An open catalog for TeV gamma-ray astronomy

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Abstract.

We present the gamma-cat, an online data collection and source catalog for TeV gamma-ray astronomy. Currently data from TODO papers is available, and the catalog contains TODO 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 it's 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. By now, TODO sources (status: October 2016) have been detected (see Figure 1). We start with a review of previous efforts to create TeV data collections, and then in the next section describe the new project presented here for the first time: gamma-cat.

Measurements of source position, morphology, spectrum and sometimes lightcurves have been published, mostly in individual papers. Often the measurements are not given in a machine-readable format, sometimes it is given in ASCII or FITS formats. There have been several prior efforts to collect and curate the available TeV gamma-ray data. A H.E.S.S. source list is available in HTML (Hypertext markup language) and CSV (character-separated values) formats at https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/sources/, some spectra and lightcurves of blazars measured by H.E.S.S. in FITS (Flexible Image Transport system) and VOTable (Virtual Observatory table) formats at http://hess.obspm.fr/. Some VERITAS images, lightcurves and spectra in FITS format are available at http://veritas.sao.arizona.edu/veritas-science/veritas-results-mainmenu-72. MAGIC at http://vobs.magic.pic.es/fits/. A light curve archive with FITS and VOTABLE data for some blazars is available at https://astro.desy.de/gamma_astronomy/magic/

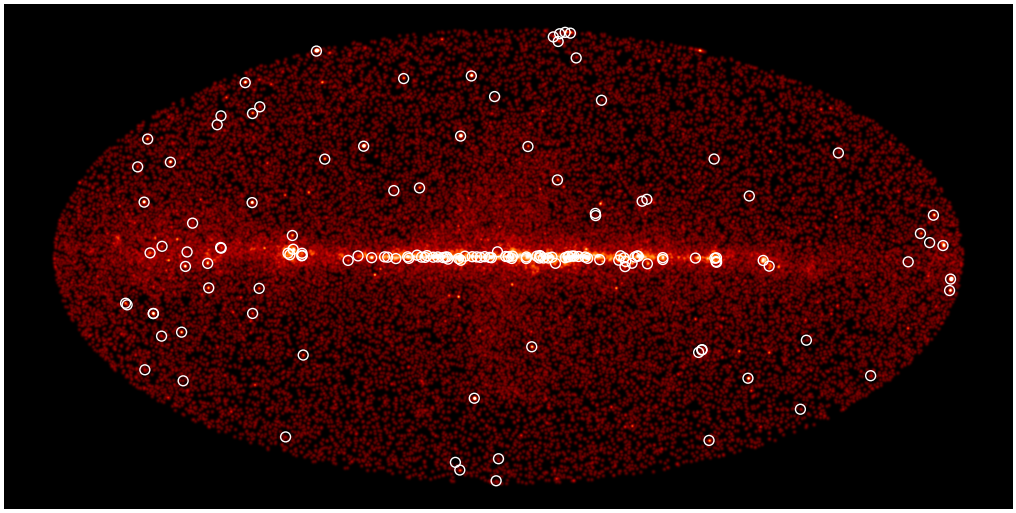

Figure 1. TeV gamma-ray sources from `gamma-cat` (white circles, TODO sources, status October 2016). The image (counts, smoothed with a Gaussian of width $\sigma = 0.3$ deg) shows the gamma-ray sky above 50 GeV using the Fermi-LAT 2FHL dataset (Ackermann et al. 2016).

`projects/light_curve_archive/`, which is an evolution of the data format and dataset described in Tluczykont et al. (2010). HAWC publications are listed at `http://www.hawc-observatory.org/publications/`, as far as we know, no HAWC data in machine-readable format is available for download

An online TeV source catalog (as of October 2016) is available at `http://tevcat.uchicago.edu/` (Wakely & Horan 2008). `TeVCat` is not available for download, and the terms and conditions page explicitly forbids systematic download of the data, e.g. by scraping the web page. `TeVCat` does not contain spectral points or lightcurve or image data. The `TeGeV` catalog is available at `http://www.asdc.asi.it/tgevcat/` Carosi et al. (2015). `TeGeV` is a larger collection of data compared to `TeVCat`, it does include spectral points and lightcurves. `TeGeV`is part of a larger collection of multi-wavelength data (including e.g. X-ray and GeV gamma-ray data) and web-based tools to browse and analyse the data (e.g. the ASDC data explorer and SED builder). The `TeGeV`data is available for download in CSV format, downloading all the data (including spectral points and lightcurves) would require scraping the website.

2. `gamma-cat` – Open TeV data collection and catalog

In this section we describe `gamma-cat` (`https://github.com/gammapy/gamma-cat`), which 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, not clearly distinguishable "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.

2.1. Guiding principles

The following guiding principles motivated the creation of this new project, and partly it's implementation.

- `gamma-cat` is fully open-access. Everyone can download all available data.
- `gamma-cat` is fully transparent. For every measurement in the catalog, it shall be possible to identify the origin (usually a paper).
- `gamma-cat` data is mostly stored in text files. Changes to `gamma-cat`are under version control.
- `gamma-cat` is fully open-source. The scripts

Note: This project is a copycat of Guillochon et al. (2016) and `https://astrocats.space/`, for TeV.

TODO: discusss terms of use and attribution here?

- Open gamma formats: Deil et al. (2016) and `http://gamma-astro-data-formats.readthedocs.io/`

TODO: discuss project scope

3. Implementation

Tools:

- PyYAML: `http://pyyaml.org/`
- Astropy: Astropy Collaboration (2013)
- Gammapy: Donath et al. (2015)
- `https://github.com/andycasey/ads` Multi-mission analysis with Sherpa (Freeman et al. 2001)

4. Examples

4.1. Spectra

Example spectrum, see Figure 2.

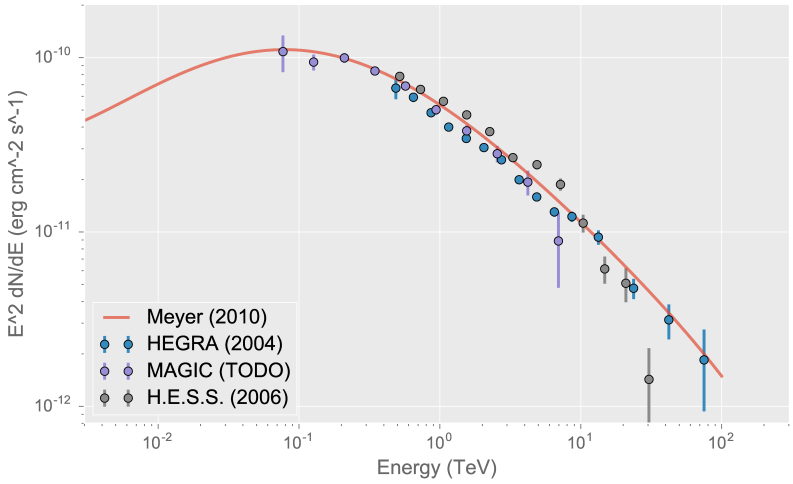

Figure 2. Spectrum example. Crab nebula.

4.2. Light curves

Example lightcurve, see Figure 3.

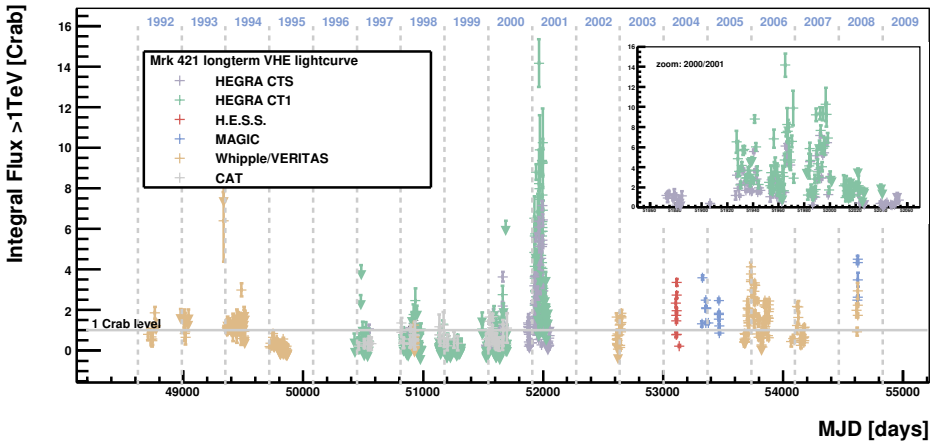

Figure 3. Lightcurve example. Mrk 421. Figure from Tluczykont et al. (2010). Data not yet available in gamma-cat.

5. Conclusions

Remember: gammacat this is useful and awesome.

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