

# **gamma-cat: an open data collection and source catalog for gamma-ray astronomy**

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**Abstract.** gamma-cat (<https://github.com/gammapy/gamma-cat>) is an open data collection and source catalog for TeV gamma-ray astronomy. Currently data from 32 papers is available, and the catalog contains 163 sources. Data is input using the hierarchical, human- and machine-readable YAML format and the tabular ECSV text formats, processed using Python scripts into an as-uniform form as possible. The data can be browsed on the `gamma-sky.net` web page, analyzed using `Gammapy`, or fully downloaded in FITS and other formats and used in whatever way the user likes. Data is collected in a git repository on Github, providing transparency, version control as well as simple maintenance and contribution workflow. This data repository was started in August 2016, the data collection as well as the specification of the input and output formats is work in progress. Here we present the project for the first time, and discuss its context, implementation, status, plans as well as some possible use cases for science analysis.

## **1. Introduction**

The first cosmic TeV gamma-ray source detected from the ground was the Crab nebula in 1989. Since then, TeV astronomy has seen rapid growth. As of October 2016, 163 sources have been detected (see Figure 1). Information on the position, morphology, spectra and lightcurves of these sources have been published by HEGRA, H.E.S.S., VERITAS, MAGIC, HAWC and other telescopes in a few hundred individual papers. There is a need for a machine-readable, curated, up-to-date collection of TeV data and a TeV source catalog. Here we give an overview of other TeV gamma-ray data collections and catalogs in Section 2, present the new project gamma-cat in Section 3 and conclude in Section 4.

## **2. Other TeV gamma-ray data collections and catalogs**

For a given paper, the measurements on TeV gamma-ray sources are often not available in a machine-readable format. Typically the source position, morphology and spectral model are fitted to the data, and the results of that fit are given in the paper text. Sometimes, spectral points or lightcurve points are given in ASCII or FITS format on some

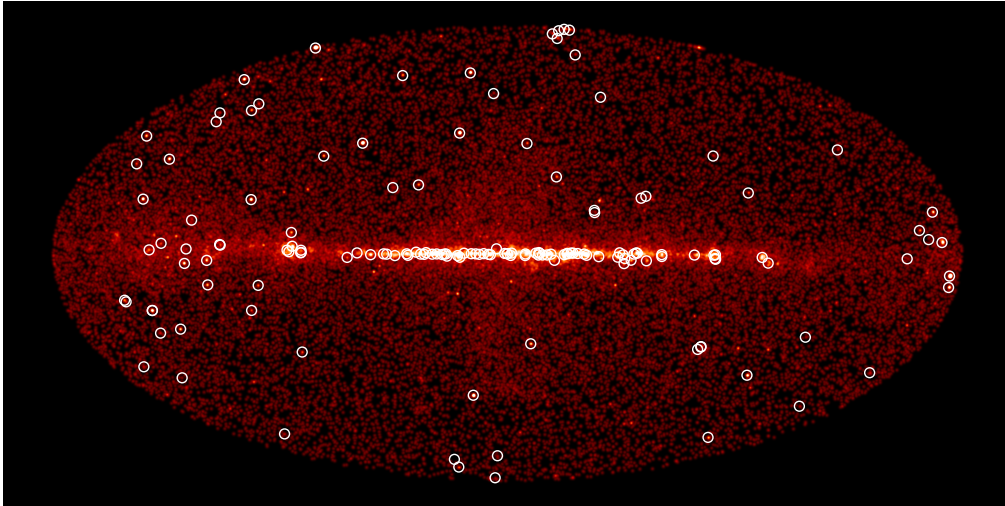


Figure 1. TeV gamma-ray sources from gamma-cat (white circles, 163 sources, status October 2016). The image (counts, smoothed with a Gaussian of width  $\sigma = 0.3$  deg) shows the gamma-ray sky above 50 GeV using the Fermi-LAT 2FHL dataset (Ackermann et al. 2016).

webpage, or can be obtained from the corresponding author. For current TeV instruments, the following data is available: A H.E.S.S. source list is available at <https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/sources/>. Spectra and lightcurves for most H.E.S.S. papers are listed as text on per-paper webpages, a curated collection for blazars in machine-readable format is available <http://hess.obspm.fr/>. For VERITAS, lightcurves and spectra in FITS format can be found at <http://veritas.sao.arizona.edu/veritas-science/veritas-results-mainmenu-72>, for MAGIC at <http://vobs.magic.pic.es/fits/>. A collection of AGN lightcurve data is available at [https://astro.desy.de/gamma\\_astronomy/magic/projects/light\\_curve\\_archive/](https://astro.desy.de/gamma_astronomy/magic/projects/light_curve_archive/), which is an evolution of the dataset described in [Tluczykont et al. \(2010\)](#).

Several other projects to collect available gamma-ray data from several telescopes exist. For Fermi-LAT, many catalogs and other high-level data products are available at <http://fermi.gsfc.nasa.gov/ssc/data/access/lat/>, and this information is also available via the HEASARC and ADSC archives. Here we focus on TeV data and not discuss Fermi-LAT data archives further for now. TeVCat is an online TeV source catalog ([Wakely & Horan 2008](#)), available at <http://tevcat.uchicago.edu/>. TeVCat is not available for download, and the terms and conditions page explicitly forbids scraping the TeVCat web page to download a copy of the data. TeVCat does not contain spectral points or lightcurve or image data.

TeVGeV is a TeV source catalog ([Carosi et al. 2015](#)) available at <http://www.asdc.asi.it/tgevcats/>. TeVGeV is part of a larger collection of multi-wavelength data and web-based tools to browse and analyze the data, and does include TeV spectra and lightcurves. The TeVGeV is available for download in CSV format, downloading all data (including spectral points and lightcurves) would require scraping the website or contacting the maintainers. 2WHSP ([Chang et al. 2016](#)), available at <http://www.asdc.asi.it/2whsp/>, is another recent ASDC catalog, focusing on gamma-ray blazars.

SIMBAD and VizieR at CDS are collections of all astronomical objects. They do contain information on TeV gamma-ray sources, e.g. a list of H.E.S.S. sources known to SIMBAD is at <http://simbad.u-strasbg.fr/simbad/sim-id?NbIdent=cat&Ident=HESS>. However, with SIMBAD it's currently not easy to get a list of gamma-ray sources, and they don't have detailed information on the gamma-ray sources, e.g. morphology information, spectral point or lightcurve data.

Given that these gamma-ray data collection exist, the question “why start a new one?” needs to be answered. We will first present gamma-cat in the next section, and then address this question in the conclusions.

### 3. gamma-cat

#### 3.1. An open TeV data collection and catalog

gamma-cat (<https://github.com/gammapy/gamma-cat>) is both a *TeV data collection* and a *TeV source catalog*. The data collection consists of measurements from papers in machine-readable form. From this collection, a TeV source catalog is derived as a higher-level data product. The source catalog is somewhat subjective and doesn't contain all data from the collection. For a given source, usually each paper contains a set of measurements (e.g. source position, morphology, spectrum) and for the catalog, the “best” available parameters are chosen. Sometimes, especially for sources in the inner Galactic plane region where the source density is high, it can even happen that a later higher-resolution image reveals that what was previously thought of as one “source” really consists of multiple “sources”. Extra-galactic sources usually don't have this issue of source confusion, but the most common source class, active galactic nuclei (AGN), are often variable in flux and spectral shape, implying that no single measurement can be the “best”. The source identification and association status can change over time, as new potential counterparts (e.g. pulsars, supernova remnants, AGN, ...) are discovered in multi-wavelength data. For these reasons, we consider the *TeV data collection* aspect of primary importance — gamma-cat is a service to the astronomical community where information from hundreds of individual papers has been collected into a machine-readable form that can be easily queried and used. The gamma-cat catalog is a secondary data product that provides a simplified summary of the available information on TeV gamma-ray sources.

The gamma-cat scope is not completely decided. Currently the focus is on collecting the published measurements for source position, morphology, spectrum and lightcurves for TeV gamma-ray sources, mostly from the past decade and the H.E.S.S., VERITAS, MAGIC and HAWC telescopes. However, if we receive contributions of similar datasets in machine-readable formats that are not readily available elsewhere, we will consider adding them (but not exposing them in the gamma-ray source catalog). Examples that come to mind are: Fermi-LAT gamma-ray source measurements from individual papers in the GeV–TeV energy range, TeV gamma-ray diffuse emission measurements or models, cosmic ray electron spectra. Whether gamma-cat will remain solely focused on TeV gamma-ray sources, or will expand to become more of a “TeV gamma-ray very-high-level datasets” repository remains to be seen. Another choice we will have to make is how to expose or merge the information from upcoming TeV source catalogs by H.E.S.S. and HAWC.

### 3.2. Guiding principles and implementation

The creation of `gamma-cat` was inspired by the other open astronomy catalogs at <https://astrocats.space/>. In the paper describing the *Open supernova catalog*, Guillochon et al. (2016) explain their guiding principles and describe the resulting implementation. `gamma-cat` is very similar, and in this section we briefly summarize our guiding principles and implementation.

*gamma-cat data is fully open-access.* Anyone can download all available data as a zip file, or clone the git repository to obtain the full version history of `gamma-cat` and use it however they like (except for an attribution request, which we state in our terms of use). Currently the size is very small, roughly 1 MB. We expect this to grow over time, but to stay within the limit of roughly 1 GB that comfortably fits in a single git repository. If large data files were added at some point (e.g. FITS images), extra repositories or other data stores could be used.

*gamma-cat is set up for fully open collaboration.* The input data collection is stored using the hierarchical, human- and machine-readable YAML format and the tabular ECSV text formats. The output data products (source catalog, spectra, lightcurves) are created using Python scripts (just run one command `python make.py all`). All scripts and Python packages we use are open-source: PyYAML (<http://pyyaml.org/>), Astropy (Astropy Collaboration 2013), Gammapy (Donath et al. 2015) and ADS (<https://github.com/andycasey/ads>). By making the data, tools and process fully open, we hope to create a community-driven project with a large scope and lifetime. Using a git repo and the simple “collection of text files as database” implementation means that the project is not tied to a given data center, website or researcher. Github pull requests provide a simple way to accept and review contributions without giving new people write access from the start.

### 3.3. Data formats, products, website, Python tools

The data products offered for `gamma-cat` are a source catalog as well as per-paper data. The source catalog is a flat table (available in ECSV, FITS and VOTABLE format) that contains one row per source with the most important information listed in a simple format. The catalog does not contain spectral points or lightcurve points or measurements from all papers for a given source. The full data available in `gamma-cat` is given as a collection of files that are generated based on collected input YAML and ECSV data, and derived information from the Python scripts. E.g. we compute the integral flux above 1 TeV according to the best-fit spectral model, even if that number wasn’t given in the paper. Currently we are using JSON for hierarchical data and ECSV for tabular output data. Other formats (e.g. YAML or FITS and VOTABLE) could easily be generated as well, this will likely change as we receive feedback on which formats are preferred by the community. Development of the data format specifications (e.g. for spectral points or lightcurves) is work in progress and happens at <http://gamma-astro-data-formats.readthedocs.io/> (Deil et al. 2016), the formats we are using now should be considered unstable prototypes. We have started to develop a Python package, `gammapy.catalog` (<http://docs.gammapy.org/en/latest/catalog/>, Donath et al. (2015)), that allows easy querying of `gamma-cat` and working with the data, e.g. plotting spectra or lightcurves or analyzing them, or generating a TeV sky model from the catalog.

#### 4. Conclusions

gamma-cat is a TeV gamma-ray astronomy data collection and source catalog. Compared to previous similar projects, gamma-cat stands out by being fully open-access and set up in a way that makes maintenance and community contributions easy, following the lead of other open astronomy catalogs from <https://astrocats.space/>. None of the other TeV data collections can easily be downloaded in full, but often this is what users want, to e.g. browse, plot or analyze the data with whatever tools they like. Merging of some previous TeV data collections (e.g. the light curve archive as DESY) as well as communication about possible collaboration with the other project is ongoing. gamma-cat is being developed in close collaboration with ongoing efforts to develop gamma-ray data format standards (gamma-astro-data-formats), open-source science tools (Gammapy) as well as a website dedicated to the gamma-ray sky (gamma-sky.net).

gamma-cat lets you quickly access all published information for all TeV sources, ready for data exploration or analysis. We hope that this will be a useful resource for daily work as well as the basis for novel studies involving the extensive set of available archival gamma-ray data. Concretely we propose gamma-cat to be used as one of the inputs to build the sky model for the planned CTA data challenge. The scope of gamma-cat is not decided yet, we will have to see if someone wants to add Fermi-LAT source information, HAWC and H.E.S.S. source catalog information, or other information. Feedback and contributions to gamma-cat are highly welcome!

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