHE $\gamma$-ray sources derived from the source sample of the H.E.S.S. Galactic plane survey (HGPS) catalogue [1] using a population synthesis method to correctly account for the observational bias. The model was originally presented in [2]. For more information beyond the summary given here, please read the original publication.

2. Model

In our model, we treat each source as a generic $\gamma$-ray emitter, i.e. we do not model specific classes of sources. This approach is complementary to detailed source modelling and allows us to determine global properties that we need, for example, to estimate the contribution of unresolved sources to the measurement of large-scale diffuse emission. The model is composed of independent distribution functions for the position of the sources, their luminosity and their physical extent. For the source position, we took five different spatial distribution functions with fixed parameters from the literature to investigate what implications this has for the other properties of the population. Next to two azimuthally symmetric distributions, three distributions following a spiral-arm structure were also chosen. Both the luminosity and the physical extent—represented here only by the radius of a spherically symmetric object—are described by simple power laws with fixed limits, so that the indices of these power laws are the only free parameters of the model.

3. Parameter estimation

The parameters of the model were reconstructed using population synthesis in combination with maximum likelihood estimation. First, the observation bias of the HGPS was estimated from the sensitivity map provided with the catalogue. In doing so, the description of the instrument’s sensitivity was extended to account for its degradation with the angular extent of the sources. With this estimate, the expected number of detected sources can be calculated for any given global source distribution, so that the model parameters were optimised based on a likelihood determined by Poissonian count statistics. The accuracy of this procedure was validated with Monte Carlo simulations of synthetic populations. The final result of this optimisation is shown in Table 1.

4. Model predictions

To assess our model and parameter estimation, we compared distributions of observable quantities such as source flux or position on the sky of the HGPS sample with simulated sources of synthetic populations that fall within the sensitivity range of the HGPS. In general, good agreement
Exploring the population of Galactic very-high-energy $\gamma$-ray sources

Table 1: Estimates of the indices of the luminosity and radius distribution functions, $\alpha_L$ & $\alpha_R$, calculated based on different spatial distributions of the sources. Details are given in [2].

| Spatial distribution | $\alpha_L$ | $\alpha_R$ |
|----------------------|------------|------------|
| mSNR                | -1.70      | -1.19      |
| mPWN                | -1.81      | -1.13      |
| mFE                 | -1.94      | -1.21      |
| mSp4                | -1.64      | -1.17      |
| mSp2B               | -1.78      | -1.62      |

is achieved between observation and model, with the exception of a spatial distribution model that assumes a two-arm spiral structure. Also, the observed asymmetry in the source distribution over Galactic latitude and the distribution over angular extent does not yet find satisfactory agreement in the model. Despite these discrepancies, the model allows us to gain insight into the Galactic population of VHE $\gamma$-ray sources. Depending on the spatial distribution model, the estimated total number of sources is between 800 and 7000. If the actual population is close to the upper limit of this range, this challenges the standard paradigm that supernova remnants and pulsar wind nebulae are the dominant source classes of VHE $\gamma$-ray emission.

The combined flux of unresolved sources in the region covered by the HGPS was estimated to be 13\%-32\% of the flux of the total source sample in this region. This magnitude is compatible with the measurement of large-scale diffuse emission by H.E.S.S. [3] and a clear indication that the contribution of unresolved sources is indeed not negligible. A template of unresolved sources that we can generate with our population synthesis approach will allow us to assess this contribution more precisely.

Next-generation instruments such as CTA will be able to resolve a significant fraction of the yet unresolved sources and help us improve our knowledge of the global population. With a targeted sensitivity for point sources of 2 mCrab in the longitude range $|l| < 60^\circ$ and the latitude range $|b| < 2^\circ$ [4] and an angular resolution of 0.05$^\circ$ at 1 TeV, the predicted number of detectable sources is in the range 200-600, which increases the known Galactic VHE $\gamma$-ray source sample by a factor of between 5-9 (within this region).

5. Outlook

The resolution of the entire population of Galactic VHE $\gamma$-ray sources will be beyond our capabilities in the foreseeable future. Therefore, population models are an important tool to assess measurements of VHE $\gamma$-ray emission and the applied analysis techniques. In our continuous efforts to improve our population model, we have developed a new, more precise method for reconstructing the model parameters based on Deep Learning. This method reduces the reconstruction errors by about a factor of two. More details on this method will be given in a future publication. Also, in future iterations of the model, we will look more closely at the impact of source confusion on the obtained sample in the sensitivity range. Rough estimates suggest that 22\%-24\% of the sources in the HGPS are already affected by source confusion and similar values are expected for the CTA GPS. While the effect of source confusion on the sample of detected sources and their measured
properties remains to be evaluated, adequately accounting for this effect in the modelling is the logical next step towards a more accurate description of the global population.

Acknowledgments

This work was conducted in the context of the CTA Consortium. We gratefully acknowledge financial support from the agencies and organisations listed here: http://www.cta-observatory.org/consortium_acknowledgments.

References

[1] H. E. S. S. Collaboration, The H.E.S.S. Galactic plane survey, A&A 612 (2018) A1 [1804.02432].

[2] C. Steppa and K. Egberts, Modelling the Galactic very-high-energy γ-ray source population, A&A 643 (2020) A137 [2010.03305].

[3] H. E. S. S. Collaboration, Diffuse Galactic gamma-ray emission with H.E.S.S., Phys. Rev. D 90 (2014) 122007 [1411.7568].

[4] Cherenkov Telescope Array Consortium, Science with the Cherenkov Telescope Array (2019), 10.1142/10986.
Exploring the population of Galactic very-high-energy γ-ray sources

Full Authors List: The Cherenkov Telescope Array Consortium

H. Abdalla1, H. Abe2, S. Abe2, A. Abusleme3, F. Acer4o4, A. Acharyya5, V. Acín Portella6, K. Ackley7, R. Adam8, C. Adams9, S.S. Adhikari10, I. Aguado-Ruesga11, I. Agudo12, R. Aguilera13, A. Aguirre-Santaella14, F. Aharonian15, A. Alberdi12, R. Alfaro16, J. Alfaro3, C. Alispach17, R. Aloisio18, R. Alves Batista19, J.-P. Amans20, L. Amati21, E. Amato22, L. Ambrogioni, G. Ambrosi23, M. Ambrosio24, R. Amendola25, J. Anderson26, M. Anduze26, E.O. Angüner27, L.A. Antonelli28, V. Antonucci29, P. Antoranz30, R. Anutarawiramkul31, J. Aragunde Gutierrez32, C. Aramo34, A. Araudo33, M. Araya35, A. Arbet-Engels36, C. Arcaro3, V. Arendt37, C. Armand38, T. Armstrong27, F. Arqueros11, L. Arrabito39, B. Arsio40, M. Artero41, K. Asano38, Y. Ascasibar14, J. Aschersleben32, M. Ashley43, P. Attina44, P. Aubert45, C. B. Singh19, D. Baack6, A. Babic47, M. Backes48, V. Baena13, S. Bajtlik49, A. Baktash50, C. Balazs7, M. Balbo35, O. Ballester41, J. Ballet4, B. Balmaverde44, A. Bamba31, R. Bandiera22, A. Baqueri Larriva11, P. Barai19, C. Barbier51, V. Barbosa Martins32, M. Barceló3, M. Barkov54, M. Barnard1, L. Baroncelli21, U. Barres de Almeida40, J.A. Barrio11, D. Bastieri55, P.I. Batista2, I. Batkovic55, C. Bauer53, R. Bautista-González56, J. Baxter2, U. Becciani29, J. Becerra González52, Y. Becherini57, G. Beck58, J. Becker Tjus59, W. Bednarek60, A. Belfiore61, L. Belluzzi62, R. Belmont6, W. Benbow63, D. Berge52, E. Bernardini52, M.I. Bernardos55, K. Bernlöhö53, A. Bertì64, M. Berton65, B. Bertucci23, V. Beshley60, N. Bhatt67, S. Bhattacharyya67, W. Bhattacharya52, S. Bhattacharyya68, B. Bi69, G. Bicknell70, N. Biederbeck66, C. Bigongiari28, A. Biland66, R. Bird71, E. Bissaldi72, J. Biteau73, M. Bitossi74, O. Blanch71, M. Blank50, J. Blazek33, J. Bobin75, C. Bocciato76, F. Bocchino77, C. Boehm78, M. Bohacova33, C. Boisson29, J. Boix41, J.-P. Bolle52, J. Bolmont79, G. Bonanno29, C. Bonavolontà34, L. Bonneau Arbeletche80, G. Bonnoli12, P. Bordes81, J. Borkowski49, S. Bórquez39, R. Bose82, D. Bose83, Z. Bosnjak47, E. Bottacini55, M. Böttcher1, M.T. Botticella34, C. Boutonner85, F. Bouyjou75, V. Bozhilov65, E. Bozzo38, L. Brahimi39, C. Braiding43, S. Braun-Nogue87, S. Breen78, J. Bregeon39, M. Breuhaus53, A. Brill9, W. Brisker88, E. Broccato28, A.M. Brown5, K. Brügge46, P. Brun89, P. Brun39, F. Brun89, L. Brunetti45, G. Brunetti90, P. Bruno29, A. Bruno91, A. Bruzzese6, N. Bucciantini22, J. Buckley82, R. Bühler52, A. Bulgarelli21, T. Bulik92, M. Bünning52, M. Bunse46, M. Burton93, A. Burtovoi76, M. Buscemi94, S. Buschjäger46, G. Busetto55, J. Bush56, K. Byrum26, A. Caccianiga95, F. Cadoux17, A. Calanducci29, C. Calderón7, J. Calvo Tobar23, R. Cameron86, P. Campana35, R. Canestrari91, F. Cangemi79, B. Cantlay31, M. Capalbi91, M. Capasso9, M. Cappi21, A. Caproni97, R. Capuzzo-Dolcetta28, P. Caraveo61, V. Cárdenas98, L. Cardiel41, M. Cardillo99, C. Carlile100, S. Caroff45, R. Carosi74, A. Carosi77, E. Carquin35, M. Carrière39, J.-M. Casandjian1, S. Casanova101, E. Cascone84, F. Cassol27, A.J. Castro-Tirado12, F. Catalani102, O. Catalano91, D. Cauz103, A. Ceccanti64, C. Celestino Silva80, S. Celli18, K. Cerny104, M. Cerruti35, E. Chabanne45, P. Chadwick5, Y. Chai105, P. Chambery106, C. Champion85, S. Chandra1, S. Chaty4, A. Chen58, K. Cheng2, M. Chernyakova107, G. Chiarelli61, A. Chiavassa64, M. Chikawa2, V.R. Chitnis109, J. Chudoba33, L. Chytka104, S. Cikota47, A. Ciriello24,110, P. Clark5, M. Colak41, E. Colombo32, J. Colome13, S. Colonges95, A. Comastri21, A. Compagnino91, V. Conforti21, E. Coniglio95, R. Conigliore94, J. Conrad111, F. Conte53, J.L. Contreras11, P. Coppi112, R. Cornat8, J. Coronado-Blazquez14, J. Cortina113, A. Costa29, H. Costantini27, G. Cotter114, B. Courty85, S. Covino95, S. Creusan101, P. Cristofari20, R. Crocker70, J. Croston115, K. Cubuk93, O. Cuevas98, X. Cui2, G. Cusumano91, S. Cutini23, A. D’Aì41, G. D’Amico116, F. D’Ammando90, P. D’Avanzo99, P. Da Vela79, M. Dadina21, S. Dai117, M. Dalchenko17, M. Dall’Ora84, M.K. Daniel63, J. Dauguet85, I. Davids88, J. Davies114,
Exploring the population of Galactic very-high-energy γ-ray sources

B. Dawson18, A. De Angelis55, A.E. de Araújo Carvalho40, M. de Bény de Lavergne45, V. De Caprio84, G. De Cesare21, F. De Franceschi20, E.M. de Gouveia Dal Pino19, I. de la Calle11, B. De Lotto103, A. De Luca61, D. De Martino84, R.M. de Menezes19, M. de Moraes85, E. de Oña Wilhelmi13, F. De Palma64, F. De Persio119, N. de Simone12, V. de Souza80, M. Del Santo91, M.V. del Valle19, E. Delagnes75, G. Deleglise45, M. Delfino Reznicek6, C. Delgado113, A.G. Delgado Giler80, J. Delgado Mengual8, R. Della Ceca95, M. Della Valle84, D. della Volpe17, D. Depaoli64,108, D. Depouvez27, J. Devlin85, T. Di Girolamo24,110, C. Di Giulio25, A. Di Piano21, F. Di Pizzo64, L. Di Venere120, C. Díaz113, C. Díaz-Bahamonde3, C. Dib15, S. Diebold69, S. Digel96, R. Dima55, A. Djannati-Ataï85, J. Dłużys116, A. Dmytriiev20, K. Kocher9, A. Domínguez11, D. Donini Presto121, A. Donath53, A. Donini41, D. Dorner122, M. Doro55, R.D.C. dos Anjos123, J.-L. Dournaux20, T. Downes107, G. Drake26, H. Drass3, D. Dravins100, C. Duangchan31, A. Duara124, G. Dubus125, L. Ducchi69, C. Duffy124, D. Dumora106, K. Dundas Morã111, A. Durkalec126, V.V. Dwarkadas127, J. Ebr53, C. Eckner45, J. Eder105, A. Ederoclite19, E. Edy8, K. Eggert128, S. Einecke118, J. Eisch129, C. Eleftheriadis130, D. Elsässer46, G. Emery17, D. Emmanoulopoulos115, J.-P. Ernenwein27, M. Errando82, P. Escarate35, J. Escudero12, C. Espinoza1, S. Ettori21, A. Ewangwanichayapant31, P. Evans124, C. Evoli18, M. Fairbairn131, D. Falcke-Goncalves132, A. Falcone133, V. Fallah Ramazani85, R. Falomo76, K. Farakos134, G. Fasola20, A. Fattorini46, Y. Favre17, R. Fedrora135, E. Fedorova136, S. Fegan8, K. Feijen118, Q. Feng9, G. Ferrando44, G. Ferrara94, O. Ferreira8, M. Fesquet75, E. Fiandrini53, A. Fiasson45, M. Filipovic117, D. Fink105, J.P. Finley137, V. Fiorletti21, D.F.G. Fiorillo24,110, M. Fiorini61, S. Fili52, H. Flores20, L. Foffano17, C. Föhr53, M.V. Fonseca11, L. Font138, G. Fontaine8, O. Fornieri52, P. Fortin63, L. Fortson88, N. Fouque45, A. Fournier106, B. Fraga40, A. Franceschini76, F.J. Franco30, A. Franco Ordoñez32, L. Freixas Coromina113, L. Fresnillo30, C. Fruck105, D. Fugazza95, Y. Fujikawa139, Y. Fujita2, S. Fukami2, Y. Fukazawa140, Y. Fukui141, D. Fulla32, S. Funk142, A. Furniss143, O. Gabella39, S. Gabici85, D. Gaggero14, G. Galanti61, G. Galaz3, P. Galdemard144, Y. Gallant39, D. Galloway7, S. Gallozzi28, V. Gammaldi14, R. Garcia41, E. Garcia55, E. Garcia13, R. García López22, M. Garzarelli52, F. Gargano120, C. Gargano61, S. Garozzo29, D. Gascon81, T. Gasparetto145, D. Gasparri25, H. Gasparyan52, M. Gaug138, N. Geffroy45, A. Gent46, S. Gennari76, L. Gesa13, A. Ghalumiyan47, A. Ghedina148, G. Ghirlanda95, F. Gianotti21, S. Giarrusso95, M. Giarrusso94, G. Giavitto52, B. Giebels8, N. Giglietto72, V. Gika134, F. Gillardio15, R. Gimenes39, F. Giordano149, G. Giovannini90, E. Giommi36, M. Giroletti90, A. Giuliani61, L. Giunti85, M. Gjaja9, J.-F. Glicenstein89, P. Gliwny60, N. Godinovic150, H. Göksu53, P. Goldoni85, J.L. Gómez12, G. Gómez-Vargas3, M.M. González16, J.M. González51, K.S. Gothe109, D. Götz4, J. Gouart Coelho123, K. Gourguehatos5, T. Grabareczyk52, R. Gracian181, P. Grandi21, G. Grasso8, D. Grasso74, A.J. Green78, D. Green105, J. Green28, T. Greenshaw153, I. Grenier4, P. Grespan55, A. Grillo29, M.-H. Grondin106, J. Grube131, V. Guarino26, B. Guest37, O. Gueta42, M. Günzüd99, S. Gunji154, A. Gusdorf20, G. Gyuk155, J. Hackfeld99, D. Hadash2, J. Haga139, L. Hagge52, A. Hahn105, J.E. Hajlouei85, H. Hakobyan35, A. Halim89, P. Hamal131, W. Hanlon63, S. Haro156, Y. Harada157, M.J. Hardcastle158, M. Harvey5, K. Hashiyama2, T. Hassan Collado113, T. Hausold105, A. Haupt52, U.A. Hautmann159, M. Havelka33, K. Hayashi141, K. Hayashi160, M. Hayashida161, H. He54, L. Heckmann105, M. Heller17, J.C. Helo35, F. Henault125, G. Henri125, G. Hermann53, R. Hermel15, S. Hernández Cadena16, J. Herrera Llorente32, A. Herrero32, O. Hervet43, J. Hinton53, A. Hiramoto157, N. Hiroshima54, K. Hirota2, B. Hnaty136, R. Hnaty136, J.K. Hoang11, D. Hoffmann27, W. Hofmann53, C. Hoischen128, J. Holder162, M. Holler163, B. Hona164, D. Hornan8, J. Hörandel165, D. Horns30, P. Horvath104.
Exploring the population of Galactic very-high-energy γ-ray sources

C. Steppa & K. Egberts

J. Houles, T. Hovatta, M. Harbovsky, D. Hrupec, Y. Huang, J.-M. Hue, G. Hughes, D. Hui, G. Hui, T.B. Humensky, M. Hüttner, R. Iaria, J.M. Illa, R. Imazawa, D. Impiombato, T. Inada, F. Incardona, A. Ingallina, Y. Inome, S. Inoue, Y. Inoue, A. Insolia, F. Iocco, K. Ioka, M. Ionica, M. Iori, S. Iovenitti, A. Iriarte, K. Ishio, W. Ishizaki, Y. Iwamura, C. Jablonski, J. Jacquemier, M. Jacquemont, M. Jamrozy, P. Janecek, F. Jankowski, A. Jardin-Blicq, C. Jarnot, P. Jean, I. Jiménez Martínez, W. Jin, J. Jocou, N. Jordana, M. Josselin, L. Jouvin, I. Jung-Richard, F.J.P.A. Junqueira, C. Juramy-Gilles, J. Jurysek, P. Kaaret, L.H.S. Kadowaki, M. Kagaya, O. Kalekin, R. Kankanyan, D. Kantzas, V. Karas, A. Karastergiou, S. Karkar, E. Kasai, J. Kasperek, H. Katagiri, J. Kataoka, K. Katarzyński, S. Katsuda, U. Katz, N. Kawanaka, D. Kazanas, D. Kerszberg, B. Khelifi, M.C. Kherlakian, T.P. Khan, D.B. Kieda, T. Kihm, S. Kim, S. Kimeswenger, S. Kisaka, R. Kissmann, R. Kleiwegt, T. Kleiner, G. Kluge, W. Kluzniak, J. Knapp, J. Knödlseder, A. Kobakhidze, Y. Kobayashi, B. Koch, J. Kocow, K. Kohri, K. Kokkotas, N. Komin, A. Kong, K. Kosack, G. Kowal, F. Krack, M. Krause, F. Krennrich, M. Krumholz, H. Kubo, V. Kudryavtsev, S. Kunwar, Y. Kuroda, J. Kushida, P. Kushwaha, A. La Barbera, N. La Palombara, V. La Parola, G. La Rosa, R. Lahmami, G. Lamanna, A. Lamastra, M. Landoni, D. Landriu, R.G. Lang, J. Lapington, P. Laporte, P. Lason, J. Lasuk, J. Lazendic-Galloway, T. Le Fleur, P. Le Sidaner, S. Leach, A. Leckngam, S.-H. Lee, W.H. Lee, S. Lee, M.A. Leigui de Oliveira, A. Lemiére, M. Lemoine-Goumard, J.-P. Lenain, F. Leone, V. Leray, G. Leto, F. Leuschner, C. Levy, R. Lindemann, E. Lindfors, L. Linhoff, I. Liodakis, A. Lipińska, S. Lloyd, M. Lobo, T. Lohse, S. Lombardi, F. Longo, A. Lopez, M. López, R. López-Coto, S. Loporchio, F. Louis, M. Louys, F. Lucarelli, D. Lucchesi, H. Ludwig Boudi, P.L. Luque-Escamilla, E. Lyard, M.C. Maccarone, T. Maccarone, E. Mach, A.J. Maciejewski, J. Mackey, G.M. Madejski, P. Maegli, C. Maggio, G. Maier, A. Majczyna, P. Majumdar, M. Makariev, M. Mallamaci, R. Malta Nunes de Almeida, S. Maltezos, D. Malyshchev, D. Malyshchev, D. Mandat, G. Maneva, M. Manganaro, G. Manicó, P. Manigot, K. Mannheim, N. Maragos, D. Marano, M. Marconi, A. Marcowith, M. Marculewicz, B. Marčun, J. Marín, N. Marinello, P. Marino, M. Mariotti, S. Markoff, P. Marquez, G. Marsella, J. Martí, J.-M. Martin, P. Martin, O. Martínez, M. Martínez, G. Martínez, O. Martínez, H. Martínez-Huerta, C. Marty, R. Marx, N. Masetti, P. Massimino, A. Mastichiadis, H. Matsumoto, N. Matthews, G. Maurin, W. Max-Moerbeck, N. Mäxted, D. Mazzini, M.N. Mazzotta, S.M. Mazzola, J.D. Mbarubucye, L. Mc Com, I. McHardy, S. McKeague, S. McMuldroch, E. Medina, D. Medina Miranda, A. Melandri, C. Melioli, D. Melkumyan, S. Menchiari, S. Mender, S. Mereghetti, G. Merino Arévalo, E. Mestre, J.-L. Meunier, T. Meures, M. Meyer, S. Micanicov, D. Miceli, M. Michalidis, J. Michalowski, T. Miener, I. Mivre, J. Miller, I.A. Minaya, T. Mineo, M. Minev, J.M. Miranda, R. Mirzoyan, A. Mitchell, T. Mizuno, B. Mode, R. Moderski, L. Mohrman, E. Molina, E. Molinari, T. Montaruli, I. Monteiro, C. Moore, A. Moralejo, D. Morcuende-Parrilla, E. Moretti, L. Morganti, K. Mori, P. Moriarty, K. Morik, G. Morlino, P. Morris, A. Morselli, K. Mosshammer, P. Moya, R. Mukherjee, J. Muller, C. Mendell, J. Mundet, T. Murach, A. Muraczewski, H. Muraishi, K. Murase, I. Musella, A. Musumarra.
Exploring the population of Galactic very-high-energy γ-ray sources

A. Nagai, N. Nagar, S. Nagataki, T. Naito, T. Nakamori, K. Nakashima, K. Nakayama, N. Nakhiiri, G. Naletto, D. Naumann, L. Nava, M.A. Nawaz, H. Ndiyavala, D. Neise, L. Nellen, R. Nenmnen, M. Newbold, N. Neyroud, K. Ngernphat, T. Nguyen Trung, L. Nicastro, L. Nickel, J. Niemiec, D. Nieto, N. Nievas, C. Nigro, M. Nikolajuk, D. Ninci, K. Nishijima, K. Noda, Y. Nogami, S. Nolan, R. Nomura, R. Norris, D. Nosek, M. Nöthe, B. Novosyadlyj, V. Novotny, S. Nozak, F. Nuncio, P. O'Brien, K. Obara, R. Oger, Y. Ohira, S. Ohi, S. Ohm, Y. Ohtani, T. Oka, N. Okazaki, A. Okumura, J.-F. Olike, C. Oliver, G. Olivera, B. Olmi, R.A. Ong, M. Orienti, R. Orito, M. Orlandini, S. Orlando, J.P. Osborne, M. Ostrowski, N. Otto, E. Ovecharov, E. Owen, I. Oya, O. Ozieblo, M. Padovani, I. Pagano, A. Pagliaro, A. Paizis, M. Palatiello, M. Palatka, J.L. Panazzoli, D. Paneque, B. Panes, S. Panny, F.R. Pantaleo, M. Pantier, R. Paoletti, M. Paoliello, A. Papito, A. Paravac, J.M. Paredes, G. Pareschi, N. Park, N. Parmigiani, R.D. Parsons, P. Paško, S. Patel, B. Patricelli, G. Pauledda, L. Pavletic, S. Pavy, A. Pe'er, Pech, M. Pecimotika, M.G. Pellegrini, P. Peñal Del Campo, M. Penzo, A. Pepato, S. Perad, C. Perennes, G. Peres, M. Peresano, A. Pérez-Aguilera, J. Pérez-Romero, M.A. Pérez-Torres, M. Perri, M. Persic, S. Petri, O. Petrucci, O. Petruck, B. Peyaud, K. Pfrang, E. Pian, G. Piano, P. Piattelli, E. Pietropaolo, R. Pillera, B. Pilszyk, D. Pimentel, F. Pintore, C. Pio García, G. Pirola, F. Piron, A. Pisarski, S. Pita, M. Pohl, V. Poireau, P. Poleerdelli, A. Pollo, M. Polo, C. Pongkitivanichkul, J. Portault, J. Powell, D. Pozzo, R.R. Prado, E. Prandini, P. Prasit, J. Prast, K. Pressard, G. Principe, C. Priyadarshi, N. Produit, D. Prokhorov, H. Prokoph, M. Prouza, H. Przybilski, E. Pueschel, G. Pühlhofer, I. Puljak, M.L. Pumo, M. Punch, F. Queiroz, J. Quinn, A. Qurirenbach, S. Rainò, P.J. Rajda, R. Rando, S. Razzaque, E. Rebert, S. Recchia, P. Reichherzer, O. Reimer, A. Reimer, A. Reisenegger, Q. Remy, M. Renaud, T. Reposeur, B. Reville, J.-M. Reynold, J. Reynolds, W. Rhode, D. Ribeiro, M. Ribó, G. Richards, T. Richtler, J. Rico, F. Rieger, L. Riitano, V. Ripepi, M. Riquelme, D. Riquelme, S. Rivoire, V. Rizi, E. Roache, B. Röben, M. Roche, J. Rodriguez, G. Rodriguez Fernandez, J.C. Rodriguez Ramirez, J.J. Rodríguez Vázquez, F. Roepke, G. Rojas, L. Romanato, P. Romano, G. Romeo, F. Romero Lobato, C. Romoli, M. Roncadelli, S. Rondi, J. Rosado, A. Rosales de León, G. Rowell, B. Rudak, A. Rugliancich, J.E. Ruiz del Mazo, W. Rujopakarn, C. Rulten, C. Russell, F. Russo, I. Sadeh, S. Sather Hatlen, S. Safi-Harb, L. Saha, P. Saha, V. Sahakian, S. Sailer, T. Saito, N. Sakaki, S. Sakurai, F. Salsa, Greus, G. Salina, H. Salzmann, D. Sanchez, M. Sánchez-Conde, H. Sandaker, A. Sandoval, P. Sangiorgi, M. Sanguillon, H. Sanó, M. Santander, A. Santangelo, E.M. Santos, R. Santos-Lima, A. Sanuy, L. Sapozhnikov, T. Saric, S. Sarkar, H. Sasaki, N. Sasaki, K. Satalecka, Y. Sato, F.G. Saturn, M. Sawada, U. Sawangwit, J. Schaefer, A. Scherer, J. Scherpenberg, P. Schipani, B. Schleicher, J. Schmolz, M. Schneider, H. Schoorlemmer, P. Schovanek, F. Schussler, B. Schwab, U. Schwanecke, J. Schwar, E. Sciaccia, N. Scuderi, M. Seglar Arroyo, A. Segreto, I. Seitenzahl, D. Semikoz, O. Sergijenko, J.E. Serna Franco, M. Servillat, K. Seweryn, V. Sguerra, A. Shalchi, R.Y. Shang, P. Sharma, R.C. Shellard, L. Sidoli, J. Sieiro, H. Siejkowski, J. Silk, A. Sillanpää, B.B. Singh, K.K. Singh.
Exploring the population of Galactic very-high-energy $\gamma$-ray sources

C. Steppa & K. Egberts

A. Sinha, C. Siqueira, G. Sironi, J. Sitarek, P. Sizun, V. Sliusar, A. Slowikowska, D. Sobczyńska, R.W. Sobrinho, H. Sol, G. Sottile, H. Spackman, A. Specoyios, S. Spencer, G. Spengler, D. Spiga, A. Spoljar, W. Springer, A. Stamerra, S. Stanić, R. Starling, L. Stawarz, R. Steenkamp, S. Stefaniak, C. Stegmann, A. Steiner, S. Steinmassi, C. Stella, C. Steppa, R. Sternberger, M. Sterzel, C. Stevens, B. Stevenson, T. Stolarczyk, G. Stratta, U. Straumann, J. Strišković, M. Strzys, R. Stükl, M. Suchenek, Y. Suda, Y. Sunada, T. Suomijarvi, T. Suric, P. Sutcliffe, H. Suzuki, P. Świerk, T. Szepieniec, A. Tachcini, K. Tachihara, G. Tagliaferri, H. Tajima, N. Tajima, D. Tak, K. Takahashi, H. Takahashi, M. Takahashi, M. Takahashi, J. Takata, R. Takeishi, T. Tam, M. Tanaka, T. Tanaka, S. Tanaka, D. Tateishi, M. Tavani, F. Tavecchio, T. Tavernier, L. Taylor, A. Taylor, L.A. Tejedor, P. Temnikov, Y. Terada, K. Terauchi, J.C. Terrazas, R. Terrier, T. Terzic, M. Teshima, V. Testa, D. Thibault, F. Thocqueau, W. Tian, L. Tibaldo, A. Tiengo, D. Tiziani, M. Tluczykont, C.J. Todero Peixoto, F. Tokanai, K. Toma, L. Tomankova, J. Tomastik, D. Tonev, M. Tornikoski, D.F. Torres, G. Torres, G. Tosti, L. Tosti, T. Totani, N. Tothill, F. Toussenel, G. Tovmassian, P. Travnické, C. Trichard, M. Trifoglio, A. Trois, S. Truzzi, A. Tshianova, T. Tsuru, B. Turk, A. Tutone, Y. Uchiyama, G. Umana, P. Uyara, L. Vlachou, M. Vacula, F. Vagelli, F. Vagnetti, F. Vakili, J.A. Valdivia, M. Valentino, A. Valio, B. Vallage, P. Vallania, J.V. Valerie Quispe, A.M. Van den Berg, W. van Driel, C. van Eldik, C. van Rensburg, B. van Soelen, J. Vandenbroucke, J. Vander Walt, G. Vasileiadis, V. Vasiliev, M. Vázquez Acosta, M. Vecchi, A. Vega, J. Veh, P. Veitch, P. Vennault, C. Venter, S. Ventura, S. Vercellone, S. Vergani, V. Verguilov, G. Verna, S. Vernetto, V. Verzi, G.P. Vettolani, C. Veyssiére, I. Viale, A. Viana, N. Viaux, J. Vich, J. Vignati, C.F. Vigorito, J. Villanueva, J. Vink, V. Vital, V. Vittorini, V. Vodeb, H. Voelk, N. Vogel, V. Voisin, S. Vorobiov, I. Vovk, M. Vrстил, T. Vuillaume, S.J. Wagner, R. Wagner, P. Wagner, K. Wakazono, S.P. Wakely, R. Walter, M. Ward, D. Warren, J. Watson, N. Webb, M. Wechakama, P. Wegner, A. Weinstein, C. Weniger, F. Werner, H. Wettleskind, M. White, R. White, A. Wierzhok, S. Wiesand, R. Wijers, M. Wilkinson, M. Wilk, D.A. Williams, J. Williams, T. Williamson, A. Wolter, Y.W. Wong, M. Wood, C. Wunderlich, T. Yamamoto, H. Yamamoto, Y. Yamane, R. Yamazaki, S. Yanagita, L. Yang, S. Yoo, T. Yoshida, T. Yoshikoshi, P. Yu, P. Yu, A. Yusafzai, M. Zacharias, G. Zaharijas, B. Zaldívar, L. Zamperini, R. Zanmar Sanchez, D. Zaric, M. Zavrtanik, D. Zavrtanik, A.A. Zdziarski, A. Zech, H. Zeclhin, A. Zemin, A. Zerwekh, V.I. Zhdanov, K. Zięta, A. Zink, J. Ziółkowski, V. Zitelli, M. Živec, A. Zmija

1: Centre for Space Research, North-West University, Potchefstroom, 2520, South Africa
2: Institute for Cosmic Ray Research, University of Tokyo, 5-1-5, Kashiwa-no-ha, Kashiwa, Chiba 277-8582, Japan
3: Pontificia Universidad Católica de Chile, Av. Libertador Bernardo O’Higgins 340, Santiago, Chile
4: AIM, CEA, CNRS, Université Paris-Saclay, Université Paris Diderot, Sorbonne Paris Cité, CEA Paris-Saclay, IRFU/DAp, Bat 709, Orme des Merisiers, 91191 Gif-sur-Yvette, France
5: Centre for Advanced Instrumentation, Dept. of Physics, Durham University, South Road, Durham, UK
Exploring the population of Galactic very-high-energy γ-ray sources

C. Steppa & K. Egberts

Durham DH1 3LE, United Kingdom

6: Port d’Informació Científica, Edifici D, Carrer de l’Albareda, 08193 Bellaterra (Cerdanyola del Vallès), Spain

7: School of Physics and Astronomy, Monash University, Melbourne, Victoria 3800, Australia

8: Laboratoire Leprince-Ringuet, École Polytechnique (UMR 7638, CNRS/IN2P3, Institut Polytechnique de Paris), 91128 Palaiseau, France

9: Department of Physics, Columbia University, 538 West 120th Street, New York, NY 10027, USA

10: University of Oslo, Department of Physics, Sem Sælandsvei 24 - PO Box 1048 Blindern, N-0316 Oslo, Norway

11: EMFTEL department and IPARCOS, Universidad Complutense de Madrid, 28040 Madrid, Spain

12: Instituto de Astrofísica de Andalucía-CSIC, Glorieta de la Astronomía s/n, 18008, Granada, Spain

13: Institute of Space Sciences (ICE-CSIC), and Institut d’Estudis Espacials de Catalunya (IEEC), and Institució Catalana de Recerca i Estudis Avançats (ICREA), Campus UAB, Carrer de Can Magrans, s/n 08193 Cerdanyola del Vallès, Spain

14: Instituto de Física Teórica UAM/CSIC and Departamento de Física Teórica, Universidad Autónoma de Madrid, c/ Nicolás Cabrera 13-15, Campus de Cantoblanco UAM, 28049 Madrid, Spain

15: Dublin Institute for Advanced Studies, 31 Fitzwilliam Place, Dublin 2, Ireland

16: Universidad Nacional Autónoma de México, Delegación Coyoacán, 04510 Ciudad de México, Mexico

17: University of Geneva - Département de physique nucléaire et corpusculaire, 24 rue du Général-Dufour, 1211 Genève 4, Switzerland

18: INFN Dipartimento di Scienze Fisiche e Chimiche - Università degli Studi dell’Aquila and Gran Sasso Science Institute, Via Vetoio 1, Viale Cristo 7, 67100 L’Aquila, Italy

19: Instituto de Astronomía, Geofísico, e Ciências Atmosféricas - Universidade de São Paulo, Cidade Universitária, R. do Matão, 1226, CEP 05508-090, São Paulo, SP, Brazil

20: LUTH, GEPI and LERMA, Observatoire de Paris, CNRS, PSL University, 5 place Jules Janssen, 92190, Meudon, France

21: INAF - Osservatorio di Astrofisica e Scienza dello spazio di Bologna, Via Piero Gobetti 93/3, 40129 Bologna, Italy

22: INAF - Osservatorio Astrofisico di Arcetri, Largo E. Fermi, 5 - 50125 Firenze, Italy

23: INFN Sezione di Perugia and Università degli Studi di Perugia, Via A. Pascoli, 06123 Perugia, Italy

24: INFN Sezione di Napoli, Via Cintia, ed. G, 80126 Napoli, Italy

25: INFN Sezione di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Rome, Italy

26: Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, USA

27: Aix-Marseille Université, CNRS/IN2P3, CPPM, 163 Avenue de Luminy, 13288 Marseille cedex 09, France

28: INAF - Osservatorio Astronomico di Roma, Via di Frascati 33, 00040, Monteporzio Catone, Italy
Exploring the population of Galactic very-high-energy γ-ray sources

C. Steppa & K. Egberts

29: INAF - Osservatorio Astrofisico di Catania, Via S. Sofia, 78, 95123 Catania, Italy
30: Grupo de Electronica, Universidad Complutense de Madrid, Av. Complutense s/n, 28040 Madrid, Spain
31: National Astronomical Research Institute of Thailand, 191 Huay Kaew Rd., Suthep, Muang, Chiang Mai, 50200, Thailand
32: Instituto de Astrofisica de Canarias and Departamento de Astrofisica, Universidad de La Laguna, La Laguna, Tenerife, Spain
33: FZU - Institute of Physics of the Czech Academy of Sciences, Na Slovance 1999/2, 182 21 Praha 8, Czech Republic
34: Astronomical Institute of the Czech Academy of Sciences, Bocni II 1401 - 14100 Prague, Czech Republic
35: CCTVal, Universidad Técnica Federico Santa María, Avenida España 1680, Valparaíso, Chile
36: ETH Zurich, Institute for Particle Physics, Schafmattstr. 20, CH-8093 Zurich, Switzerland
37: The University of Manitoba, Dept of Physics and Astronomy, Winnipeg, Manitoba R3T 2N2, Canada
38: Department of Astronomy, University of Geneva, Chemin d’Ecogia 16, CH-1290 Versoix, Switzerland
39: Laboratoire Univers et Particules de Montpellier, Université de Montpellier, CNRS/IN2P3, CC 72, Place Eugène Bataillon, F-34095 Montpellier Cedex 5, France
40: Centro Brasileiro de Pesquisas Físicas, Rua Xavier Sigaud 150, RJ 22290-180, Rio de Janeiro, Brazil
41: Institut de Fisica d’Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Campus UAB, 08193 Bellaterra (Barcelona), Spain
42: University of Groningen, KVI - Center for Advanced Radiation Technology, Zernikelaan 25, 9747 AA Groningen, The Netherlands
43: School of Physics, University of New South Wales, Sydney NSW 2052, Australia
44: INAF - Osservatorio Astrofisico di Torino, Strada Osservatorio 20, 10025 Pino Torinese (TO), Italy
45: Univ. Savoie Mont Blanc, CNRS, Laboratoire d’Annecy de Physique des Particules - IN2P3, 74000 Annecy, France
46: Department of Physics, TU Dortmund University, Otto-Hahn-Str. 4, 44221 Dortmund, Germany
47: University of Zagreb, Faculty of electrical engineering and computing, Unska 3, 10000 Zagreb, Croatia
48: University of Namibia, Department of Physics, 340 Mandume Ndemufayo Ave., Pioneerspark, Windhoek, Namibia
49: Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, ul. Bartycka 18, 00-716 Warsaw, Poland
50: Universität Hamburg, Institut für Experimentalphysik, Luruper Chaussee 149, 22761 Hamburg, Germany
51: Graduate School of Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
Exploring the population of Galactic very-high-energy $\gamma$-ray sources
C. Steppa & K. Egberts

52 : Deutsches Elektronen-Synchrotron, Platanenallee 6, 15738 Zeuthen, Germany
53 : Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
54 : RIKEN, Institute of Physical and Chemical Research, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan
55 : INFN Sezione di Padova and Università degli Studi di Padova, Via Marzolo 8, 35131 Padova, Italy
56 : Escuela Politécnica Superior de Jaén, Universidad de Jaén, Campus Las Lagunillas s/n, Edif. A3, 23071 Jaén, Spain
57 : Department of Physics and Electrical Engineering, Linnaeus University, 351 95 Växjö, Sweden
58 : University of the Witwatersrand, 1 Jan Smuts Avenue, Braamfontein, 2000 Johannesburg, South Africa
59 : Institut für Theoretische Physik, Lehrstuhl IV: Plasma-Astroteilchenphysik, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany
60 : Faculty of Physics and Applied Computer Science, University of Lódz, ul. Pomorska 149-153, 90-236 Lódz, Poland
61 : INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica di Milano, Via A. Corti 12, 20133 Milano, Italy
62 : INFN and Università degli Studi di Siena, Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente (DSFTA), Sezione di Fisica, Via Roma 56, 53100 Siena, Italy
63 : Center for Astrophysics | Harvard & Smithsonian, 60 Garden St, Cambridge, MA 02180, USA
64 : INFN Sezione di Torino, Via P. Giuria 1, 10125 Torino, Italy
65 : Finnish Centre for Astronomy with ESO, University of Turku, Finland, FI-20014 University of Turku, Finland
66 : Pidstryhach Institute for Applied Problems in Mechanics and Mathematics NASU, 3B Naukova Street, Lviv, 79060, Ukraine
67 : Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India
68 : Center for Astrophysics and Cosmology, University of Nova Gorica, Vipavska 11c, 5270 Ajdovščina, Slovenia
69 : Institut für Astronomie und Astrophysik, Universität Tübingen, Sand 1, 72076 Tübingen, Germany
70 : Research School of Astronomy and Astrophysics, Australian National University, Canberra ACT 0200, Australia
71 : Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA
72 : INFN Sezione di Bari and Politecnico di Bari, via Orabona 4, 70124 Bari, Italy
73 : Laboratoire de Physique des 2 infinis, Irene Joliot-Curie,IN2P3/CNRS, Université Paris-Saclay, Université de Paris, 15 rue Georges Clemenceau, 91406 Orsay, Cedex, France
74 : INFN Sezione di Pisa, Largo Pontecorvo 3, 56217 Pisa, Italy
75 : IRFU/DEDIP, CEA, Université Paris-Saclay, Bat 141, 91191 Gif-sur-Yvette, France
76 : INAF - Osservatorio Astronomico di Padova, Vicolo dell’Osservatorio 5, 35122 Padova, Italy
Exploring the population of Galactic very-high-energy \( \gamma \)-ray sources

C. Steppa & K. Egberts

77 : INAF - Osservatorio Astronomico di Palermo "G.S. Vaiana", Piazza del Parlamento 1, 90134 Palermo, Italy
78 : School of Physics, University of Sydney, Sydney NSW 2006, Australia
79 : Sorbonne Université, Université Paris Diderot, Sorbonne Paris Cité, CNRS/IN2P3, Laboratoire de Physique Nucléaire et de Hautes Energies, LPNHE, 4 Place Jussieu, F-75005 Paris, France
80 : Instituto de Física de São Carlos, Universidade de São Paulo, Av. Trabalhador São-carlense, 400 - CEP 13566-590, São Carlos, SP, Brazil
81 : Departament de Física Quàntica i Astrofísica, Institut de Ciències del Cosmos, Universitat de Barcelona, IEEC-UB, Martí i Franquès, 1, 08028, Barcelona, Spain
82 : Department of Physics, Washington University, St. Louis, MO 63130, USA
83 : Saha Institute of Nuclear Physics, Bidhannagar, Kolkata-700 064, India
84 : INAF - Osservatorio Astronomico di Capodimonte, Via Salita Moiariello 16, 80131 Napoli, Italy
85 : Université de Paris, CNRS, Astroparticule et Cosmologie, 10, rue Alice Domon et Léonie Duquet, 75013 Paris Cedex 13, France
86 : Astronomy Department of Faculty of Physics, Sofia University, 5 James Bourchier Str., 1164 Sofia, Bulgaria
87 : Institut de Recherche en Astrophysique et Planétologie, CNRS-INSU, Université Paul Sabatier, 9 avenue Colonel Roche, BP 44346, 31028 Toulouse Cedex 4, France
88 : School of Physics and Astronomy, University of Minnesota, 116 Church Street S.E. Minneapolis, Minnesota 55455-0112, USA
89 : IRFU, CEA, Université Paris-Saclay, Bât 141, 91191 Gif-sur-Yvette, France
90 : INAF - Istituto di Radioastronomia, Via Gobetti 101, 40129 Bologna, Italy
91 : INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo, Via U. La Malfa 153, 90146 Palermo, Italy
92 : Astronomical Observatory, Department of Physics, University of Warsaw, Aleje Ujazdowskie 4, 00478 Warsaw, Poland
93 : Armagh Observatory and Planetarium, College Hill, Armagh BT61 9DG, United Kingdom
94 : INFN Sezione di Catania, Via S. Sofia 64, 95123 Catania, Italy
95 : INAF - Osservatorio Astronomico di Brera, Via Brera 28, 20121 Milano, Italy
96 : Kavli Institute for Particle Astrophysics and Cosmology, Department of Physics and SLAC National Accelerator Laboratory, Stanford University, 2575 Sand Hill Road, Menlo Park, CA 94025, USA
97 : Universidade Cruzeiro do Sul, Núcleo de Astrofísica Teórica (NAT/UCS), Rua Galvão Bueno 8687, Bloco B, sala 16, Liberdade 01506-000 - São Paulo, Brazil
98 : Universidad de Valparaíso, Blanco 951, Valparaiso, Chile
99 : INAF - Istituto di Astrofisica e Planetologia Spaziali (IAPS), Via del Fosso del Cavaliere 100, 00133 Roma, Italy
100 : Lund Observatory, Lund University, Box 43, SE-22100 Lund, Sweden
101 : The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, 31-342 Cracow, Poland
Exploring the population of Galactic very-high-energy \( \gamma \)-ray sources

C. Steppa & K. Egberts

127 : Enrico Fermi Institute, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637, USA
128 : Institut für Physik & Astronomie, Universität Potsdam, Karl-Liebknecht-Strasse 24/25, 14476 Potsdam, Germany
129 : Department of Physics and Astronomy, Iowa State University, Zaffarano Hall, Ames, IA 50011-3160, USA
130 : School of Physics, Aristotle University, Thessaloniki, 54124 Thessaloniki, Greece
131 : King’s College London, Strand, London, WC2R 2LS, United Kingdom
132 : Escola de Artes, Ciências e Humanidades, Universidade de São Paulo, Rua Arlindo Bettio, CEP 03828-000, 1000 São Paulo, Brazil
133 : Dept. of Astronomy & Astrophysics, Pennsylvania State University, University Park, PA 16802, USA
134 : National Technical University of Athens, Department of Physics, Zografos 9, 15780 Athens, Greece
135 : University of Wisconsin, Madison, 500 Lincoln Drive, Madison, WI, 53706, USA
136 : Astronomical Observatory of Taras Shevchenko National University of Kyiv, 3 Observatorna Street, Kyiv, 04053, Ukraine
137 : Department of Physics, Purdue University, West Lafayette, IN 47907, USA
138 : Unitat de Física de les Radiacions, Departament de Física, and CERES-IEEC, Universitat Autònoma de Barcelona, Edifici C3, Campus UAB, 08193 Bellaterra, Spain
139 : Institute for Space-Earth Environmental Research, Nagoya University, Chikusa-ku, Nagoya 464-8601, Japan
140 : Department of Physical Science, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8526, Japan
141 : Department of Physics, Nagoya University, Chikusa-ku, Nagoya, 464-8602, Japan
142 : Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen Centre for Astroparticle Physics (ECAP), Erwin-Rommel-Str. 1, 91058 Erlangen, Germany
143 : Santa Cruz Institute for Particle Physics and Department of Physics, University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA
144 : IRFU / DIS, CEA, Université de Paris-Saclay, Bat 123, 91191 Gif-sur-Yvette, France
145 : INFN Sezione di Trieste and Università degli Studi di Trieste, Via Valerio 2 I, 34127 Trieste, Italy
146 : School of Physics & Center for Relativistic Astrophysics, Georgia Institute of Technology, 837 State Street, Atlanta, Georgia, 30332-0430, USA
147 : Alikhanyan National Science Laboratory, Yerevan Physics Institute, 2 Alikhanyan Brothers St., 0036, Yerevan, Armenia
148 : INAF - Telescopio Nazionale Galileo, Roche de los Muchachos Astronomical Observatory, 38787 Garafia, TF, Italy
149 : INFN Sezione di Bari and Università degli Studi di Bari, via Orabona 4, 70124 Bari, Italy
150 : University of Split - FESB, R. Boskovica 32, 21 000 Split, Croatia
151 : Universidad Andres Bello, República 252, Santiago, Chile
152 : Academic Computer Centre CYFRONET AGH, ul. Nawojki 11, 30-950 Cracow, Poland
Exploring the population of Galactic very-high-energy $\gamma$-ray sources

C. Steppa & K. Egberts

153: University of Liverpool, Oliver Lodge Laboratory, Liverpool L69 7ZE, United Kingdom
154: Department of Physics, Yamagata University, Yamagata, Yamagata 990-8560, Japan
155: Astronomy Department, Adler Planetarium and Astronomy Museum, Chicago, IL 60605, USA
156: Faculty of Management Information, Yamanashi-Gakuin University, Kofu, Yamanashi 400-8575, Japan
157: Department of Physics, Tokai University, 4-1-1, Kita-Kaname, Hiratsuka, Kanagawa 259-1292, Japan
158: Centre for Astrophysics Research, Science & Technology Research Institute, University of Hertfordshire, College Lane, Hertfordshire AL10 9AB, United Kingdom
159: Cherenkov Telescope Array Observatory, Saupfercheckweg 1, 69117 Heidelberg, Germany
160: Tohoku University, Astronomical Institute, Aobaku, Sendai 980-8578, Japan
161: Department of Physics, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima-ku, Tokyo, Japan
162: Department of Physics and Astronomy and the Bartol Research Institute, University of Delaware, Newark, DE 19716, USA
163: Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Technikerstr. 25/8, 6020 Innsbruck, Austria
164: Department of Physics and Astronomy, University of Utah, Salt Lake City, UT 84112-0830, USA
165: IMAPP, Radboud University Nijmegen, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands
166: Josip Juraj Strossmayer University of Osijek, Trg Ljudevita Gaja 6, 31000 Osijek, Croatia
167: Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560-0043, Japan
168: Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
169: Astronomical Observatory, Jagiellonian University, ul. Orla 171, 30-244 Cracow, Poland
170: Landessternwarte, Zentrum für Astronomie der Universität Heidelberg, Königstuhl 12, 69117 Heidelberg, Germany
171: University of Alabama, Tuscaloosa, Department of Physics and Astronomy, Gallalee Hall, Box 870324 Tuscaloosa, AL 35487-0324, USA
172: Department of Physics, University of Bath, Claverton Down, Bath BA2 7AY, United Kingdom
173: University of Iowa, Department of Physics and Astronomy, Van Allen Hall, Iowa City, IA 52242, USA
174: Anton Pannekoek Institute/GRAPPA, University of Amsterdam, Science Park 904 1098 XH Amsterdam, The Netherlands
175: Faculty of Computer Science, Electronics and Telecommunications, AGH University of Science and Technology, Kraków, al. Mickiewicza 30, 30-059 Cracow, Poland
176: Faculty of Science, Ibaraki University, Mito, Ibaraki, 310-8512, Japan
177: Faculty of Science and Engineering, Waseda University, Shinjuku, Tokyo 169-8555, Japan
