A **Python** package for
gamma-ray astronomy

10 years of Gammapy

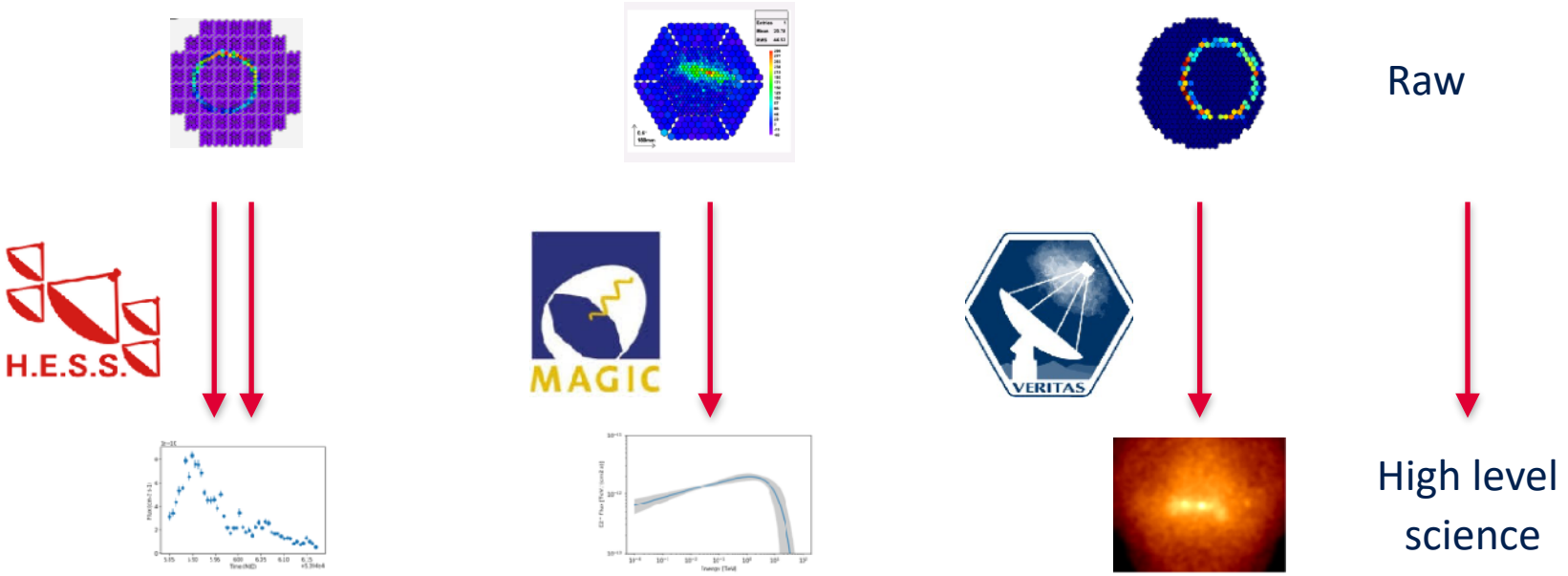
open source tools for gamma-ray astronomy

Régis Terrier for the Gammapy team

Gamma 2024 Sep 5th 2024

The landscape 10 years ago

- Proprietary data and formats & closed software tools



Issue for :

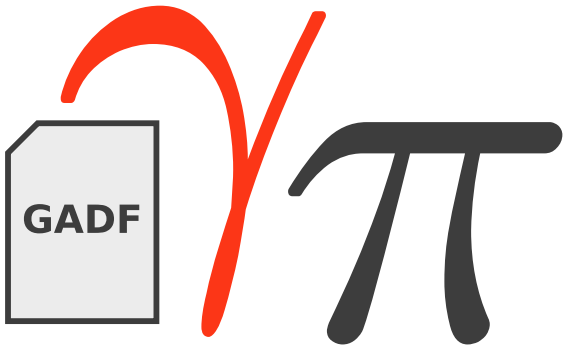
- **Reproducibility**
- **Interoperability**

VHE analysis needs common open *data formats* and common open *tools*

The Gammapy concept

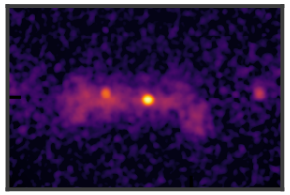
Pointing γ-ray Observatories

All-sky γ-ray Observatories

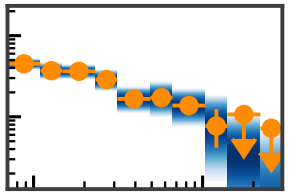


Common
data format

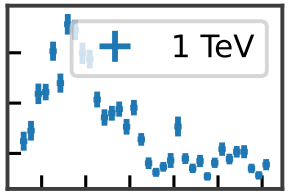
Sky maps



Spectra



Lightcurves

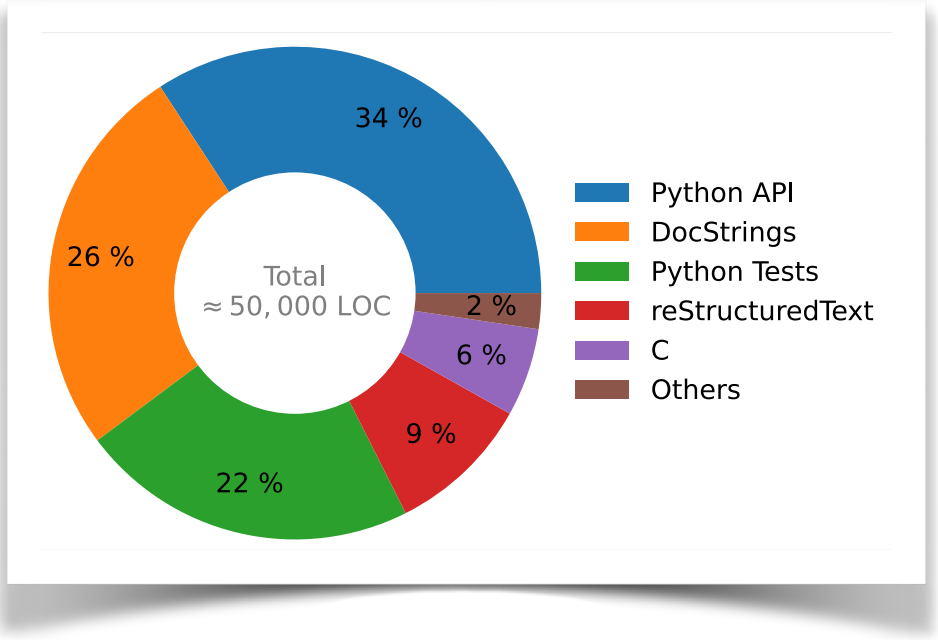


The Gammapy library

- lightweight python library & astropy-affiliated package

- openly developed on GitHub
  - 8-10 core contributors
  - more than 80 contributors from the whole γ-ray astronomy community and beyond

- Structured project
  - Coordination committee & managers
  - Lead developers and sub-package maintainers



distributed via PyPI and conda-forge

Early steps : 2014-2017

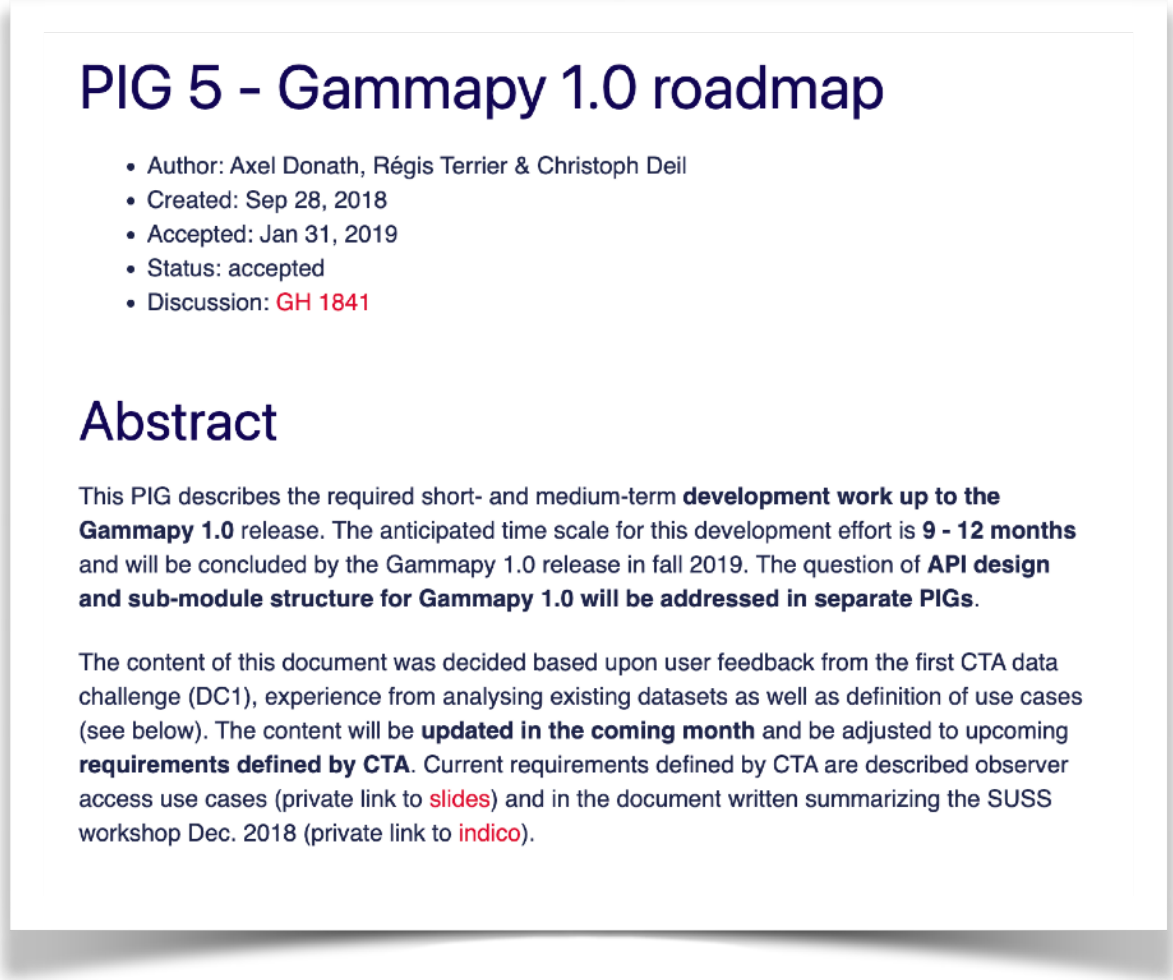
- First gammapy release (version 0.1) on August 25th, 2014
- project evolved into a generic library for TeV astronomy and CTAO science tools

> « We would like to introduce Gammapy to the community and present our vision of Gammapy as a future community-developed, general purpose analysis toolbox for γ-ray astronomers. […] Its scope will continuously grow and we hope that many users and developers show interest in open and reproducible γ-ray astronomy with Python. As long-term goal we would like Gammapy to turn into a fully community-developed package. »

Donath, A., Deil, C. et al. ICRC 2015

Towards v1.0 : 2018-2022

- rapid development cycle with frequent releases (~ 2 month)
  - from v0.7 to 0.20
- structuration of the library & abstraction of analysis steps
- 19000 commits from more than 80 contributors
- version 1.0 released Nov 10th 2022



PIG 5 - Gammapy 1.0 roadmap

- Author: Axel Donath, Régis Terrier & Christoph Deil
- Created: Sep 28, 2018
- Accepted: Jan 31, 2019
- Status: accepted
- Discussion: GH 1841

Abstract

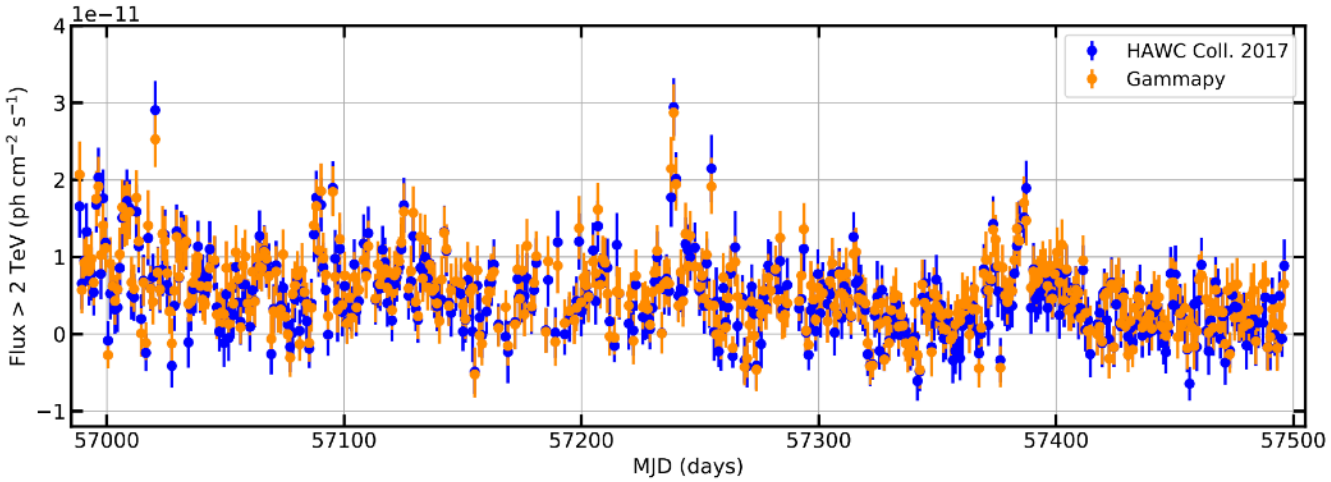
This PIG describes the required short- and medium-term **development work up to the Gammapy 1.0** release. The anticipated time scale for this development effort is **9 - 12 months** and will be concluded by the Gammapy 1.0 release in fall 2019. The question of **API design and sub-module structure for Gammapy 1.0 will be addressed in separate PIGs**.

The content of this document was decided based upon user feedback from the first CTA data challenge (DC1), experience from analysing existing datasets as well as definition of use cases (see below). The content will be **updated in the coming month** and be adjusted to upcoming **requirements defined by CTA**. Current requirements defined by CTA are described observer access use cases (private link to slides) and in the document written summarizing the SUSS workshop Dec. 2018 (private link to indico).

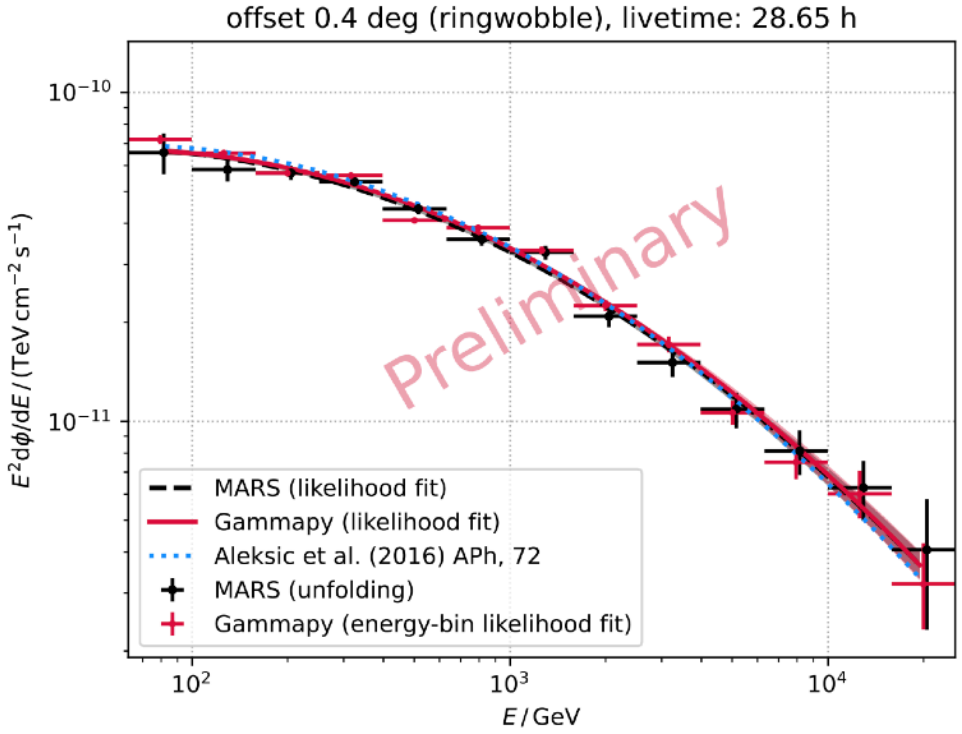
See v1.0 gammapy paper: Donath et al (2023)

Science validation

Comparison of results obtained with Gammapy and proprietary collaboration tools for various analysis scenarios



HAWC Albert et al (2022)



MAGIC Nigro (2023)

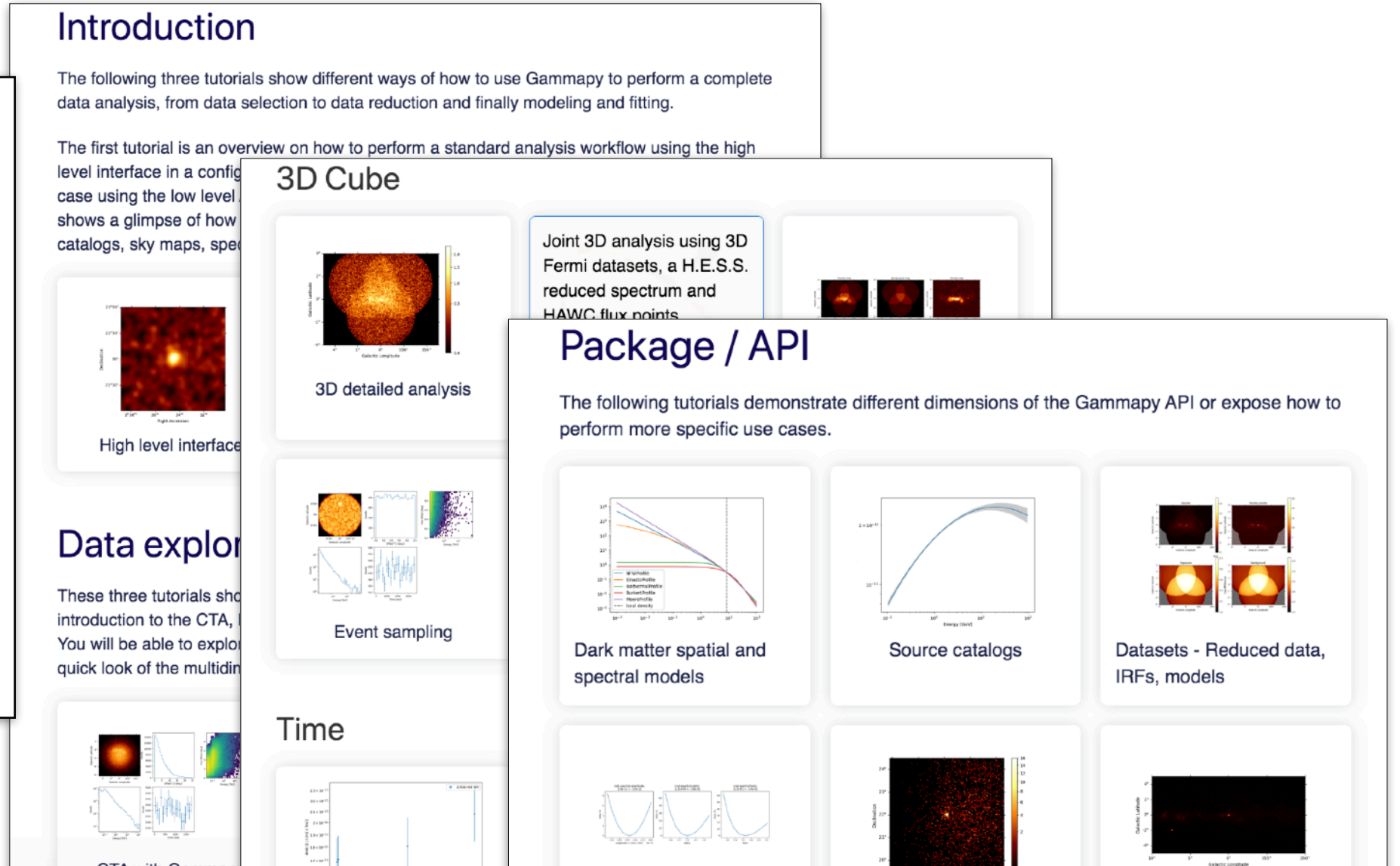
Documentation : tutorials

See docs.gammapy.org

42 tutorials:

- **standard data analysis cases**
- **use the general API**
  - go beyond regular use cases
  - exploit Gammapy flexibility

More complex use cases in gammapy recipes



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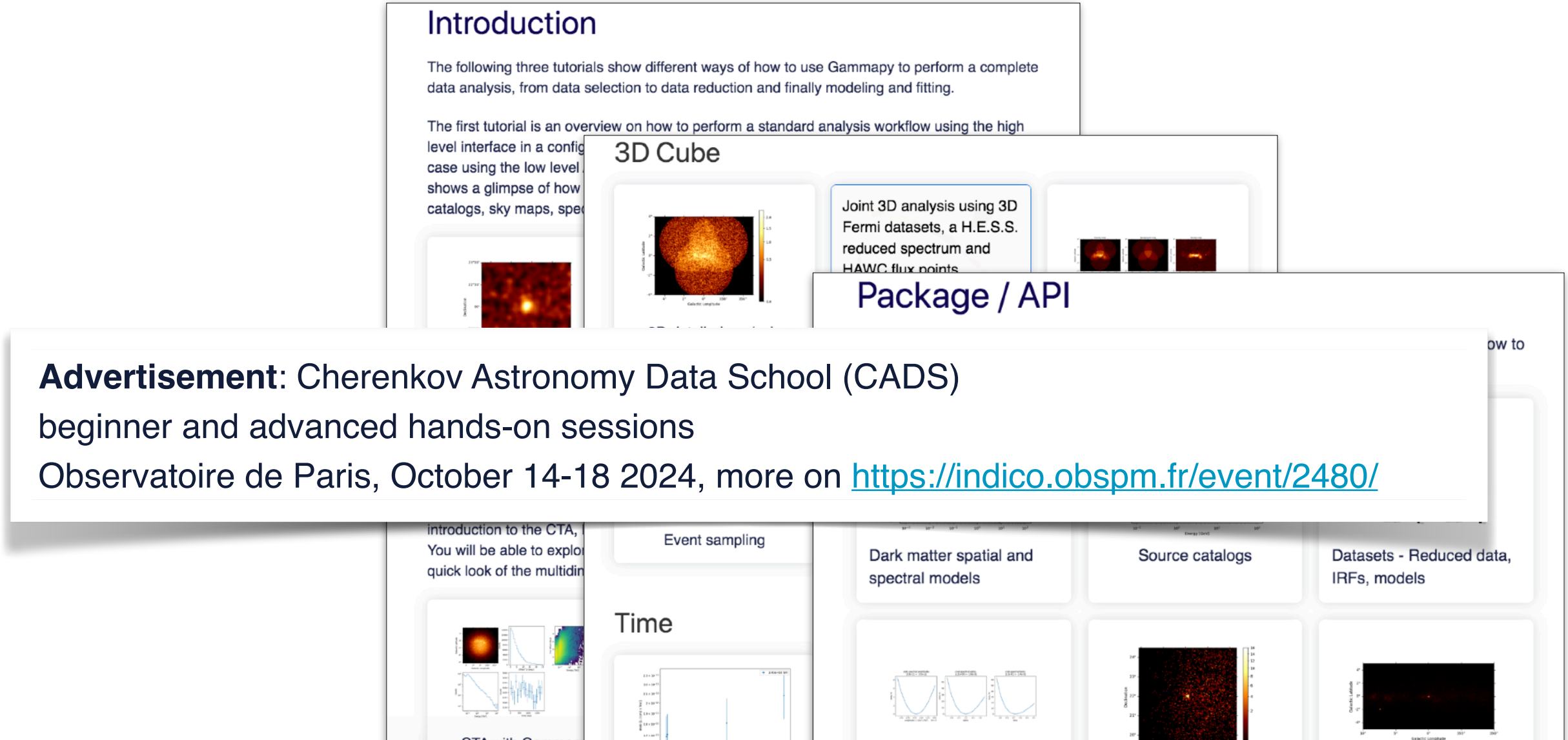


Advertisement: Cherenkov Astronomy Data School (CADS)
beginner and advanced hands-on sessions
Observatoire de Paris, October 14-18 2024, more on https://indico.obspm.fr/event/2480/

Towards v2.0 : selection of new features

- Parameter prior can now be defined on parameters and the associated log-prior is added to the total statistics during fitting.
- Added timing studies utility functions for light curves, see tutorial
- Preliminary support for asymmetric IRFs. See tutorial.
- Energy dependent ON-region size for 1D spectral analysis
- And many more…

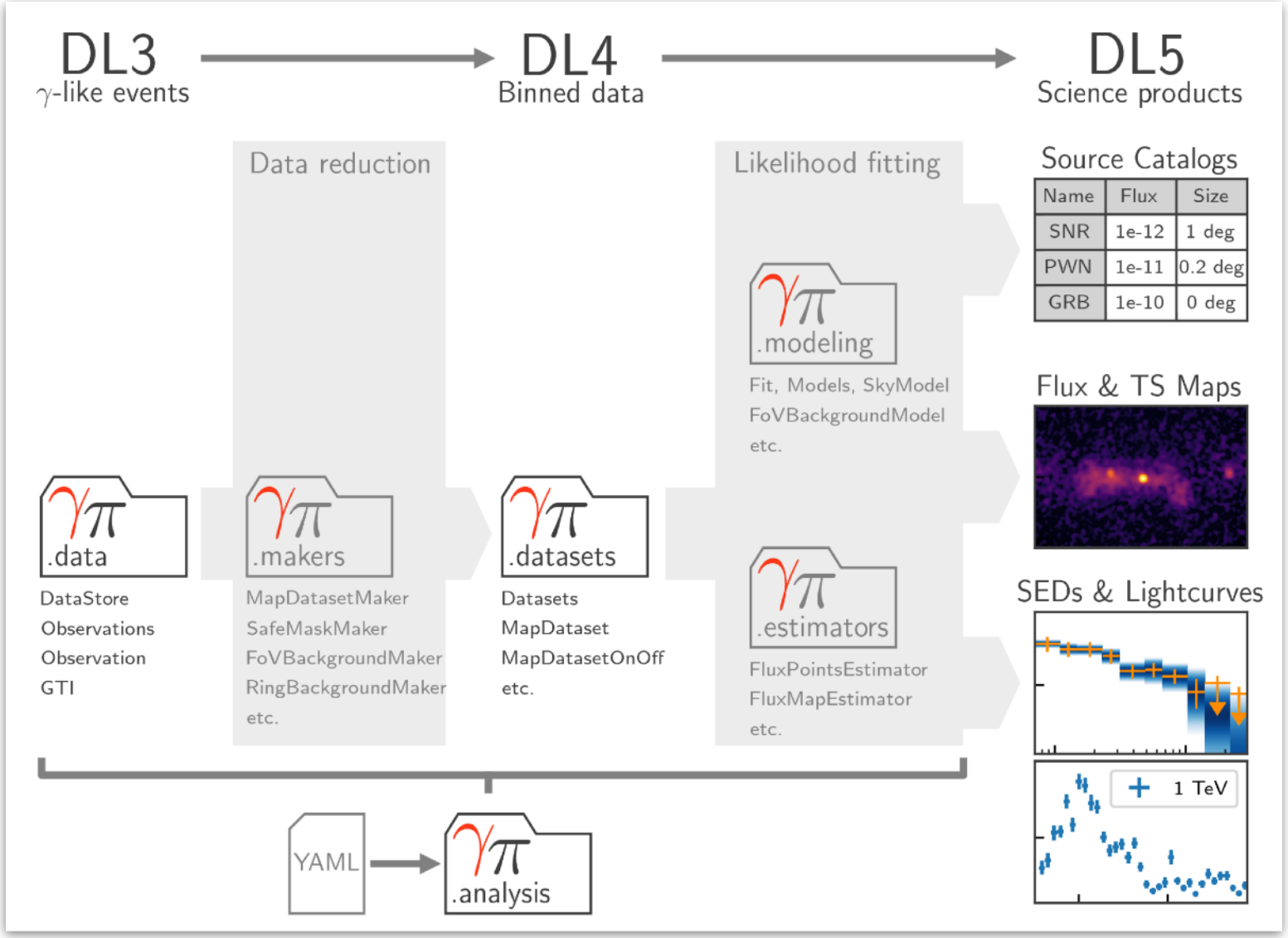
- More to come in v1.3 and beyond
  - Improved support for event types and joint analyses
  - Multi-parameters priors and spectral unfolding
  - Lightcurve simulation and PSD study tools . See C. Galleli poster
  - …

Data analysis workflow & package structure

2-step analysis procedure:
- data aggregation and reduction (DL3 to 4)
- modeling / fitting (DL4 to 5)

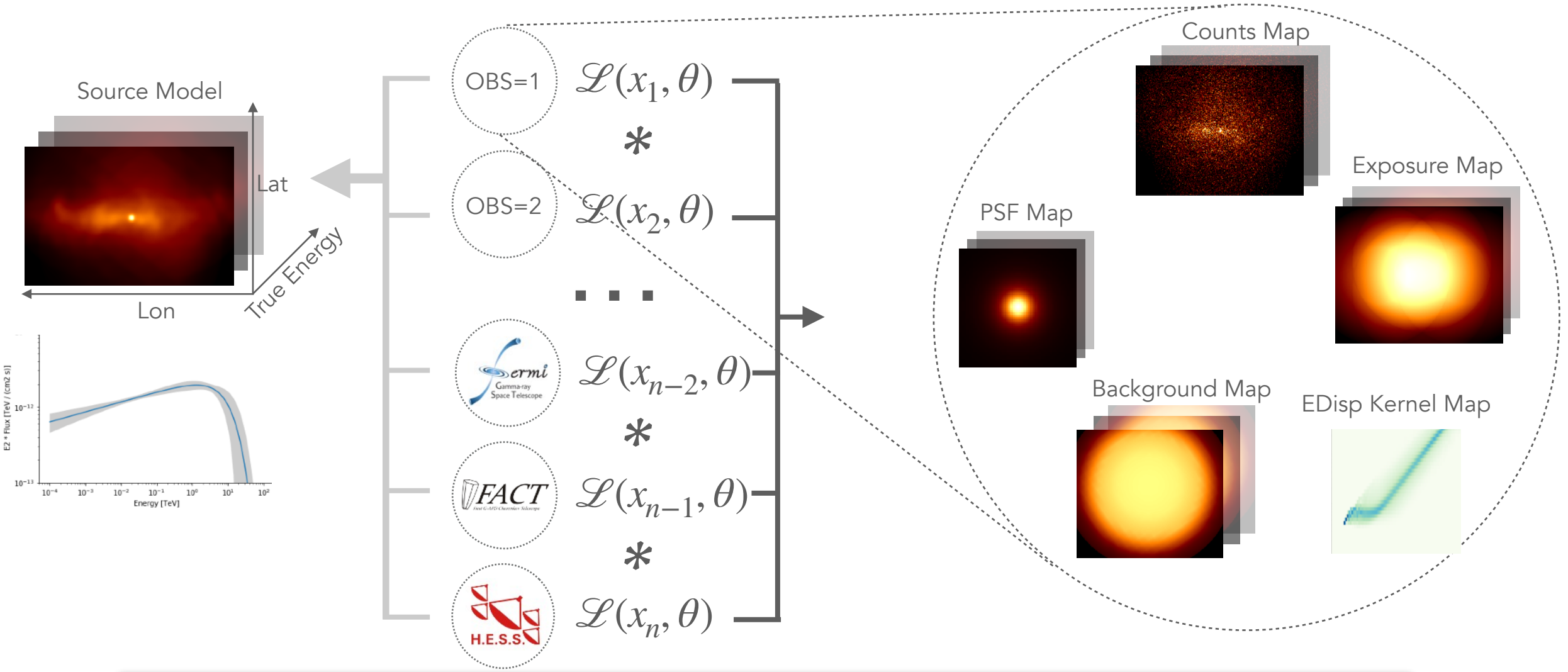
Allow for joint data modeling at DL4 level

Flexible modeling library:
- physical models (e.g. naima)
- user designed models



Joint likelihood and multi-instrument analysis

Combining heterogeneous datasets

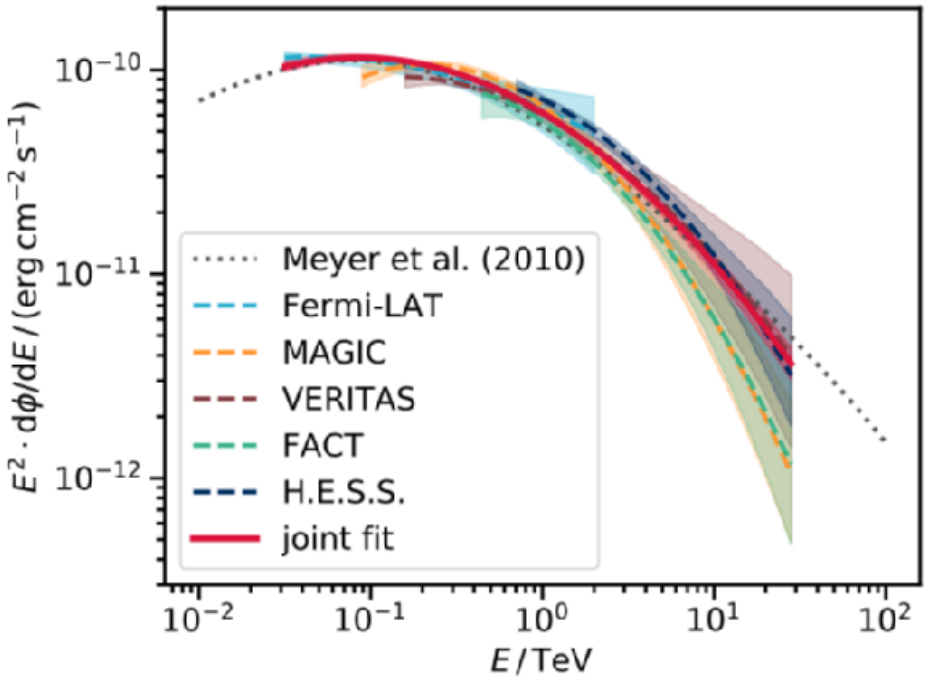


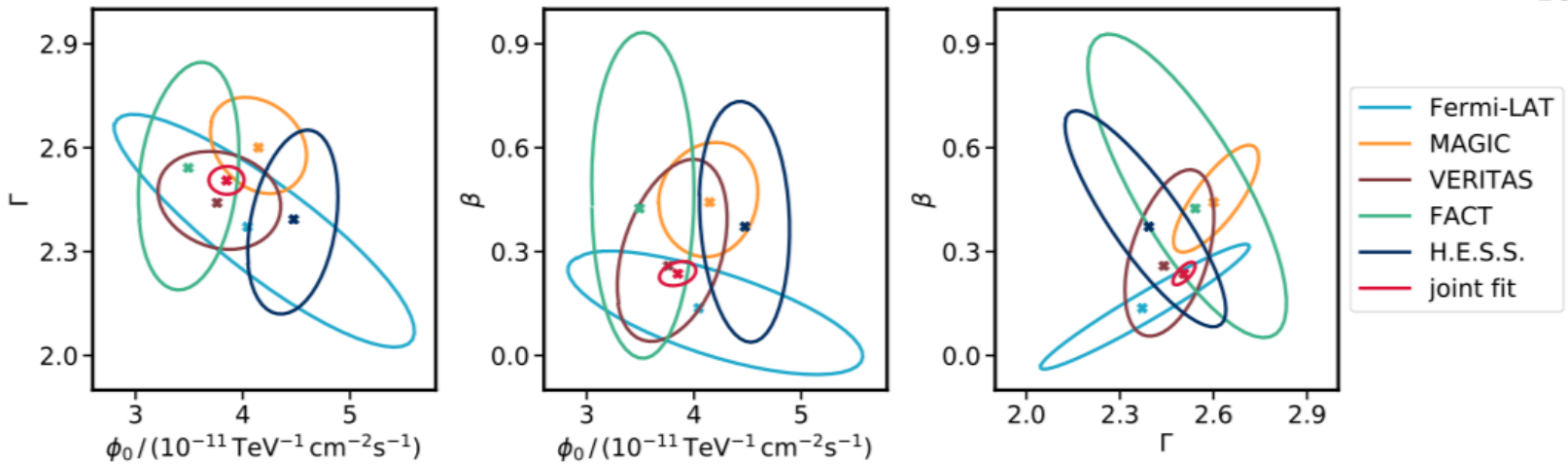
Gammapy Dataset structure allows heterogeneous data fitting. See [joint fit tutorial]

An example of multi-instrument analysis

Combining Crab observations

- Joint point-like 1D spectral analysis of the Crab nebula
- 5 different instruments over 3 decades in energy
  - Simple log-parabola & physical inverse Compton model
  - Modeling of some systematic uncertainties
- Fully reproducible analysis





[Nigro et al. 2019]

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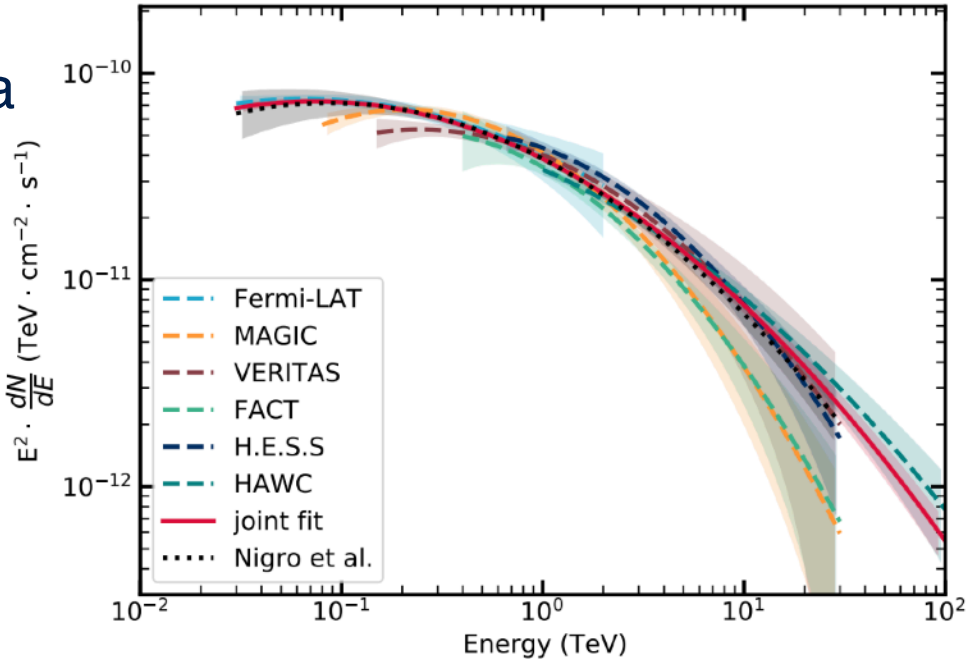
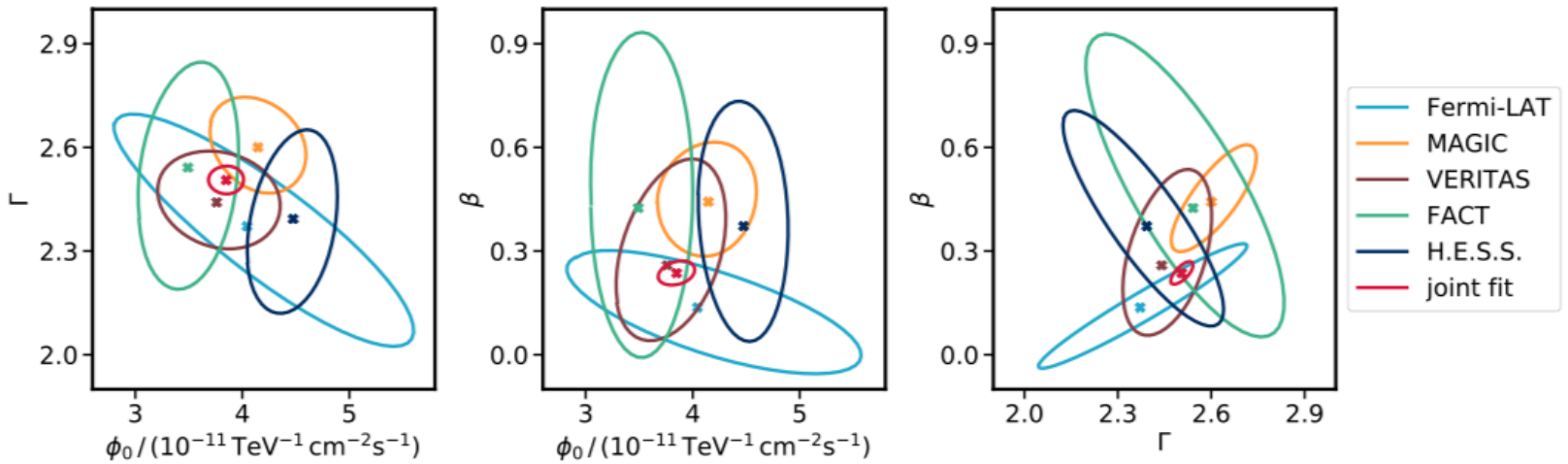


+HAWC data [Albert et al (2022)]



[Nigro et al. 2019]

Multi-instrument analysis examples

Joint X-ray and γ-ray fits

First approach:

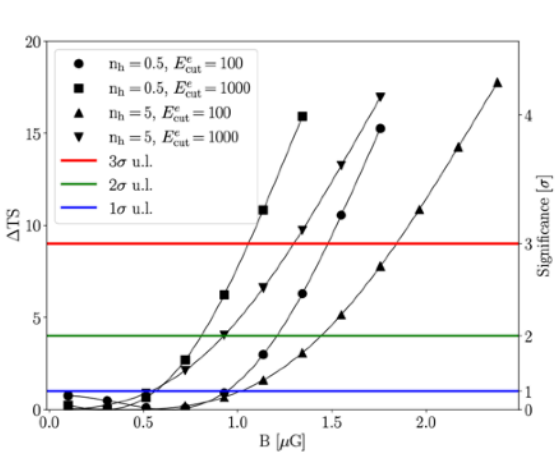
- Read OGIP spectra (1D DL4) produced by X-ray telescopes and fit

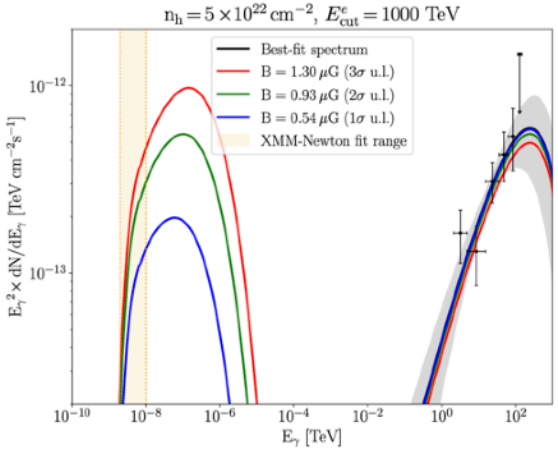
gammapyXray package DOI 10.5281/zenodo.7092736

Second approach:

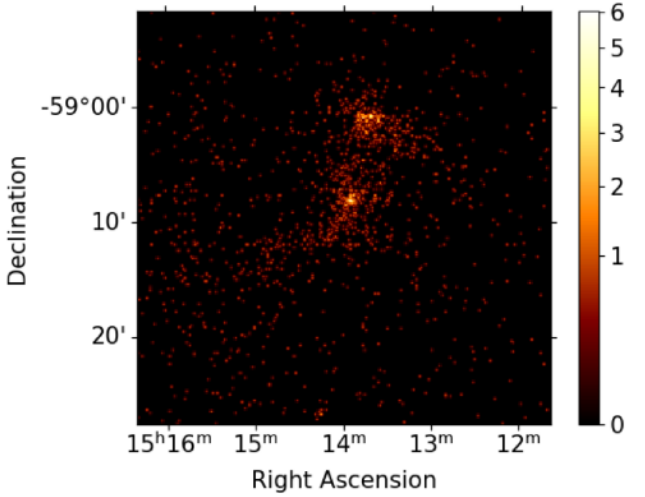
- Read X-ray events, IRFs and create 3D DL4 dataset

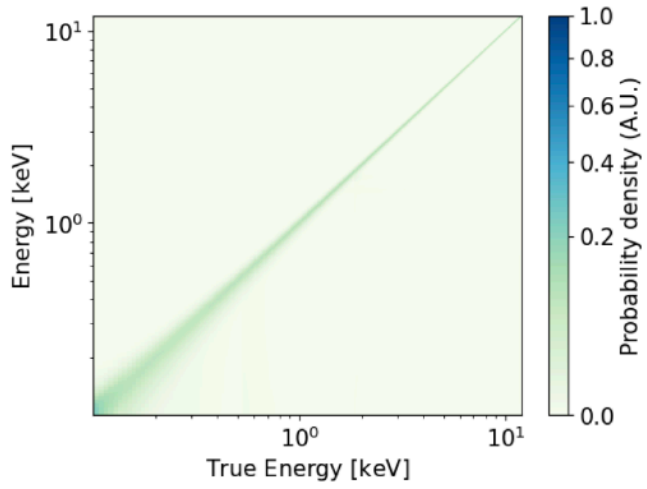
See e-ROSITA converter in K. Egg poster





XMM-Newton & H.E.S.S.: Giunti et al (2022)



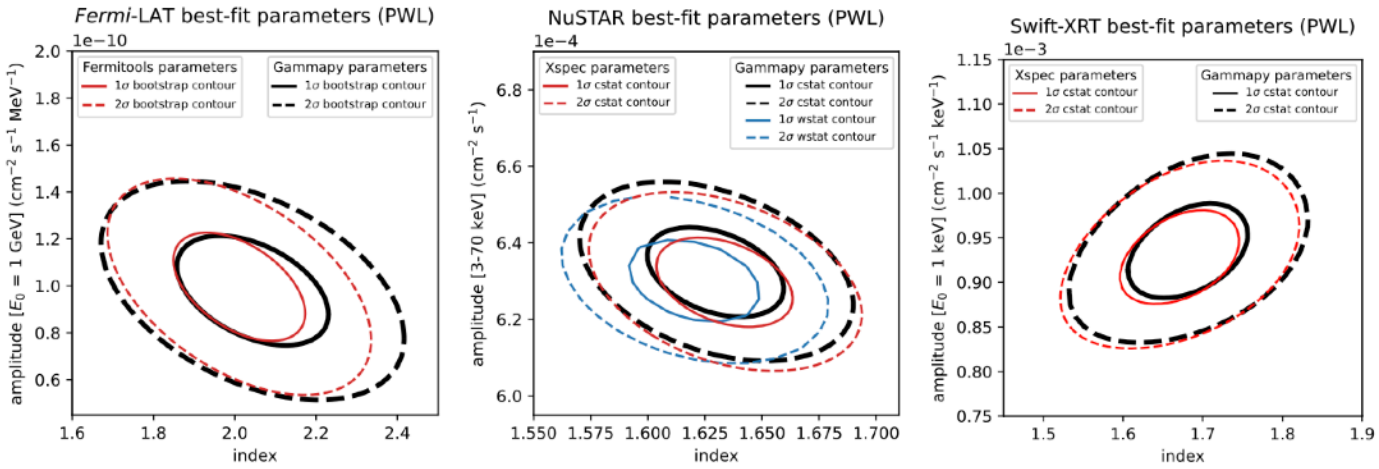


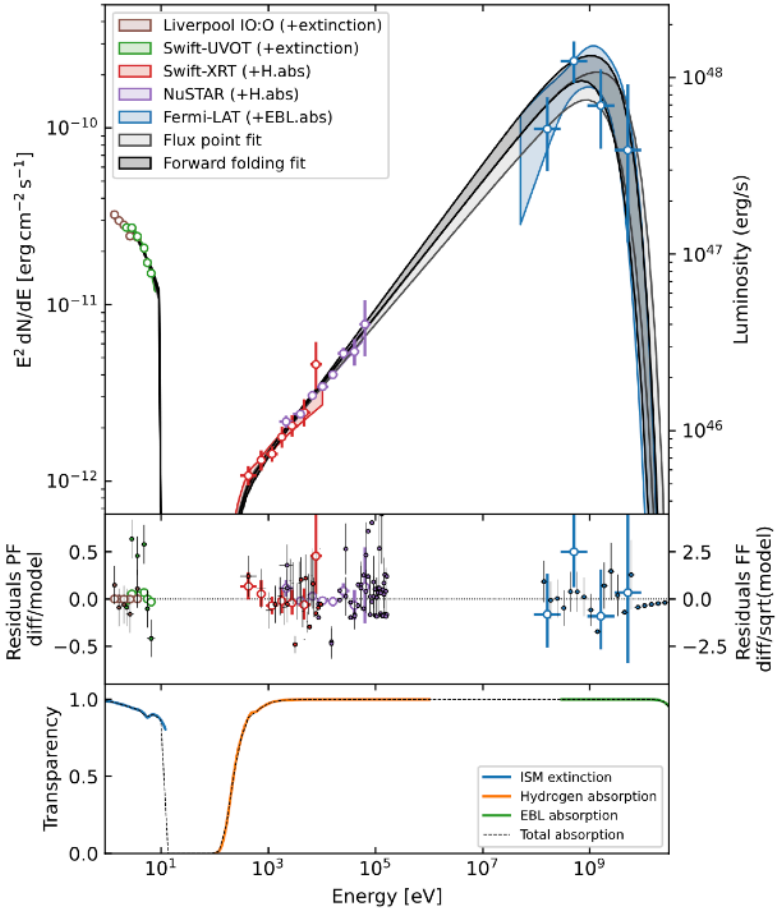
Multi-instrument analysis over 10 decades

OP 313 campaign

- Joint forward fitting fit from eV to 10^{10} eV with Gammapy:
  Liverpool OT, Swift-UVOT, Swift-XRT, NUSTAR, Fermi-LAT

- Flux points lose some stat. information (e.g U.L.)
- Full forward fit provides more accurate results
- Gammapy facilitates the distribution and reproducibility of the results





From M. Nievas et al (2024) in prep.

Conclusions and outlook

- Gammapy is a mature openly-developed library for gamma-ray astronomy
  - Its flexibility and multi-instrument capabilities open exciting new scientific opportunities

- To improve scientific scope (e.g. more complex IRFs, extending to neutrinos) and reproducibility, the community needs new data and model format standards:
  - See very high energy open data format initiative

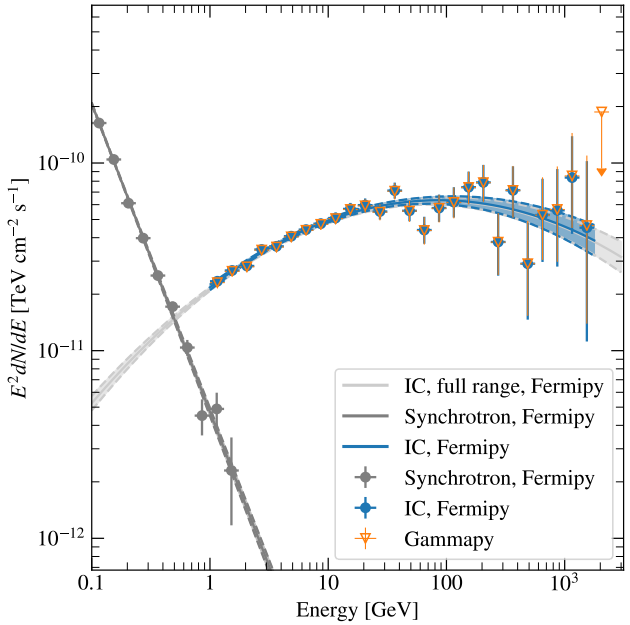
- Lot of work still ahead. Get involved!

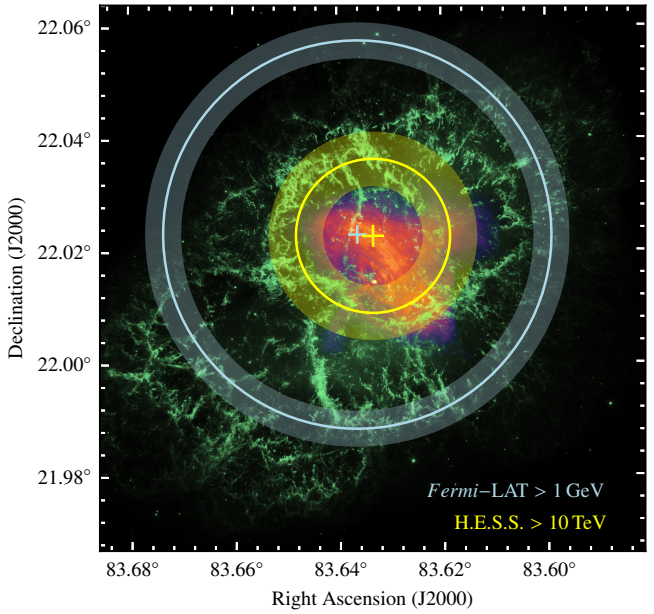
- How to provide feedback / get help:
  - #help channel on gammapy.slack or GitHub discussions
- How to report issues and bugs or request a new feature: GitHub issues
- How to take part to the effort and contribute:
  - #dev on gammapy.slack, open a PR on GitHub, join dev Zoom calls
- Don't forget to acknowledge/cite it.

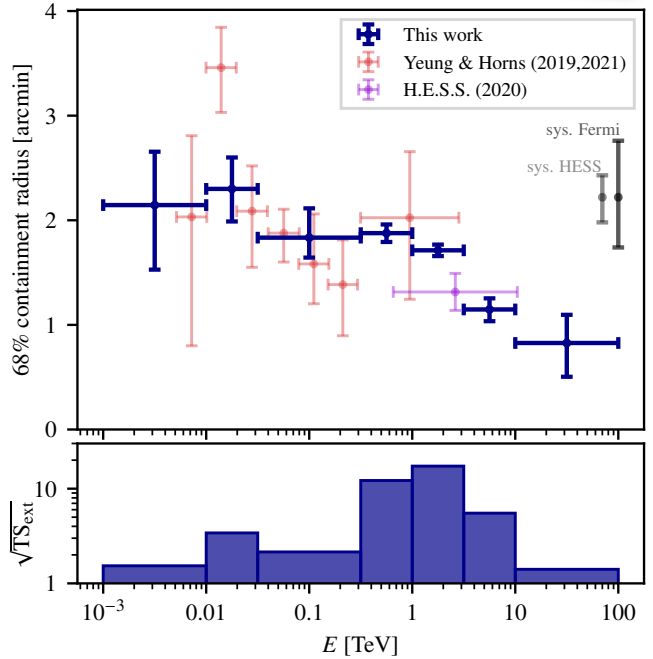
Multi-instrument analysis examples

Spectrum and extension of the inverse-Compton emission of the Crab Nebula from a combined *Fermi*-LAT and H.E.S.S. analysis HESS Collab. 2024

GAMMAPY has the advantage that it enables a combination of the *Fermi*-LAT data with that of H.E.S.S., and it offers the possibility to include customised physical models in the analysis.







Getting the software

- **Download tutorials & associated data**

```
gammapy download notebooks
gammapy download datasets
```

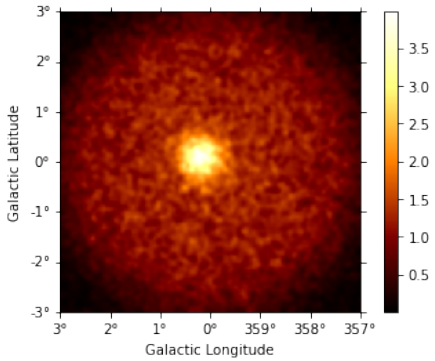
If using conda environment, set GAMMAPY_DATA with conda

```
conda env config vars set GAMMAPY_DATA=$PWD/gammapy-datasets/1.2
conda activate gammapy-1.2
```

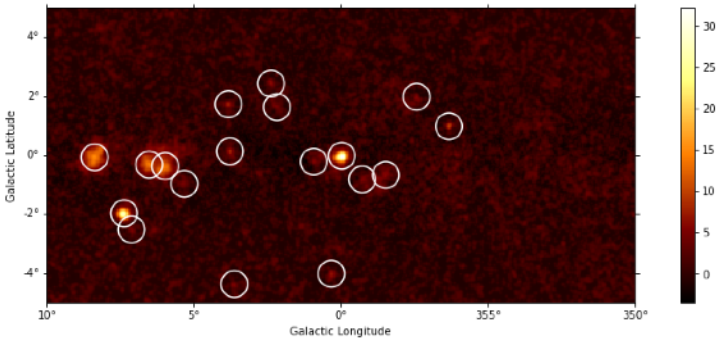
else set with shell:

```
export GAMMAPY_DATA=$PWD/gammapy-datasets/1.2
```

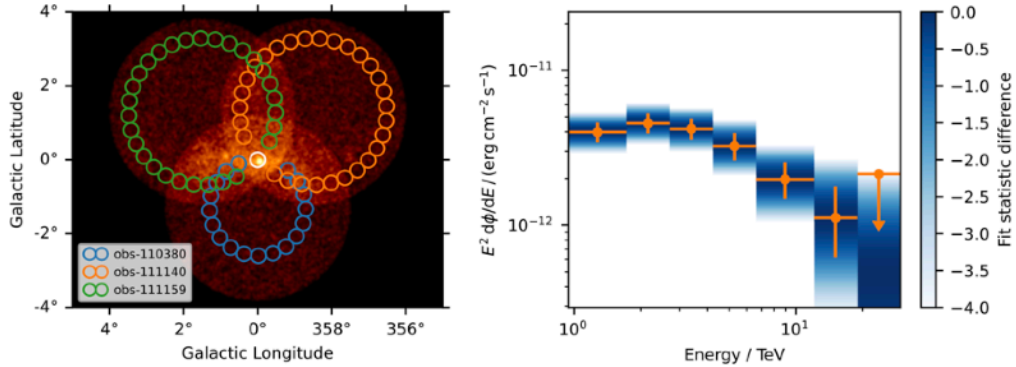
Typical analysis use cases



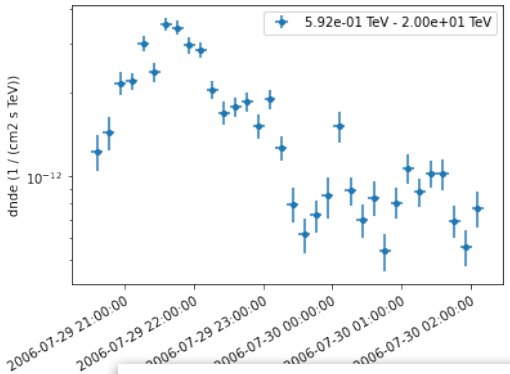
observation simulation



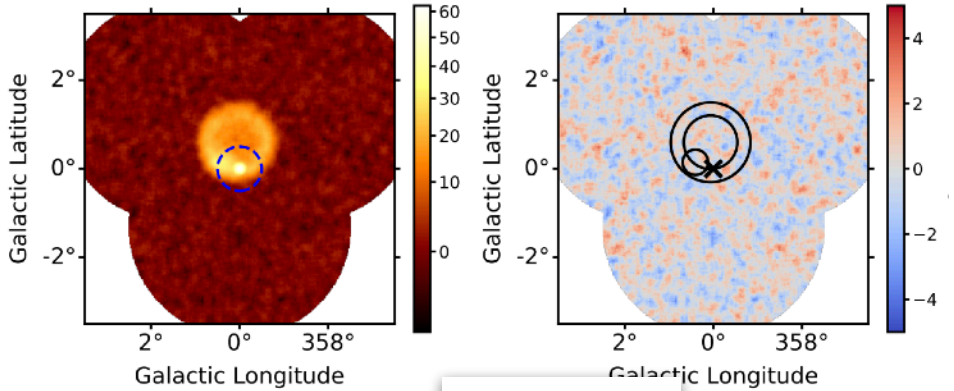
Source detection



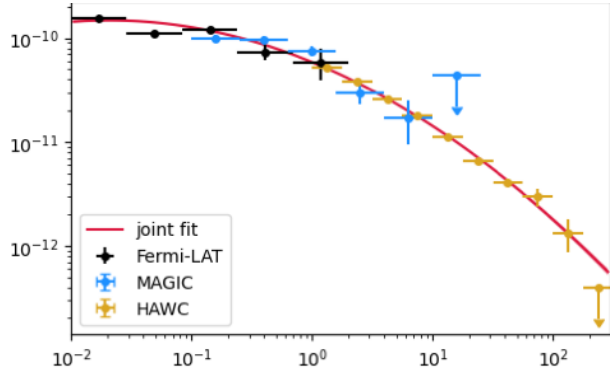
1D spectral analysis



light-curve extraction



3D analysis



Multi-instrument fitting