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

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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 tesselated 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/gammapy/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 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), 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 evident need for a central hub of all relevant catalog and image data. 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 presents an overlay of multi-wavelength survey images, most of which are all-sky images, wrapped around a three-dimensional sphere. The map features pan-and-zoom functionality for easily

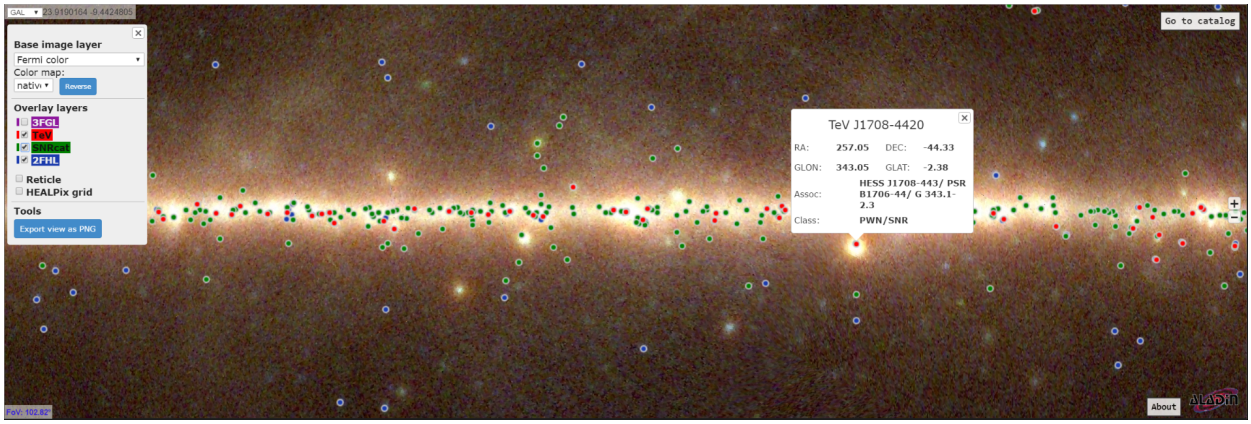

FIGURE 1. Map View of `gamma-sky.net` showing the gamma-ray sky observed by the Fermi-LAT space telescope, broken into three bands: 0.3 - 1 GeV (red-band), 1 - 3 GeV (green-band), and 3-300 GeV (blue-band). The pop-up for one TeV source is displayed, as well as the toolbar on the side containing widgets 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 the CDS' HiPS database (`http://aladin.u-strasbg.fr/hips/list`). We plan to produce our own gamma-ray survey images from the GeV energy range (high-energy Fermi-LAT data) and the TeV energy range (H.E.S.S. Galactic Plane Survey) to be displayed on `gamma-sky.net` .

Image	Type	Description
Fermi color	gamma-ray	Fermi-LAT RGB all-sky survey
AKARI 90um	infrared	AKARI Wide-S all-sky survey @ 1 arcmin
CGPS-VGPS CONT	radio	galactic plane continuum @ 1 arcmin
Haslam 408	radio	408 MHz all-sky continuum @ 51 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
Spitzer GLIMPSE360	infrared	Spitzer galactic plane survey @ 0.02 arcmin

navigating and quickly browsing the sky. Gamma-ray sources from our catalog data have been pinpointed onto the sphere, as shown in Figure 1. See Table 1 for our selection of images on the website and Table 2 for the catalogs we display. 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 allows the user to easily find their sources and study their visual context in relation to other objects. `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. See the Catalog View page in Figure 2.

`gamma-sky.net` aims to be a resource for analyzing a source or region; however, any tools for further analysis will not be incorporated into the website. In order to continue an investigation from our site, we point users to Gammapy [5], a Python package for gamma-ray astronomy, which can used to run scripts locally. These scripts will generate the detailed plots and noteworthy results that astronomers are interested in. Alternatively, users may navigate to TeVCat [6] for investigating TeV sources, or the ASI Science Data Center (ASDC) website for their online tools (e.g. ASDC Data Explorer[1], SED Builder[2]) and their TeGeV Catalogue for TeV sources [7].

It is imperative for all of our data on the online portal to be openly available for download and local analysis by any user. Additionally, `gamma-sky.net` 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.`

[1] http://www.asdc.asi.it/tutorial/DataExplorer/DataExplorerTutorial.html
[2] http://www.asdc.asi.it/tutorial/SEDBuilder/SEDBuilderTutorial.html

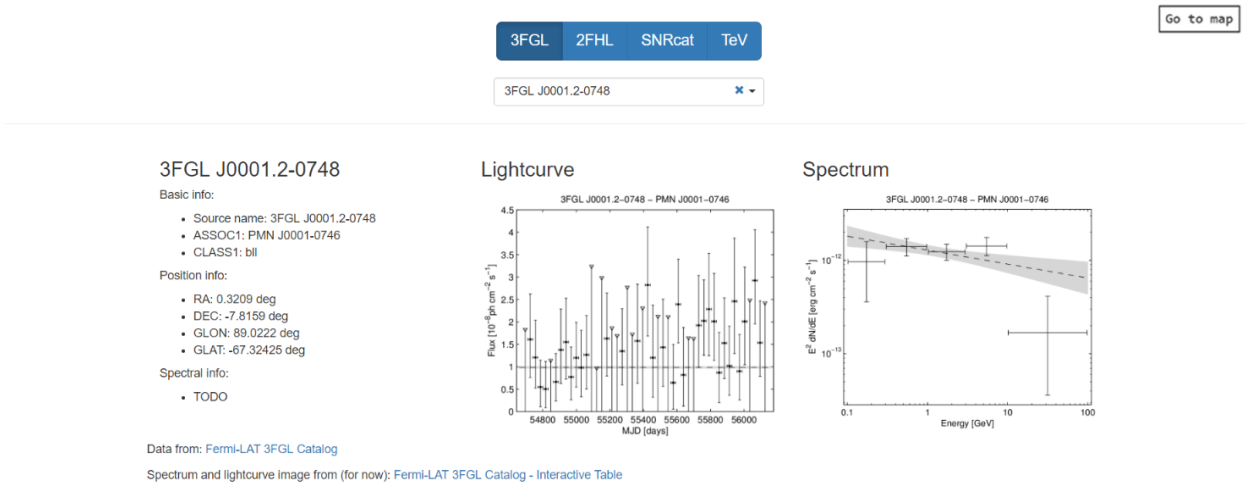

FIGURE 2. Catalog View of `gamma-sky.net` showing the catalog and source selection field at the top, and the source detail view for one source from the Fermi-LAT 3FGL source catalog.

TABLE 2. Source catalogs currently displayed on `gamma-sky.net` . 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.

Catalog	Sources	Updates	Description
gamma-cat	153	continuous	Open TeV gamma-ray source catalog `https://github.com/gammapy/gamma-cat`
2FHL	360	fixed	Second Fermi-LAT catalog of high-energy sources [2] `http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2FHL/`
3FGL	3034	fixed	Third Fermi-LAT point source catalog [3] `http://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/`
SNRcat	378	continuous	A census of high-energy observations of Galactic supernova remnants [4] `http://www.physics.umanitoba.ca/snr/SNRcat/`

`com/gammapy/gamma-sky`.

Features

The items listed below illustrate the interface of `gamma-sky.net` and its utilization as a tool for astronomers.

1. **Browsing and navigation features** in the Map View component:
   - 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)
2. **Analysis tools** in the Catalog View component*:
   - Search and select a source by its name
   - Basic information - position, association and class
   - Extension information

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

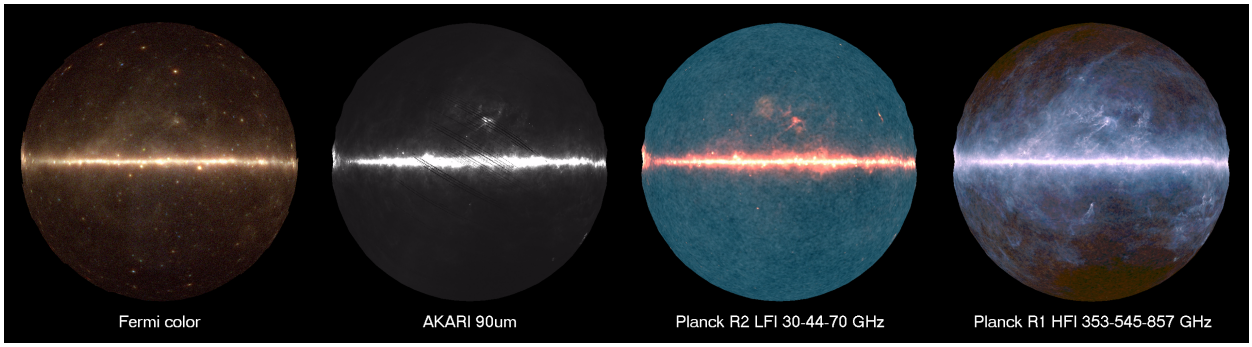

FIGURE 3. Survey images (left to right): Fermi color, AKARI 90um, Planck LFI, Planck HFI. Images centered on the Galactic Center, FOV 180 degrees.

- Spectral index, brightness and flux
- Distance and redshift
- Graphs of light curves and emission spectra
- Detection/observation information - instrument, date of discovery and relevant papers

Data

The default base 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 HEALPix[1] tesselation 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 8 survey images also prepared by CDS in this format. The 8 images, which are outlined in Table 1, come from CDS's HiPS database[2], of over 300 prepared HiPS images.

Our website incorporates 4 catalogs which are displayed in Table 2. 3FGL [3] and 2FHL [2] are the latest surveys from Fermi-LAT, the main space-based instrument we display sources from. SNRcat [4] 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 fúr Kernphysik (MPIK) and is open to contribution from other developers. All of its catalog 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 service[3]. 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.

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 Table[4].

[1] `http://healpix.sourceforge.net/`
[2] `http://aladin.u-strasbg.fr/hips/list`
[3] `http://cds.u-strasbg.fr/cgi-bin/Sesame`
[4] `http://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/3FGL-table`

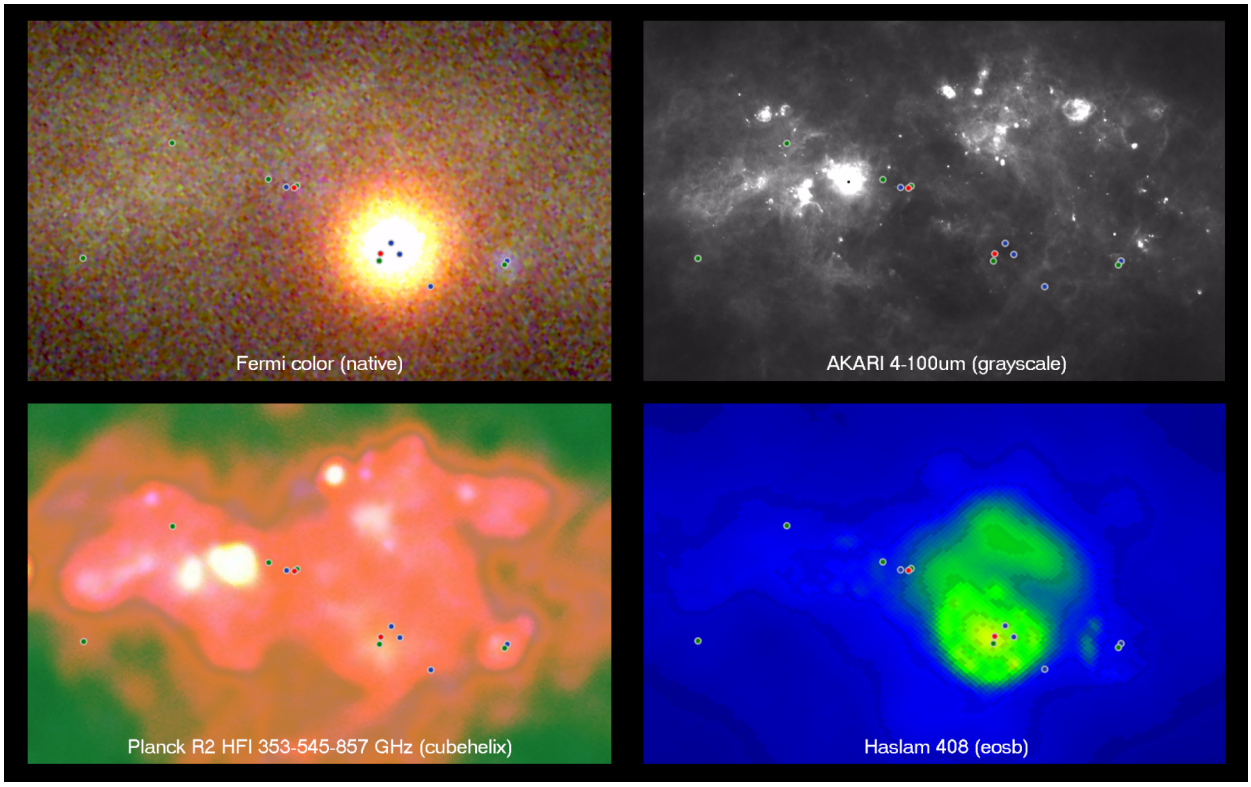

FIGURE 4. The Vela Region in various survey images and color maps, FOV 20 degrees.

Implementation

Scientific Python packages Astropy [9] and Gammapy were used to prepare and generate all of the catalog and source data on `gamma-sky.net` . The 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 `gamma-sky.net` into a single-page application. The sphere interface and visualization was implemented using the Aladin Lite tool [10] developed at CDS.

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 our website is simply a starting point; we have plans to greatly expand on our catalog and image data. Such data includes additional 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 to Gammapy for any further analysis, and we strive to link our website more closely to Gammapy's tools and scripts in the future.

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

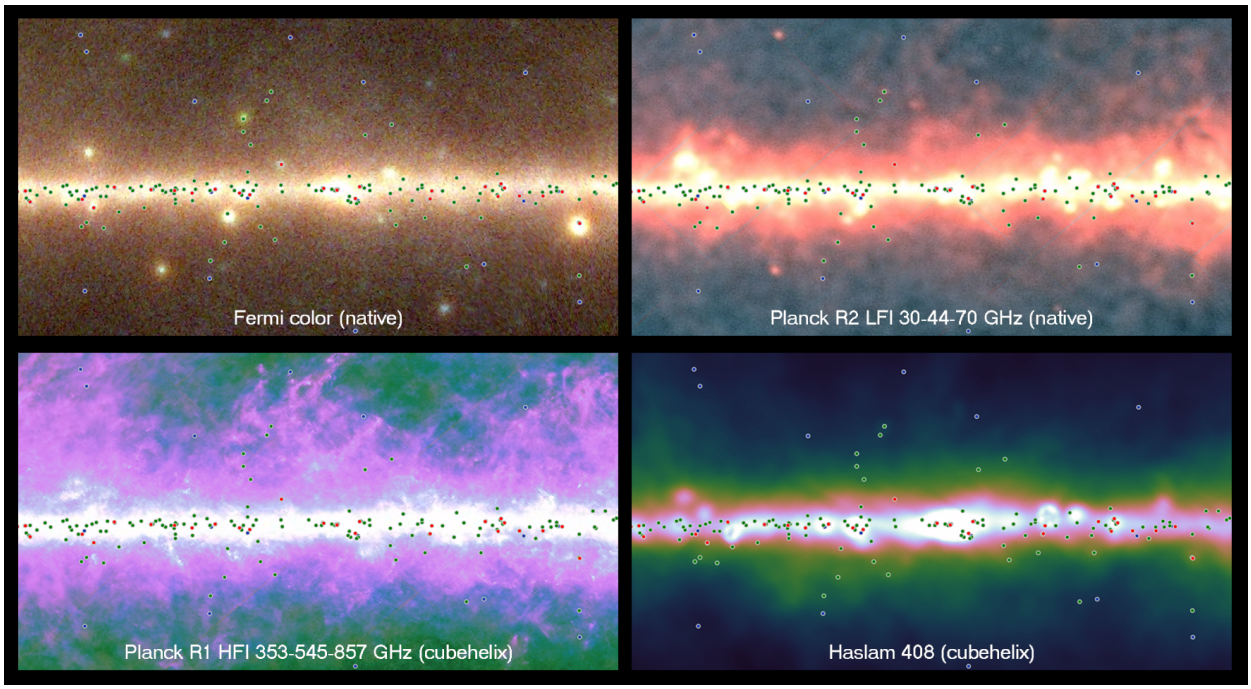

FIGURE 5. The inner Galaxy in various survey images and color maps, FOV 45 degrees.

contributors to the open-source projects, including Angular 2, Astropy, and Gammapy, that we have used to build `gamma-sky.net` .

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