

gamma-sky.net: Portal to the Gamma-Ray Sky

Arjun Voruganti^{1,a)}, Christoph Deil¹, Axel Donath¹ and Johannes King¹

^{a)}Corresponding author: arjun.voruganti@gmail.com

¹*MPIK, Heidelberg, Germany*

Abstract. <http://gamma-sky.net> is a novel interactive website designed for exploring the gamma-ray sky. The Map View portion of the site is powered by the Aladin Lite sky atlas, providing a scalable survey image tessellated onto a three-dimensional sphere. The map allows for interactive pan and zoom navigation as well as search queries by sky position or object name. The default image overlay shows the gamma-ray sky observed by the Fermi-LAT gamma-ray space telescope. Other survey images (e.g. Planck microwave images in low/high frequency bands, ROSAT X-ray image) are available for comparison with the gamma-ray data. Sources from major gamma-ray source catalogs of interest (Fermi-LAT 2FHL, 3FGL and a TeV source catalog) are overlaid over the sky map as markers. Clicking on a given source shows basic information in a popup, and detailed pages for every source are available via the Catalog View component of the website, including information such as source classification, spectrum and light-curve plots, and literature references, with details such as source type, literature references, spectra and light curves.

We intend for `gamma-sky.net` to be applicable for both professional astronomers as well as the general public. The website started in early June 2016 and is being developed as an open-source, open data project on GitHub (<https://github.com/gammipy/gamma-sky>). We plan to extend it to display more gamma-ray and multi-wavelength data. Feedback and contributions are very welcome!

Introduction

The field of very-high-energy (VHE) astronomy is growing tremendously – while only a decade ago we observed no more than a handful of sources in the GeV range, today we have thousands, including hundreds within the TeV range. This advancement has been made possible due to our novel ground-based Cherenkov telescope instruments. Such systems exhibit more accurate source detections and higher angular resolutions than ever before. Space-based satellites sharing similar technological breakthroughs have further developed the high-energy (HE) range of gamma-ray astronomy, as can be observed in the latest images from the Fermi Large Area Telescope (Fermi-LAT). As a whole, the instruments can capture gamma-rays in a wide spectrum of energies from 10 MeV to 10 TeV. The High Energy Stereoscopic System (H.E.S.S.) Galactic Plane Survey [1], the High-Altitude Water Cherenkov Observatory (HAWC) 1st Year Catalog, and the fourth Fermi-LAT Point Source Catalog (4FGL) are among the highly anticipated surveys that will be unveiled in the near future. Furthermore, with an incoming wave of notable systems planned to operate soon, such as the ground-based Cherenkov Telescope Array (CTA) for TeV observations [2], we expect to discover numerous never-before-seen sources in the gamma-ray sky. With such abundance of HE and VHE sources and a rapid growth of interest in gamma-ray astronomy, there is an increasingly evident need for a central hub of all relevant catalog and image data, prepared in a standard format. Our website (<http://gamma-sky.net>) was designed to function as such.

Idea

`gamma-sky.net` is a one-stop resource for browsing images and catalogs but also for closely examining a specific gamma-ray source. Although it was mainly built for the greater astronomical community, the webpage additionally targets the general public through a user-friendly interface and a clean information layout, all of which are compiled under cutting-edge web tools.

Individuals who access <http://gamma-sky.net> via any modern internet browser will be welcomed with the Map View homepage. This page displays overlays of multi-wavelength survey images, most of which are all-sky,

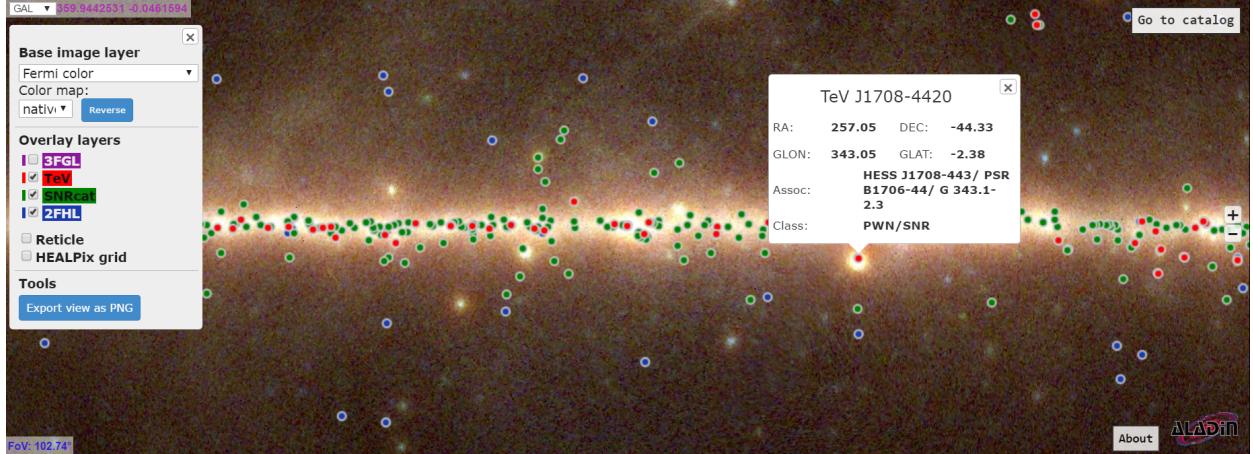


FIGURE 1. Map View of gamma-sky.net showing the gamma-ray sky observed by the space-based Fermi-LAT, broken into three bands: 0.3–1 GeV (red-band), 1–3 GeV (green-band), and 3–300 GeV (blue-band). The pop-up for one TeV source is displayed, as well as the toolbar on the side containing widgets for controlling the map overlays.

TABLE 1. Survey images of interest to gamma-ray astronomers available on the Aladin Lite map at gamma-sky.net. Note that these surveys only make up very small selection of the 300+ multi-wavelength survey images available from CDS’ HiPS database (<http://aladin.u-strasbg.fr/hips/list>). We plan to produce add gamma-ray survey images in the GeV energy range (high-energy Fermi-LAT data) and the TeV energy range (H.E.S.S. Galactic Plane Survey) to the website when they become available.

| Image | Waveband | Description |
|--------------------|-----------|--|
| Fermi color | gamma-ray | Fermi-LAT RGB all-sky survey (0.3–1 GeV, 1–3 GeV, 3–300 GeV) |
| RASS | x-ray | ROSAT all-sky survey (0.1–2.4 keV) @ 1.8 arcmin |
| XMM-EPIC-RGB | x-ray | XMM-Newton EPIC RGB composition |
| AKARI 90um | infrared | AKARI Wide-S all-sky survey @ 1 arcmin |
| Spitzer GLIMPSE360 | infrared | Spitzer galactic plane survey @ 0.02 arcmin |
| IRIS Band 4-100um | infrared | IRIS all-sky survey |
| Planck R1 + R2 HFI | microwave | Planck 353-545-857 GHz all-sky survey |
| Planck R2 LFI | microwave | Planck 30-44-70 GHz all-sky survey |
| CGPS-VGPS CONT | radio | galactic plane continuum @ 1 arcmin |
| Haslam 408 | radio | 408 MHz all-sky continuum @ 51 arcmin |

wrapped around a three-dimensional sphere. Gamma-ray sources from our catalog data have then been pinpointed onto the sphere, as shown in Figure 1. The map features pan-and-zoom functionality for easily navigating and quickly browsing the sky. The Map View page also utilizes a powerful search tool to either pan the view to a given sky position or locate a source by name. This functionality is intended to work similar to Google Maps¹ and allows the user to easily find sources of interest and study their visual context. See Table 1 for our selection of images on the website and Table 2 for the catalogs we display. gamma-sky.net additionally embodies a Catalog View, which incorporates more detailed information for each of the sources in our catalogs. Professional astronomers will navigate to this component of the website for the deep investigation of a particular source. The Catalog View page is shown in Figure 2.

gamma-sky.net aims to be a resource for browsing a region or examining a specific source (see Figures 4 and 5 for examples); however, any tools for extended analysis will not be incorporated into the website. Instead of limiting analysis to only pre-built functionality facilitated through the webpage, we want to allow users to be able to utilize data for their specific use case. We point users to Gammapy [6], a Python package for gamma-ray astronomy, for continued investigation at the local level. Gammapy’s scripts will generate the detailed plots and publication-worthy results that astronomers are interested in. Alternatively, users may navigate to TeVCat [7] for investigating TeV sources, or the ASI Science Data Center (ASDC) website for their online tools.

¹<https://www.google.com/maps>

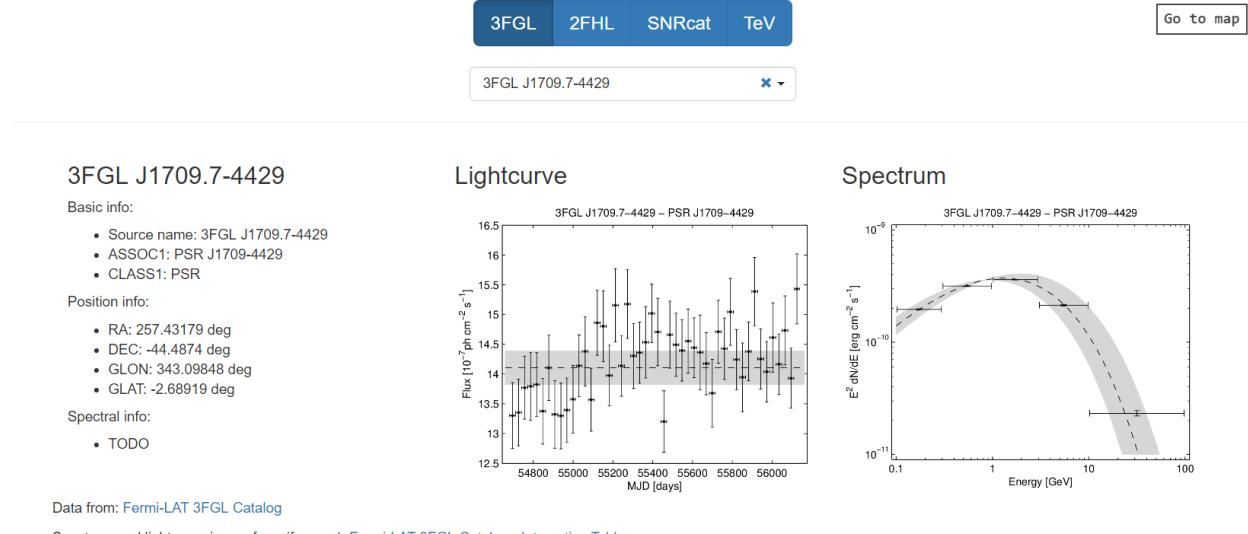


FIGURE 2. Catalog View of `gamma-sky.net` showing the catalog and source selection fields at the top, and the detailed view for one source from the Fermi-LAT 3FGL catalog.

TABLE 2. Source catalogs currently displayed on `gamma-sky.net`. The `gamma-cat` and `SNRcat` catalogs are live and updated often, while the Fermi catalogs are fixed and never updated. We intend to add additional catalogs of interest to gamma-ray astronomers to the website in the future, including the upcoming H.E.S.S. and HAWC TeV source catalogs, as well as the ATNF Pulsar Catalogue (<http://www.atnf.csiro.au/people/pulsar/psrcat/>).

| Catalog | Sources | Type | Description |
|---------|---------|-------|---|
| TeV | 163 | live | gamma-cat: Open TeV gamma-ray source catalog https://github.com/gammify/gamma-cat |
| 2FHL | 360 | fixed | Second Fermi-LAT catalog of high-energy sources [3] http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2FHL/ |
| 3FGL | 3034 | fixed | Third Fermi-LAT point source catalog [4] http://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/ |
| SNRcat | 378 | live | A census of high-energy observations of Galactic supernova remnants [5] http://www.physics.umanitoba.ca/snr/SNRcat/ |

The motivation for creating `gamma-sky.net` was to provide an open-source dataset from all newly developed surveys to the gamma-ray astronomical community, all while presenting catalog and image data in a clean view by utilizing modern web development tools. We serve data in a widely accepted and standard format for astronomers to easily produce their own results in extended local analysis. It is imperative for all of our data on the online portal to be openly available for download for any user. Additionally, the website is an entirely open-source project, and other developers are welcome to contribute to the code. We advise those interested in contributing to visit our GitHub repository at <https://github.com/gammify/gamma-sky>.

Features

1. Map View interface:

- Pan and zoom
- Search tools - locate objects by name, association, or coordinate position
- Toggle and view specific catalog layers and sky images
- Pop-up information over each source
- Export and share images from the sky map (in PNG format)

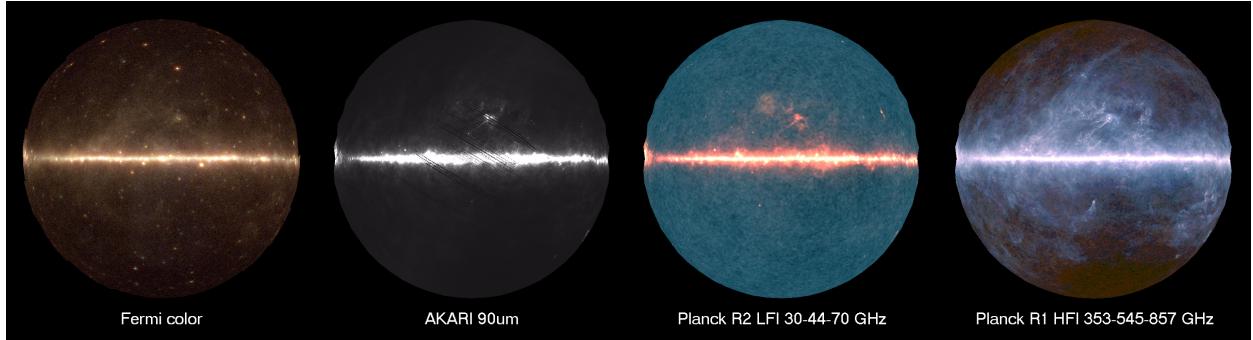


FIGURE 3. Survey images (left to right): Fermi color, AKARI 90um, Planck LFI, Planck HFI. Images centered on the Galactic Center, FOV 180 degrees.

2. Catalog View information panels*:

- Search and select a source by its name
- Basic information - position, association and class
- Extension information
- Spectral index, brightness and flux
- Distance and redshift
- Light curve and emission spectrum plots
- Detection/observation information - instrument, date of discovery and literature references

Data

The default image layer displayed on the website's Map View page is a multi-wavelength all-sky survey from Fermi-LAT. As Fermi data is broken into multiple bands of energies, the map's native color scheme represents detected energies as categorized colors - red/yellow for the 0.3–1 GeV band, green for the 1–3 GeV band, and blue for the 3–300 GeV band.

The Fermi color image is presented on the website as a Hierarchical Progressive Survey (HiPS) image [8]. HiPS is a hierarchical data structure utilizing the HEALPix⁴ tessellation of a sphere that organizes data onto pixelated tiles of scalable resolution. The image mechanism allows catalog data and source markers on gamma-sky.net to be visualized accurately on the sky map at various zoom levels. The Centre de Données astronomiques de Strasbourg (CDS) developed the HiPS technology, and gamma-sky.net currently encompasses 10 survey images also prepared by CDS in this format. The 10 images, which are outlined in Table 1, come from CDS's HiPS database⁵ of over 300 prepared HiPS images. Four selected images are displayed on the three-dimensional sphere in Figure 3.

Our website incorporates 4 source catalogs, as illustrated in Table 2. 3FGL [4] and 2FHL [3] are the latest source catalogs from Fermi-LAT, the main space-based instrument we display sources from. SNRcat [5] is an up-to-date compilation of galactic SNRs observed from a variety of instruments. The database is maintained by the University of Manitoba and can be accessed at <http://www.physics.umanitoba.ca/snr/SNRcat/>. gamma-cat is an open-data catalog of sources in the TeV range. As a project that has just recently begun in early September 2016, it is undergoing rapid growth and will be updated frequently on gamma-sky.net. gamma-cat was started at the Max-Planck-Institut für Kernphysik (MPIK) and is open to contribution from other developers. All of its source information can be found at <https://gammapy.github.io/gamma-cat/>.

User inputs for search fields under the Map View portion of the website are interpreted by the Sesame service⁶. Sesame is a search term resolver for astronomical objects which queries several databases and returns the resolved sources. Both Sesame and the databases searched (SIMBAD, NED, and VizieR) are maintained by CDS.

*Some of the features listed for the Catalog View are currently only available for select source catalogs, but they are expected to be a part of all catalogs in the near future.

⁴<http://healpix.sourceforge.net/>

⁵<http://aladin.u-strasbg.fr/hips/list>

⁶<http://cds.u-strasbg.fr/cgi-bin/Sesame>

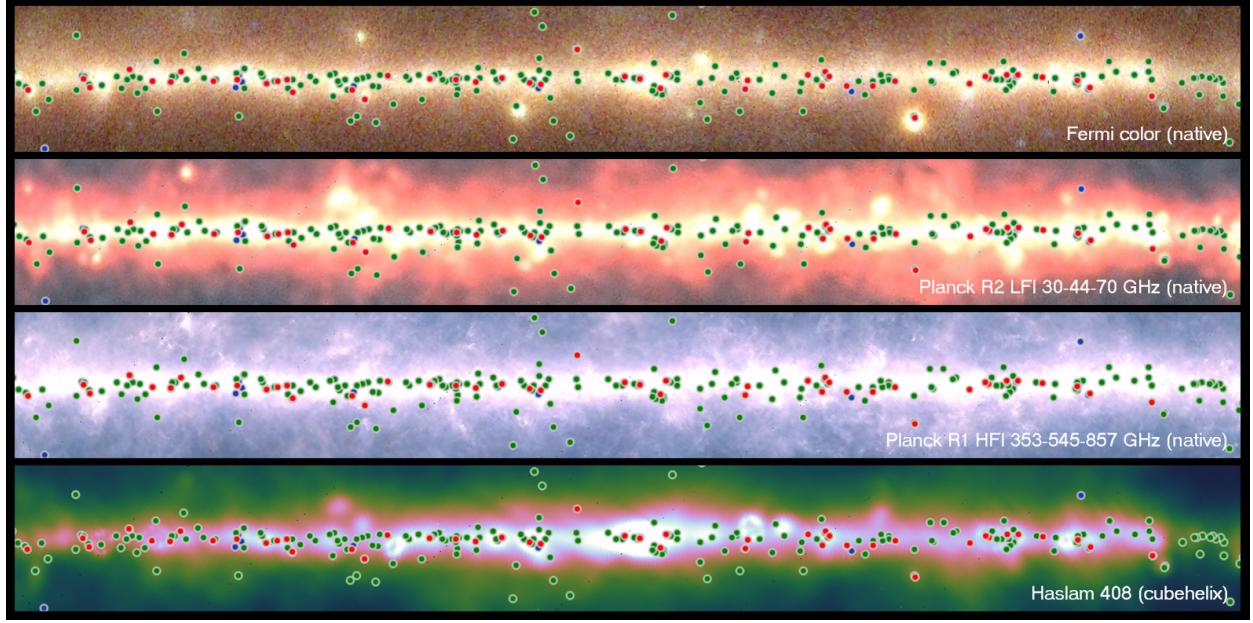


FIGURE 4. The inner galaxy in various survey images and color maps, FOV 90×15 degrees. The red (TeV) and green (SNRcat) markers indicate many galactic SNRs and pulsars detected at very-high-energies.

Under the Catalog View of `gamma-sky.net`, we are currently showing 3FGL light curve and emission spectrum plots from NASA's Fermi-LAT 3FGL Catalog Interactive Table⁷.

Implementation

Scientific Python packages Astropy [9] and Gammapy were used to generate all of the catalog and source data on `gamma-sky.net`. This step includes preparing formatted JSON files from fetched raw FITS data for display in our Catalog View panels. Serving our catalog data in such manner requires us to frequently update the “live” catalogs SNRcat and gamma-cat stored in our server. All data is consumed with the JavaScript and HTML front-end. The website’s architecture was organized using Angular 2, a modern web application framework for JavaScript. Using Angular 2 has allowed us to compile the site into a single-page application. The sphere interface and visualization in the Map View page was implemented under the Aladin Lite tool [10] developed at CDS.

`gamma-sky.net` exists as a static webpage, meaning that there is no backend server doing real-time data processing or content generating on request. The JavaScript client is still capable of downloading any static assets, including very large HiPS survey images and catalog datasets. Advantages to the static website technology include easy implementation and maintainence and efficient data loading.

Status and Outlook

Our website is a new project, having been deployed very recently at <http://gamma-sky.net> in early June 2016. The website is being hosted by GitHub Pages. The current content of `gamma-sky.net` is simply a starting point; we have plans to greatly expand on our catalog and image data. Such data includes additional image surveys from CDS’ HiPS database, as well as source and image data from upcoming surveys upon their public release. We additionally strive to enhance the user interface of `gamma-sky.net` through additional features, including new source groupings by classification and position, deeper communication between the Map View and Catalog View, and more intricate data panels for the Catalog View. We will continue to point directly to Gammapy scripts for any further analysis and keep server-heavy tools off our website.

⁷http://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/3FGL-table

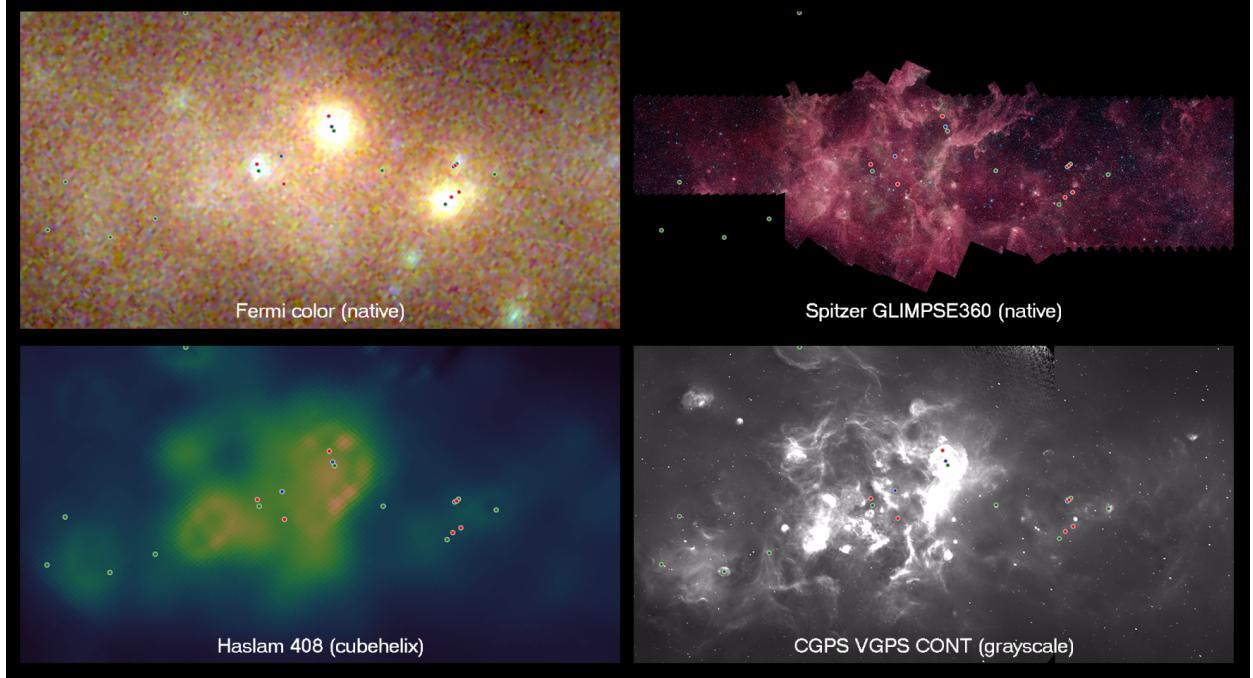


FIGURE 5. The Cygnus Region in various survey images and color maps, FOV 20×10 degrees. Sources of interest include: the diffuse emission nebula surrounding the Gamma Cygni star, the cosmic-ray Cygnus Cocoon observed by Fermi, and a handful of unidentified TeV sources indicated with red (TeV) markers.

Acknowledgements

We would like to thank CDS (Centre de Données astronomiques de Strasbourg) for developing the data formats (HiPS) and tools (Aladin Lite) that make `gamma-sky.net` possible. Thomas Boch helped us configure Aladin Lite to our use case. We would also like to thank: GitHub for hosting our website; CDS for serving the HiPS images; and all of the contributors to the open-source projects, including Angular 2, Astropy, and Gammapy, that we have used to build `gamma-sky.net`.

REFERENCES

- [1] H. E. S. S. Collaboration, ArXiv e-prints July (2013), arXiv:1307.4690 [astro-ph.HE].
- [2] CTA Consortium, Elsevier **43**, 317–330 March (2013), arXiv:1208.5686 [astro-ph.HE].
- [3] Fermi-LAT Collaboration, APJS **222**, p. 5 January (2016), arXiv:1508.04449 [astro-ph.HE].
- [4] Fermi-LAT Collaboration, APJS **218**, p. 23 June (2015), arXiv:1501.02003 [astro-ph.HE].
- [5] G. Ferrand and S. Safi-Harb, Advances in Space Research **49**, 1313–1319 May (2012), arXiv:1202.0245 [astro-ph.HE].
- [6] A. Donath, C. Deil, M. P. Arribas, J. King, E. Owen, R. Terrier, I. Reichardt, J. Harris, R. Bühler, and S. Klepser, ArXiv e-prints September (2015), arXiv:1509.07408 [astro-ph.IM].
- [7] S. P. Wakely and D. Horan, International Cosmic Ray Conference **3**, 1341–1344 (2008).
- [8] P. Fernique, M. G. Allen, T. Boch, A. Oberto, F.-X. Pineau, D. Durand, C. Bot, L. Cambrésy, S. Derrière, F. Genova, and F. Bonnarel, AAP **578**, p. A114 June (2015), arXiv:1505.02291 [astro-ph.IM].
- [9] Astropy Collaboration, AAP **558**, p. A33 October (2013).
- [10] T. Boch and P. Fernique, “Aladin Lite: Embed your Sky in the Browser,” in *Astronomical Data Analysis Software and Systems XXIII*, Astronomical Society of the Pacific Conference Series, Vol. 485, edited by N. Manset and P. Forshay (2014) p. 277.
- [11] A. Carosi, F. Lucarelli, L. A. Antonelli, and P. Giommi, ArXiv e-prints October (2015), arXiv:1510.08681 [astro-ph.IM].