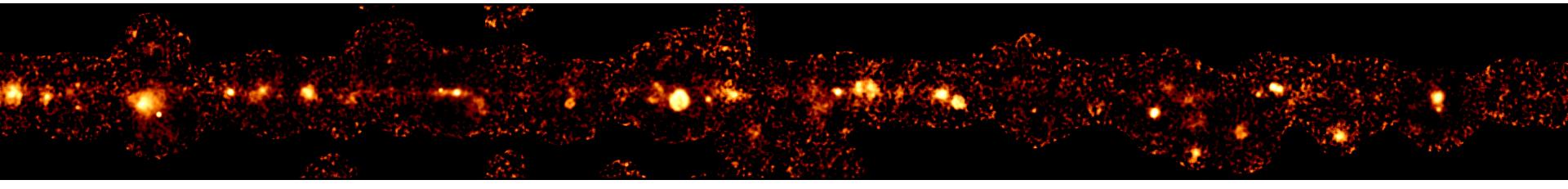


A **Python** package for
gamma-ray astronomy

Gammapy overview

Bruno Khélifi, for the Gammapy Team
APC (CNRS/IN2P3, Université Paris Cité)





About me



- Researcher at the laboratory [AstroParticule and Cosmology](#) (APC, Paris) –  [0000-0001-6876-5577](#)
- Gamma-ray astrophysicist (galactic sources: PWN, PeVatron), software developer (C++, Python) and data formatting
- Member of the H.E.S.S. collaboration and the CTA consortium, supporting scientist of SWGO
- Responsible of one of the 3 official pipelines of the H.E.S.S. low-level analysis ([HAP-Fr](#)), Project Manager of Gammapy (core library of the CTA [Science Analysis Tool](#))
- Convener of the Very-high-energy Open Data Format ([VODE](#)) initiative
- Involved in the Open Science movement: SoftWare Heritage, IVOA, referent in my university and in IN2P3, etc



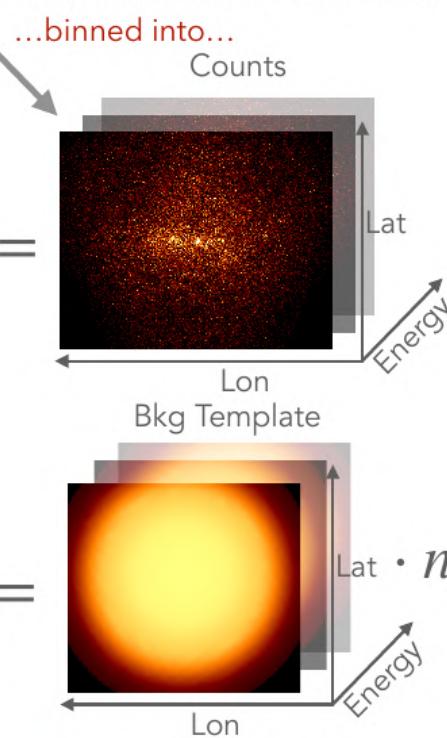
A short introduction to Gamma-ray Data Analysis

From **A. Donath** (CfA), Lead Developer of Gammapy
Presentation made during the Scipy 2023 conference

Binned Poisson Log-Likelihood

List of gamma-like events...

EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
int64	float64	float32	float32	float32
5407363825684	123890826.66805482	84.97964	23.89347	10.352011
5407363825695	123890826.69749284	84.54751	21.004095	4.0246882
5407363825831	123890827.23673964	85.39696	19.41868	2.2048872



"Cash statistics": summed over all "bins"

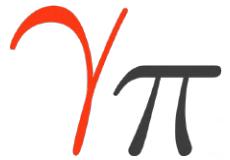
$$\mathcal{C} = 2 \sum_i N_{Pred}^i - N_{Obs}^i \cdot \log N_{Pred}^i$$

$$N_{Pred} = N_{Bkg} + \sum_{Src} N_{Pred,Src}$$

- Predicted counts are **computed per model component** ("source / object") and summed
- A "**global background model template** with "correction parameters" is added

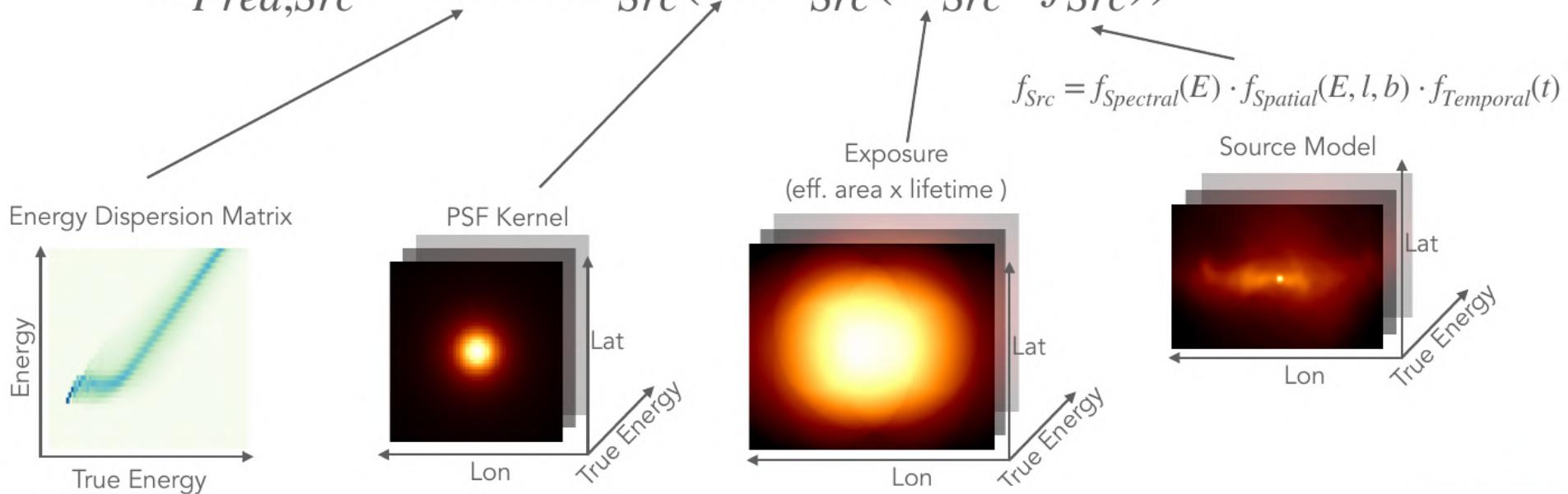


Data Model / Instrument Response



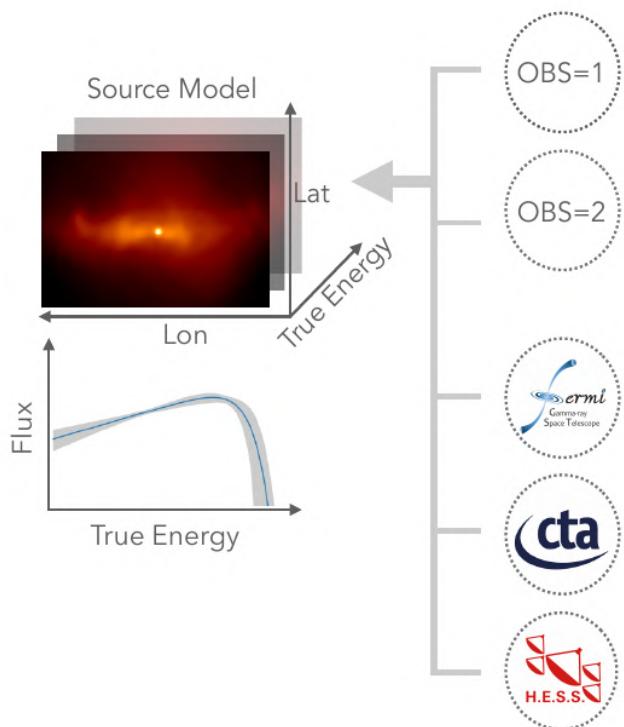
An analytical source model or template is
"forward folded" through the instrument response
function (IRF) to predict the measured
number of counts...

$$N_{Pred,Src} = \text{EDISP}_{Src}(\text{PSF}_{Src}(\mathcal{E}_{Src} \cdot f_{Src}))$$



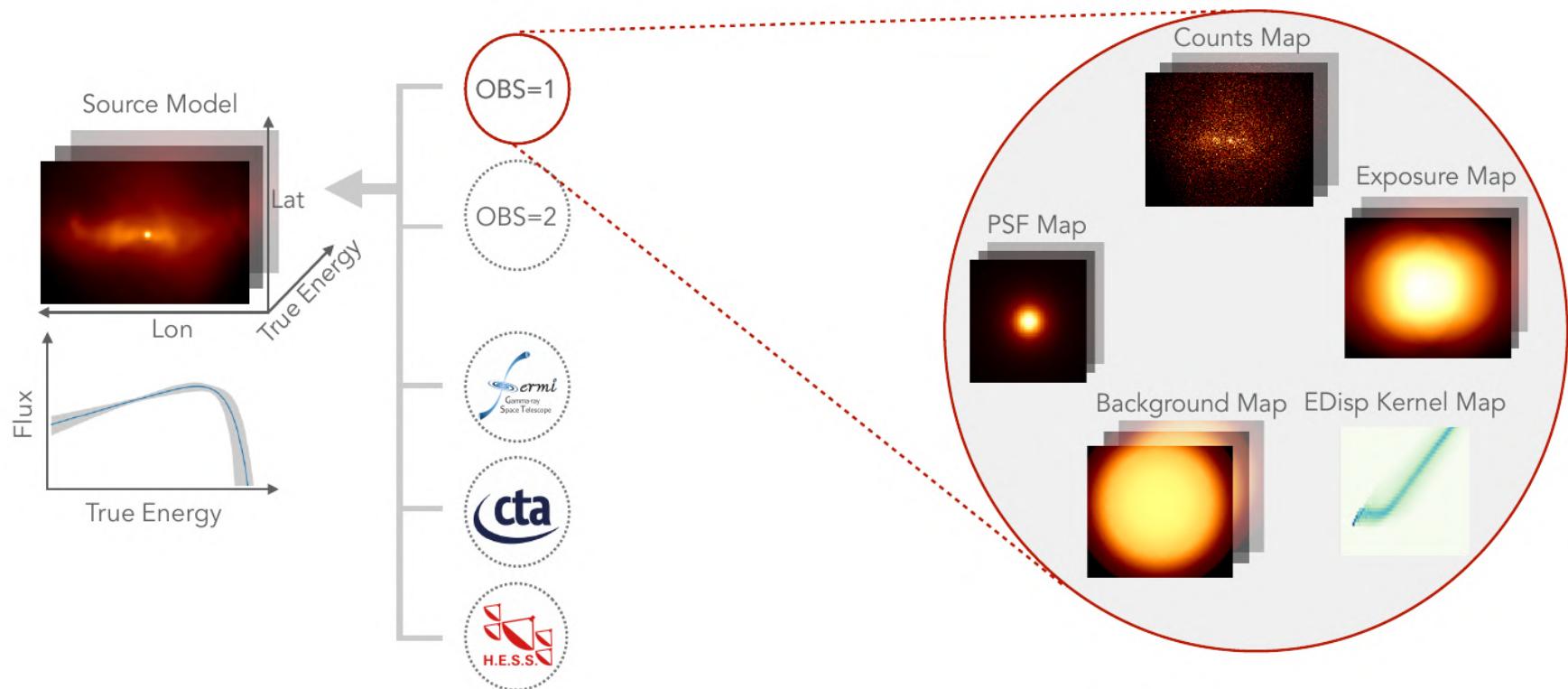


Joint Likelihood



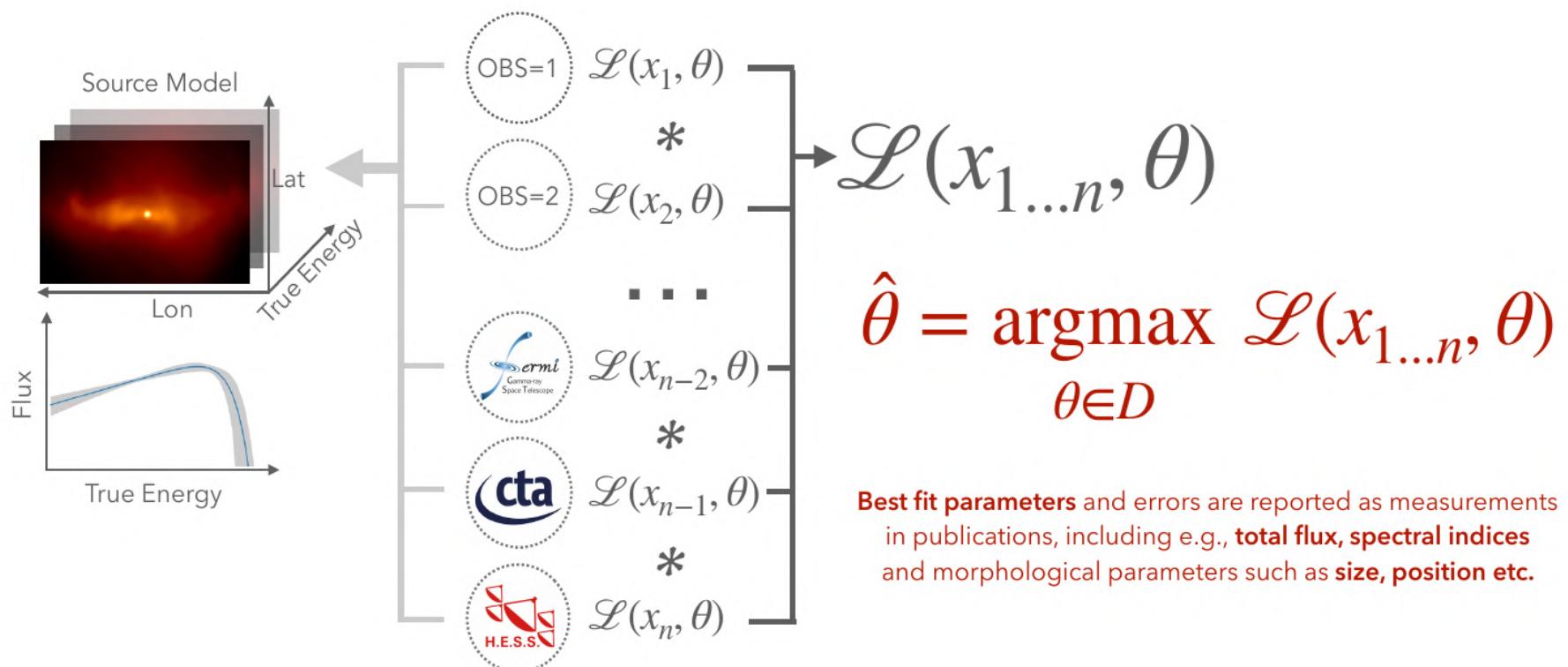


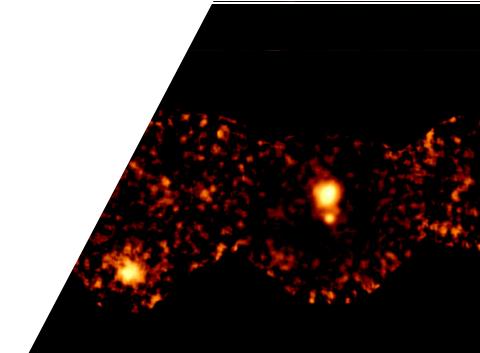
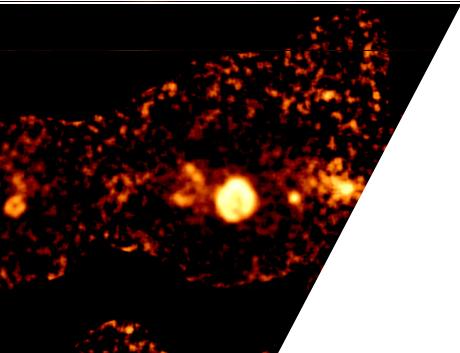
Joint Likelihood





Joint Likelihood





The Gammapy package



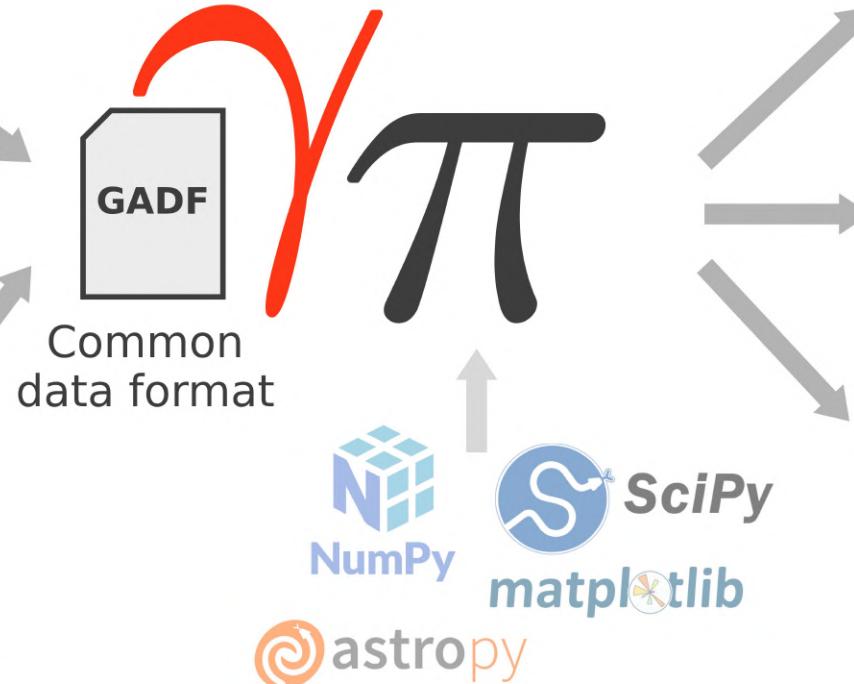
Main concept of Gammappy



Pointing γ -ray Observatories



All-sky γ -ray Observatories



V1.2rc1 released on Feb., 16th



Gammapy dependencies



Optional dependencies: bring in useful functionality

Pydantic

Configuration

PyYAML

YAML I/O

matplotlib

Plotting, visualisation

click_

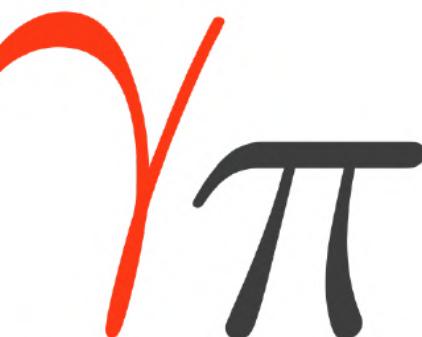
Command line tools

astropy

Coordinates, Quantities, Tables,
FITS I/O, etc.

Optional dependencies

Required dependencies



SciPy

Interpolation, minimisation,
FFT convolution, etc.
Gammapy - A.Donath - Scipy 2023



NumPy

ND-data structures
and computations



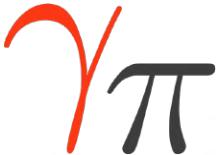
Optimisation, sampling

healpy

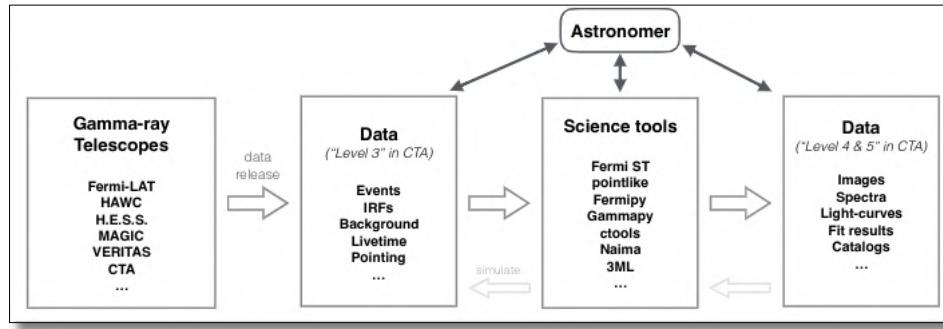
Healpix maps

jupyter

Tutorial notebooks



Read/Input format



The screenshot shows the homepage of the 'Data formats for gamma-ray astronomy' documentation. It includes a sidebar with links to About, General, Events, IRFs, Data storage, Sky Maps, Spectra, and Light curves. The main content area features the title 'Data formats for gamma-ray astronomy 0.3', a 'Data formats for gamma-ray astronomy' logo, and a brief description of the initiative. It lists the repository (<https://github.com/open-gamma-ray-astro/gamma-astro-data-formats>), documentation (<https://gamma-astro-data-formats.readthedocs.io>), and mailing list (<https://lists.nasa.gov/mailman/listinfo/open-gamma-ray-astro>). Below this are sections for References (listing a paper by Nigro et al. 2021) and Content (links to the same categories as the sidebar).

- The TeV γ -ray community agrees to use an open common format:
Gamma Astro Data Format (GADF)
 - Creation within an open initiative
- Define mainly 2 levels of data:
 - The DL3
 - The DL5 (partially)
- Format validated for Cherenkov telescopes and for Water detectors

Deil, C., et al., Proc. of 'Gamma 2016', DOI: [10.1063/1.4969003](https://doi.org/10.1063/1.4969003)
Deil, C., et al., Zenodo DOI: [10.5281/zenodo.1409830](https://zenodo.org/record/1409830)



Read/Input format

The screenshot shows the VODF website homepage. At the top, there is a navigation bar with links for "Context", "Data Model", "Data Format", "Tools", "Contributing", and "Contact". Below the navigation bar, the word "Astronomer" is displayed in a box. The main title "VODF" is prominently displayed in large, bold letters, with the subtitle "very-high-energy open data format" underneath. A note below the title states: "The *Very-high-energy Open Data Format*, VODF, is an open data model and format for Very-High-Energy (VHE) gamma-ray and neutrino astronomy. Its goal is to provide a standard set of file formats and standards for data starting at the reconstructed event level as well as higher-level products such as N-dimensional binned data cubes (including sky images, light curves, and spectra) and source catalogues. With these standards, common science tools can be used to analyze data from multiple high-energy instruments. VODF aims to follow as much as possible the IVOA standards." A sidebar on the left contains the letters "G", "T", and "C". A note at the bottom of the page says: "This web site is still under construction".

The VODF Working group

The VODF working group contains members from the following astronomical telescopes and observatories:

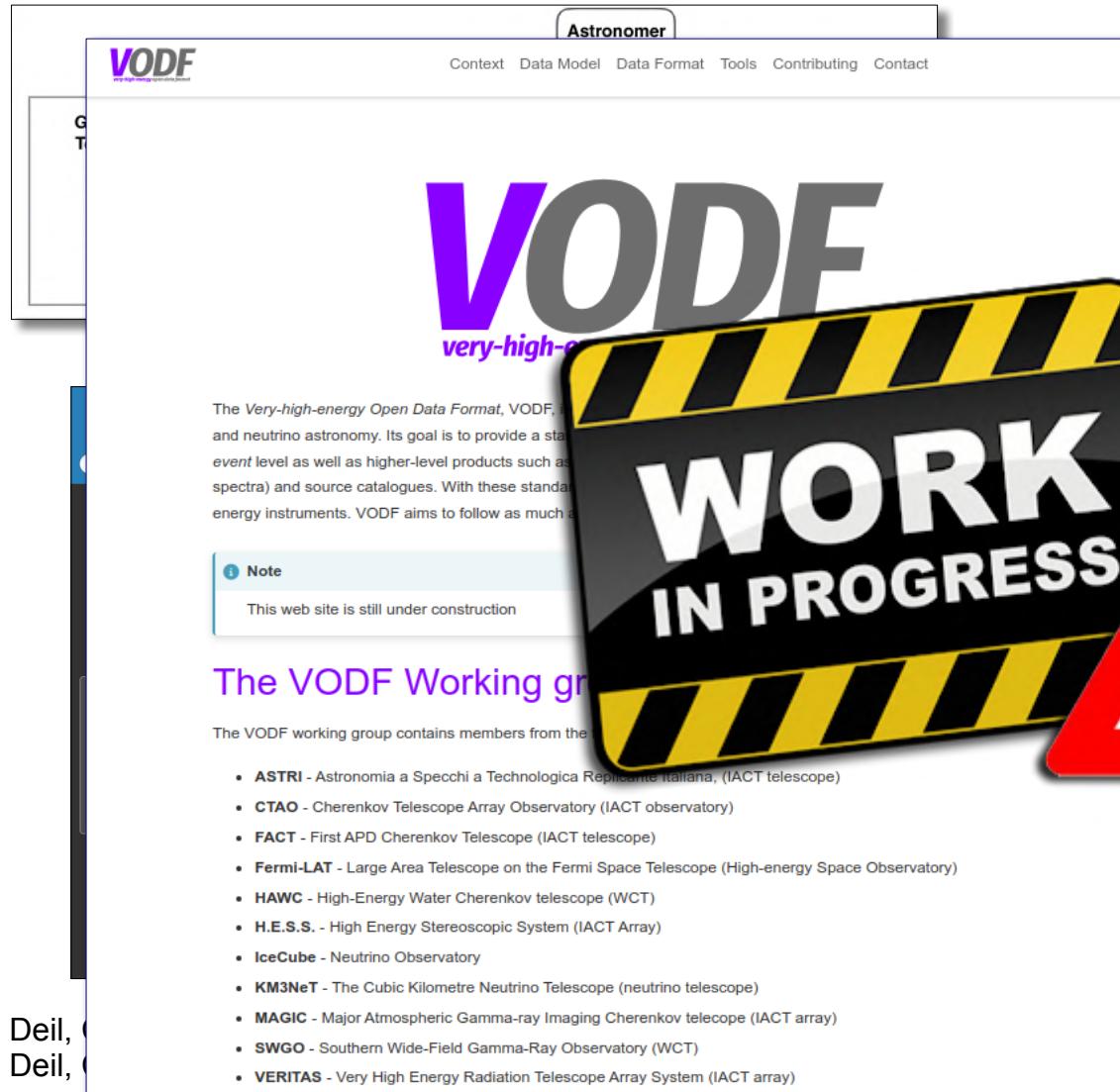
- **ASTRI** - Astronomia a Specchi a Technologica Replicante Italiana, (IACT telescope)
- **CTAO** - Cherenkov Telescope Array Observatory (IACT observatory)
- **FACT** - First APD Cherenkov Telescope (IACT telescope)
- **Fermi-LAT** - Large Area Telescope on the Fermi Space Telescope (High-energy Space Observatory)
- **HAWC** - High-Energy Water Cherenkov telescope (WCT)
- **H.E.S.S.** - High Energy Stereoscopic System (IACT Array)
- **IceCube** - Neutrino Observatory
- **KM3NeT** - The Cubic Kilometre Neutrino Telescope (neutrino telescope)
- **MAGIC** - Major Atmospheric Gamma-ray Imaging Cherenkov telescope (IACT array)
- **SWGO** - Southern Wide-Field Gamma-Ray Observatory (WCT)
- **VERITAS** - Very High Energy Radiation Telescope Array System (IACT array)

- The HE astroparticle community created an open initiative to create an open format for gamma and neutrino VHE data:
Very-high-energy Open Data Format (VODF)
 - 11 major experiments are on-board
- Aim to define 4 levels of data: DL3, DL4, DL5
 - FAIR compliant
 - Following IVOA recommendations

Khélifi, B., et al., Proc. of the 38th ICRC,
DOI: [10.48550/arXiv.2308.13385](https://arxiv.org/abs/2308.13385)



Read/Input format



The screenshot shows the VODF website homepage. At the top, there's a navigation bar with links for Context, Data Model, Data Format, Tools, Contributing, and Contact. Below the navigation, the VODF logo is prominently displayed with the text "very-high-energy Open Data Format". A large yellow and black "WORK IN PROGRESS" sign is overlaid on the page. On the left side, there's a sidebar with a "Note" section stating "This web site is still under construction". The main content area contains sections about the VODF Working group and a list of member organizations.

VODF
very-high-energy Open Data Format

The *Very-high-energy Open Data Format*, VODF, is an open initiative for the astroparticle community. It aims to provide a standard for data exchange in gamma and neutrino astronomy. Its goal is to provide a standard for data exchange at the event level as well as higher-level products such as spectra and source catalogues. With these standards, VODF aims to follow as much as possible the IVOA standard for astronomical data exchange. This will facilitate the use of VODF by major experiments both on-board and on-ground.

Note
This web site is still under construction

The VODF Working group

The VODF working group contains members from the following organizations:

- ASTRI - Astronomia a Specchi a Technologica Replicante Italiana, (IACT telescope)
- CTAO - Cherenkov Telescope Array Observatory (IACT observatory)
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- VERITAS - Very High Energy Radiation Telescope Array System (IACT array)

- The HE astroparticle community created an open initiative to create an open format for gamma and neutrino VHE data:

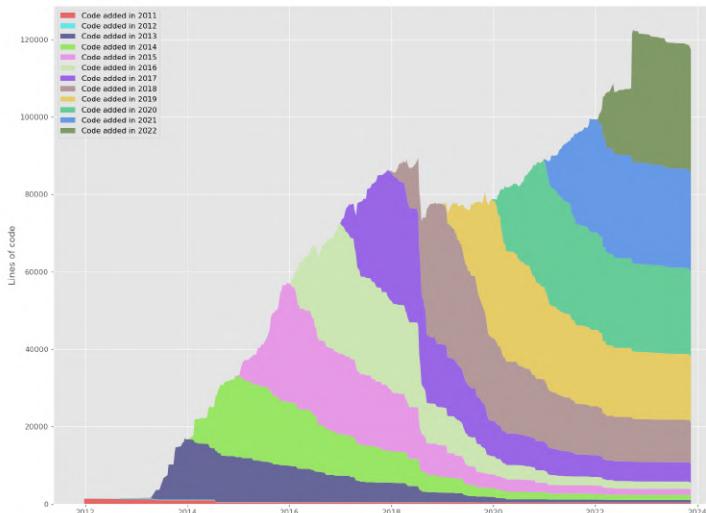
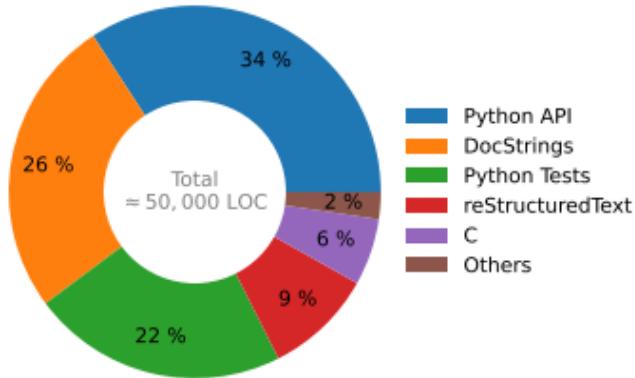
Very-high-energy Open Format (VODF)
major experiments on-board

fine 4 levels of
DL1, DL2, DL3, DL4, DL5

- FAIR compliant
- Following IVOA recommendations

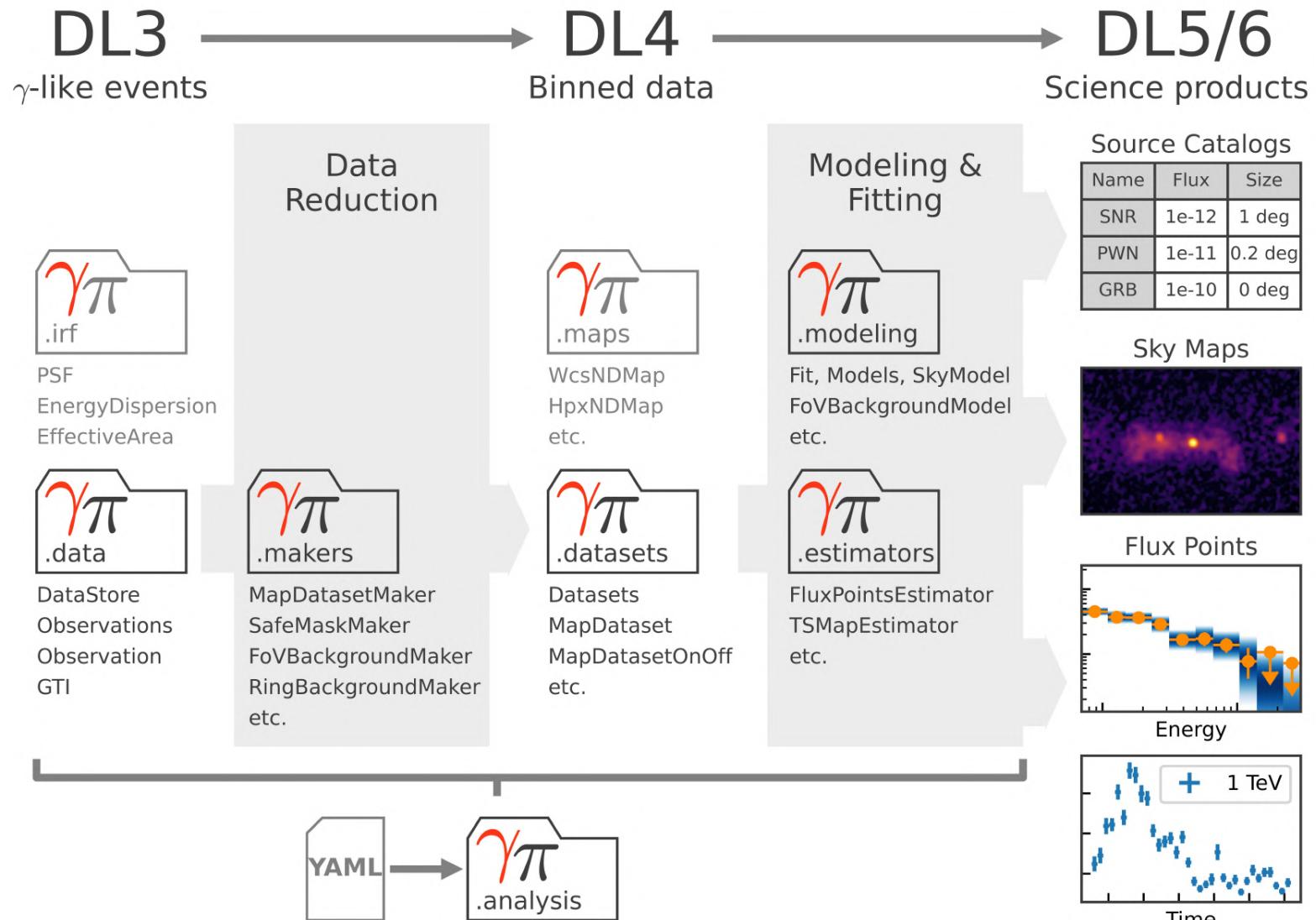
Khélifi, B., et al., Proc. of the 38th ICRC,
DOI: [10.48550/arXiv.2308.13385](https://arxiv.org/abs/2308.13385)

Some statistics



- We have achieved a healthy distribution of approximately 1/3 code, 1/3 docs and 1/4 tests
- Since its birth, in Aug. 19th 2013, the team made 33 tags, 24 releases including one long-term supported (LTS v1.0) and 10 Zenodo deposit

Data workflow and package structure





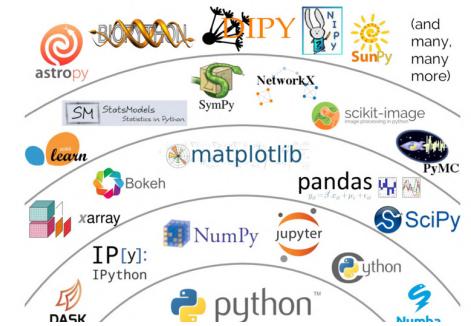
The organization of the Gammapy project



Open Python research software

- All the library and its associated repositories are freely accessible
- Contributions to the code are open to everyone
 - The Gammapy community is wide and diversified
- Written in Python, it benefits from a large ecosystem
 - The project is linked with many other software projects
- Although without legal structure, the project is supported by many laboratories, institutes and university
- And as the core library of the CTA Science Analysis Tool, it is widely used by students and researchers
 - An active user support is in place

Python in science today

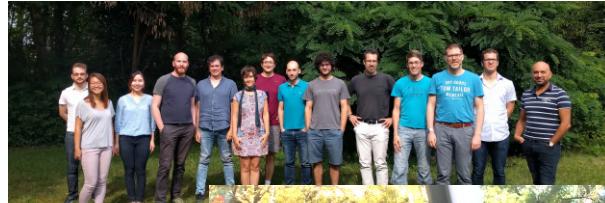




Well structured project



The teams of developers



Coordination Committee



Project Management



B. Khélifi
(APC)



C. van Eldik
(ECAP)

Lead Development



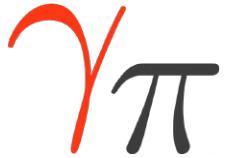
R. Terrier
(APC)



A. Donath
(CfA)



Development scheme



- Development repository:
[https://github.com/gammipy/](https://github.com/gammipy)
 - ~ GitHub actions to run the continuous integration
 - ~ Pytest used for testing
 - ~ Black, isort and Flake 8 to respect Python standards
- Documentation: <https://docs.gammipy.org/>
- Contributions
 - ~ Code, test functions and documentation
 - ~ Pull request reviews by at least 2 persons
- Developer call each Friday at 2pm (CET)





Recognition and valorization

PIG 24 - Authorship policy

- Authors: Bruno Khélifi, Thomas Vuillaume
- Created: May 25th, 2022
- Accepted: Oct. 20th, 2022
- Status: accepted
- Discussion: [GH 3970](#)

Abstract

Given that the Gammapy library is more widely used by the community, a proper citation of the project including a policy about the authorship is necessary. This PIG addresses this issue by setting an authorship policy for the Gammapy project for each type of products (releases, papers and conferences).

On this page

- Abstract
- Introduction
- Citation scheme
- Authorship policy
- Metadata files
- Possible implementations
- Suggestions
- Decision

- Each Gammapy release is an official publication
 - ~ The SWH/ZenodoDOI has an author list
- Technical papers on developments are very encouraged
- Each presentation, hands-on session, school is promoted

Following the Open Science recommendation
about academic evaluation

Gammapy Presentations

A collection of Gammapy presentations given at conferences, including posters and slides for talks.

Conference	Topics and Material	Contributors
Scipy 2023	Gammapy - slides talk	A. Donath et al.
ICRC 2023	Gammapy - poster	B. khélifi et al.
Gamma2022	Gammapy - talk	A. Sinha et al.

Gammapy hands-on sessions and schools

Disclaimer: list under construction! Please, do not hesitate to make a pull request in order to add your contribution..

Name	Material and links	Contributors
CTA Hands-on (Granada, 2023)	Hands-on	B. Khélifi, R. Terrier
ASTRI Hands-on (Palermo, 2022)	Hands-on	F. Pintore
ISAPP School (Orsay, 2022)	Hands-on	R. Terrier, F. Acero
CTA Hands-on (Bologna, 2022)	Hands-on	A. Sinha, L. Guinti
Hands-on (KU, 2022)	Hands-on	A. Sinha, R. Terrier
Thai-CTA workshop (Bangkok, 2021)	Hands-on	A. Sinha, B. Khélifi
Hands-on (Vaxjo, 2020)	Hands-on	B. Khélifi
CTA Hands-on (Lugano, 2019)	Hands-on (private)	A. Donath
CTA Hands-on (Berlin, 2018)	Hands-on (private)	A. Donath
CTA Hands-on (Orsay, 2018)	Hands-on (private)	C. Deil, R. Terrier, B. Khélifi
Hands-on (Meudon, 2017)	Hands-on	F. Acero, B. Khélifi
PyGamma15	Hands-on	C. Deil, A. Donath et al.



The documentation of Gammapy

See docs.gammipy.org



Getting started: documentation



Getting started User guide Tutorials API reference Developer guide Release notes dev [Q](#) [Twitter](#) [GitHub](#)

Search the docs ...

 A Python package for
gamma-ray astronomy

Gammapy

Date: Feb 09, 2024 Version: 1.3.dev0

Useful links: [Web page](#) | [Recipes](#) | [Discussions](#) | [Acknowledging](#) | [Contact](#)

Gammapy is a community-developed, open-source Python package for gamma-ray astronomy built on Numpy, Scipy and Astropy. It is the core library for the CTA Science Tools but can also be used to analyse data from existing imaging atmospheric Cherenkov telescopes (IACTs), such as H.E.S.S., MAGIC and VERITAS. It also provides some support for Fermi-LAT and HAWC data analysis.



Getting started

New to Gammapy? Check out the getting started documents. They contain information on how to install and start using Gammapy on your local desktop computer.

[To the quickstart docs](#)



User guide

The user guide provide in-depth information on the key concepts of Gammapy with useful background information and explanation, as well as tutorials in the form of Jupyter notebooks.

[To the user guide](#)



Tutorials

Interactive tutorials for Gammapy, including examples for point source detection, spectral analysis, and more.



Developer guide

Documentation for Gammapy's internal components, including the API reference, developer guides, and release notes.

B. Khélifi

23



Getting started: documentation



The screenshot shows the Gammapy documentation homepage. At the top, there's a navigation bar with links to 'Getting started', 'User guide', 'Tutorials', 'API reference', 'Developer guide', and 'Release notes'. There's also a 'dev' dropdown and social media icons. Below the navigation is a search bar labeled 'Search the docs ...'. The main content features the Gammapy logo and a brief introduction: 'A Python package for gamma-ray astronomy'. Below this, the title 'Gammapy' is displayed, along with the date ('Date: Feb 09, 2024') and version ('Version: 1.3.dev0'). A 'Useful links' section includes links to the 'Web page', 'Recipes', 'Discussions', 'Acknowledging', and 'Contact'. The main text describes Gammapy as a community-developed, open-source Python package for gamma-ray astronomy, built on Numpy, Scipy and Astropy. It mentions its use in CTA Science Tools and various telescopes like H.E.S.S., MAGIC, and VERITAS. It also supports Fermi-LAT and HAWC data analysis. Two main sections are shown: 'Getting started' (with a running person icon) and 'User guide' (with an open book icon). The 'User guide' section is highlighted with a large blue circle and a callout box containing the text 'slide between versions' with an arrow pointing to it. Below each section is a button: 'To the quickstart docs' for the first and 'To the user guide' for the second.

slide between versions



Getting started: documentation



Getting started User guide Tutorials API reference Developer guide Release notes 1.0.1

Search the docs ...

Gammappy analysis workflow and package structure

How To

Model gallery

Gammappy recipes ↗

Glossary and references

User guide

Analysis workflow and package structure

TO BE READ

To the package overview

How To

Some tips

To the How To

Model gallery

Gammappy provides a large choice of spatial, spectral and temporal models.

To the model gallery

Gammappy recipes

Collaborative exchanges

To the recipes



Getting started: documentation



The screenshot shows the Gammapy documentation website. At the top is a dark blue header bar with the logo $\gamma\pi$, navigation links for "Getting started", "User guide", "Tutorials", "API reference", "Developer guide", and "Release notes", a version dropdown set to "1.0.1", and social media icons for GitHub, Twitter, and LinkedIn.

Search bar (highlighted with a black box and an arrow pointing to it) is located at the top left of the main content area, above the search input field.

Powerful tool (highlighted with a black box) is located below the search bar.

The main content area contains six cards:

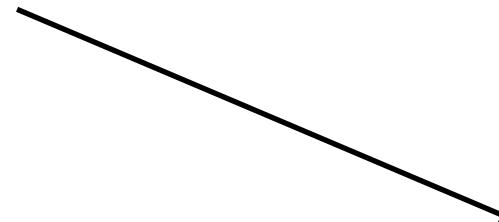
- Getting started**: Features a running icon. Description: "New to *Gammapy*? Check out the getting started documents. They contain information on how to install and start using *Gammapy* on your local desktop computer." Call-to-action button: "To the quickstart docs".
- User guide**: Features an open book icon. Description: "The user guide provide in-depth information on the key concepts of *Gammapy* with useful background information and explanation, as well as tutorials in the form of Jupyter notebooks." Call-to-action button: "To the user guide".
- API reference**: Features a [...] icon. Description: "The reference guide contains a detailed description of the *Gammapy* API. The reference describes how the methods work and which parameters can be used. It assumes that you have an understanding of the key concepts." Call-to-action button: "To the reference guide".
- Developer guide**: Features a >_ icon. Description: "Saw a typo in the documentation? Want to improve existing functionalities? The contributing guidelines will guide you through the process of improving *Gammapy*." Call-to-action button: "To the developer guide".

B. Kh
started/index.html



Getting started: documentation

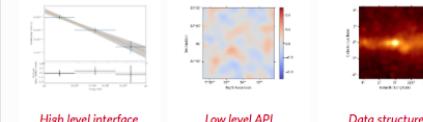
- Learning with examples: the [Tutorials](#)



Introduction

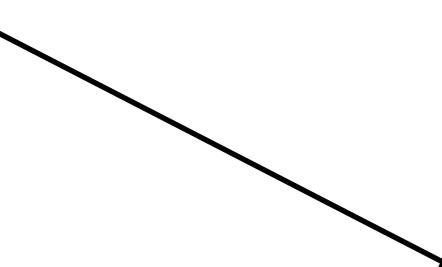
The following three tutorials show different ways of how to use Gammapy to perform a complete data analysis, from data selection to data reduction and finally modeling and fitting.

The first tutorial is an overview on how to perform a standard analysis workflow using the high level interface in a configuration-driven approach, whilst the second deals with the same use-case using the low level API and showing what is happening *under-the-hood*. The third tutorial shows a glimpse of how to handle different basic data structures like event lists, source catalogs, sky maps, spectral models and flux point tables.



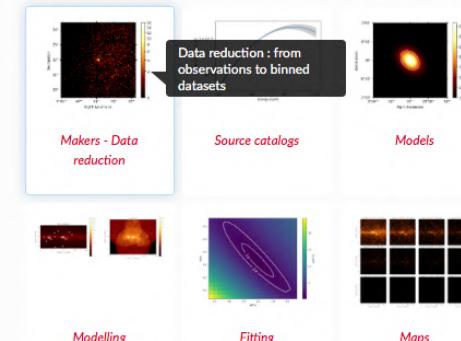
Data exploration

- More in depth: the [API description](#)



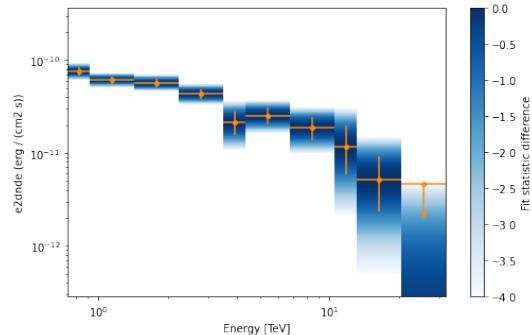
Package / API

The following tutorials demonstrate different dimensions of the Gammapy API or expose how to perform more specific use cases.

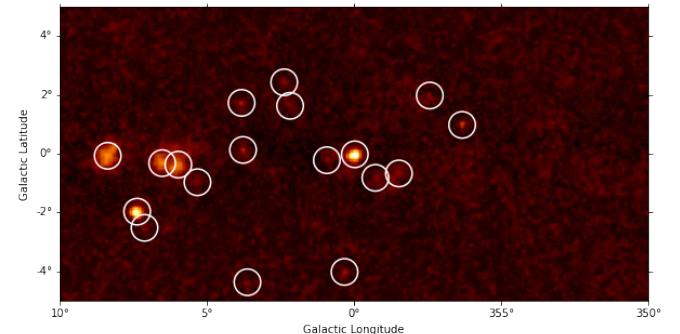




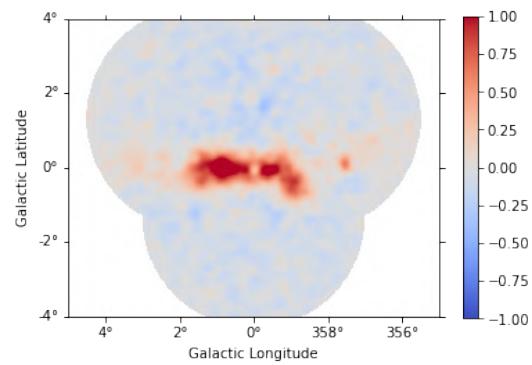
Typical analysis use cases



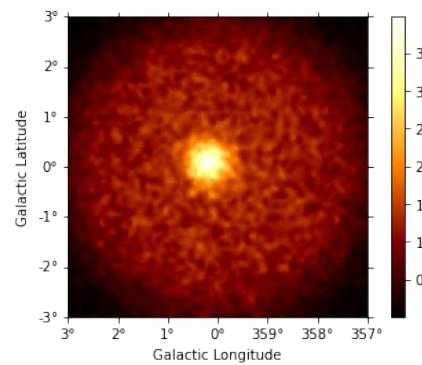
1D spectral analysis



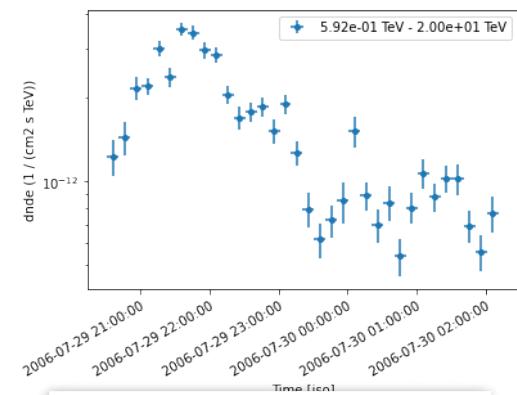
Source detection



3D analysis



Observation simulation



Light-curve extraction

All analysis types follow the same workflow and the same API

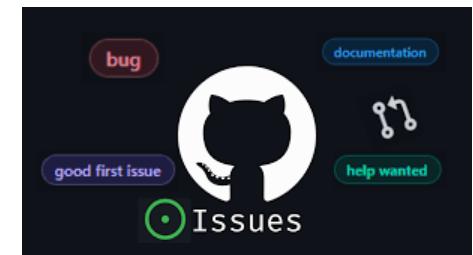


Getting help



- Where/How to interact with dev team and experienced users, provide feedback, get help:

- gammipy.slack
 - In particular: #help channel
- GitHub discussions
 - help category
- GitHub issues to report bugs or feature requests

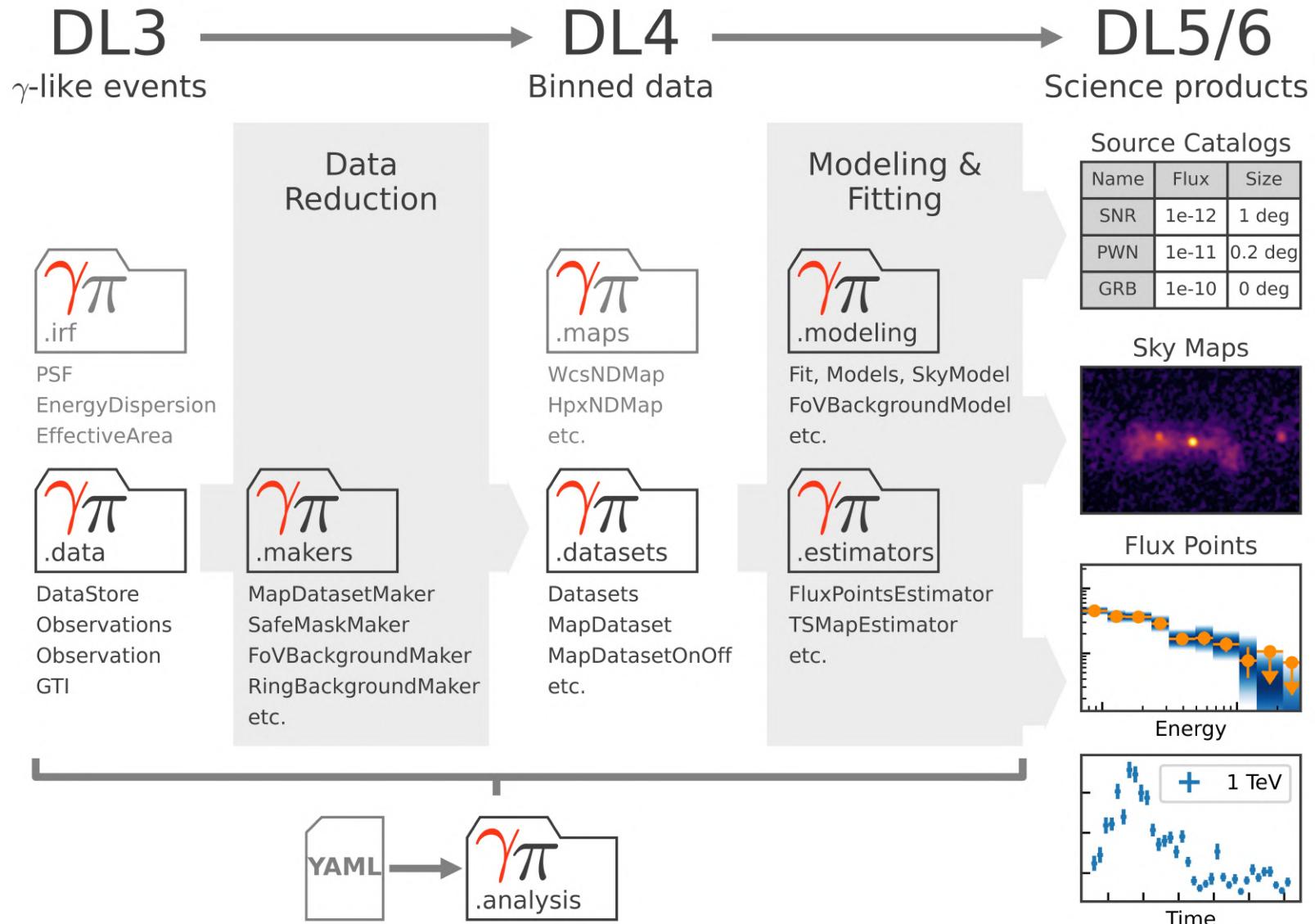




The Gammapy workflow



Data workflow and package structure



DL3 → DL4 → DL5/6

γ-like events Binned data Science products

2-step analysis procedure:

- data reduction (DL3 to DL4)
- data modelling / fitting (DL4 to DL5)

.irf

PSF
EnergyDispersion
EffectiveArea

.data

DataStore
Observations
Observation
GTI

.maps

WcsNDMap
HpxNDMap
etc.

.datasets

Datasets
MapDataset
MapDatasetOnOff
etc.

Data

Modeling &
Fitting

.modeling

Fit, Models, SkyModel
FoVBackgroundModel
etc.

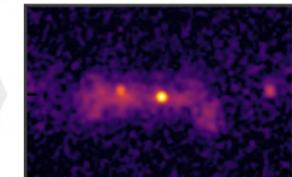
.estimators

FluxPointsEstimator
TSMapEstimator
etc.

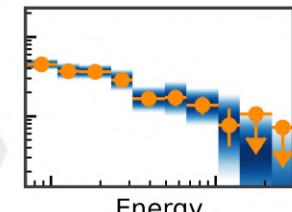
Source Catalogs

Name	Flux	Size
SNR	1e-12	1 deg
PWN	1e-11	0.2 deg
GRB	1e-10	0 deg

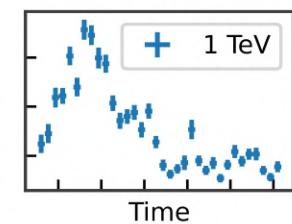
Sky Maps



Flux Points



1 TeV

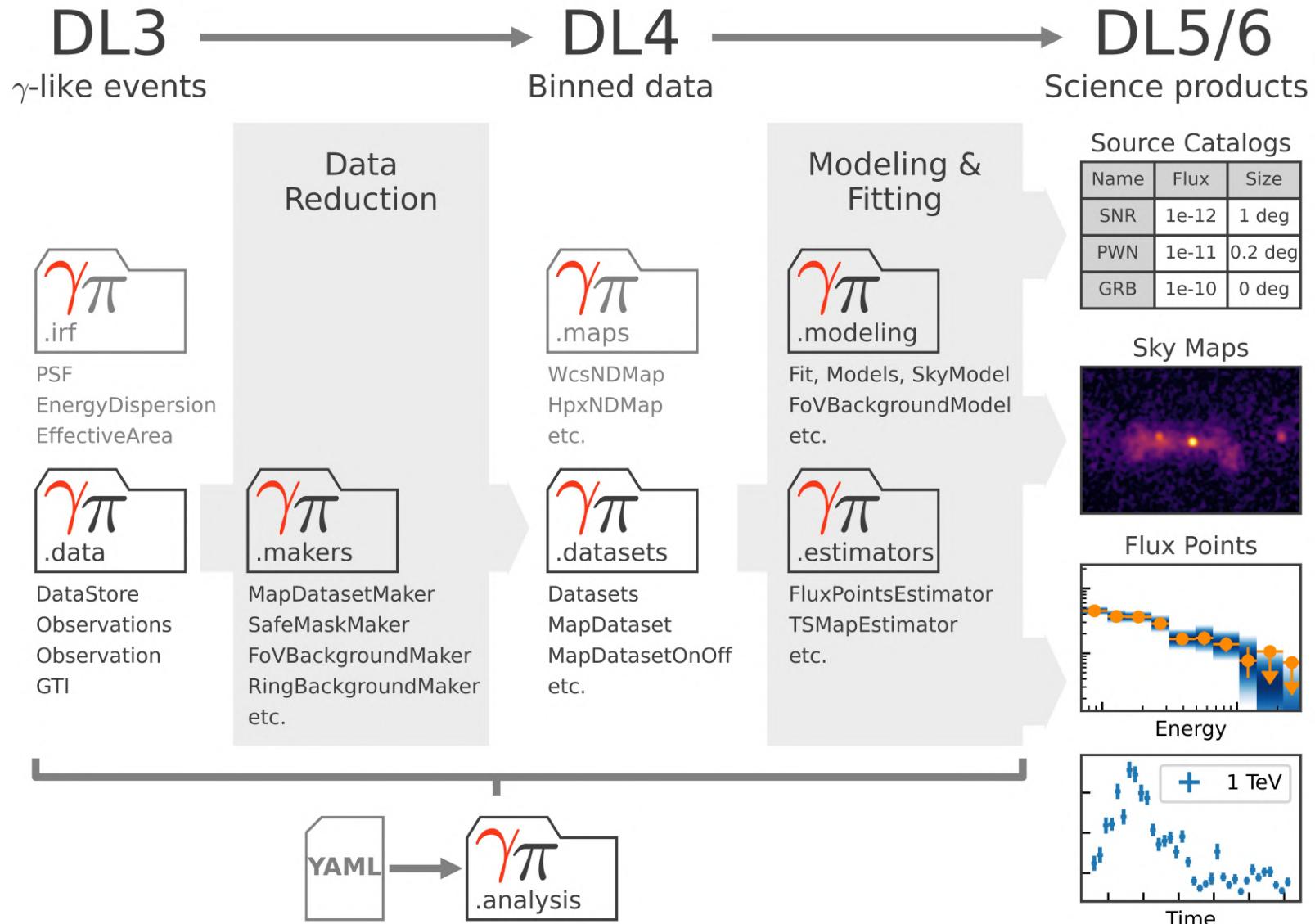


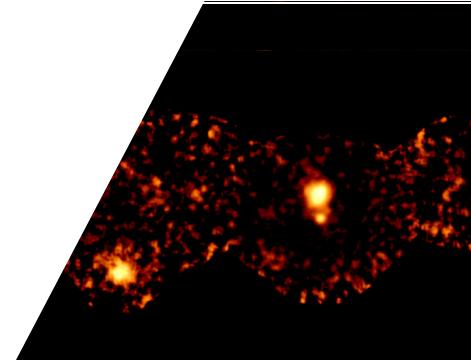
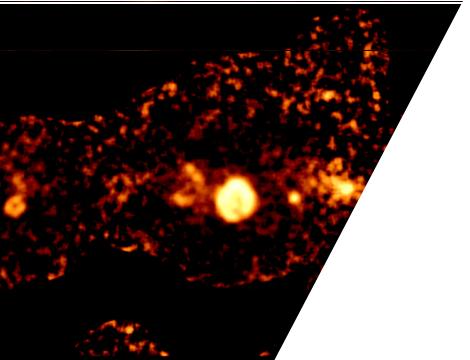
YAML

.analysis



Data workflow and package structure





From DL3 to DL4



The basic analysis steps

DL3 to DL4

1. Select and retrieve observations

- Datastore → list of Observation

See the backup slides...

DL4 to DL5



The basic analysis steps



DL3 to DL4

1. Select and retrieve observations
2. Define the reduced dataset geometry
 - Is the analysis 1D or 3D?
 - Define target binning and projection

DL4 to DL5

See the backup slides...

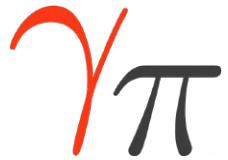


The basic analysis steps

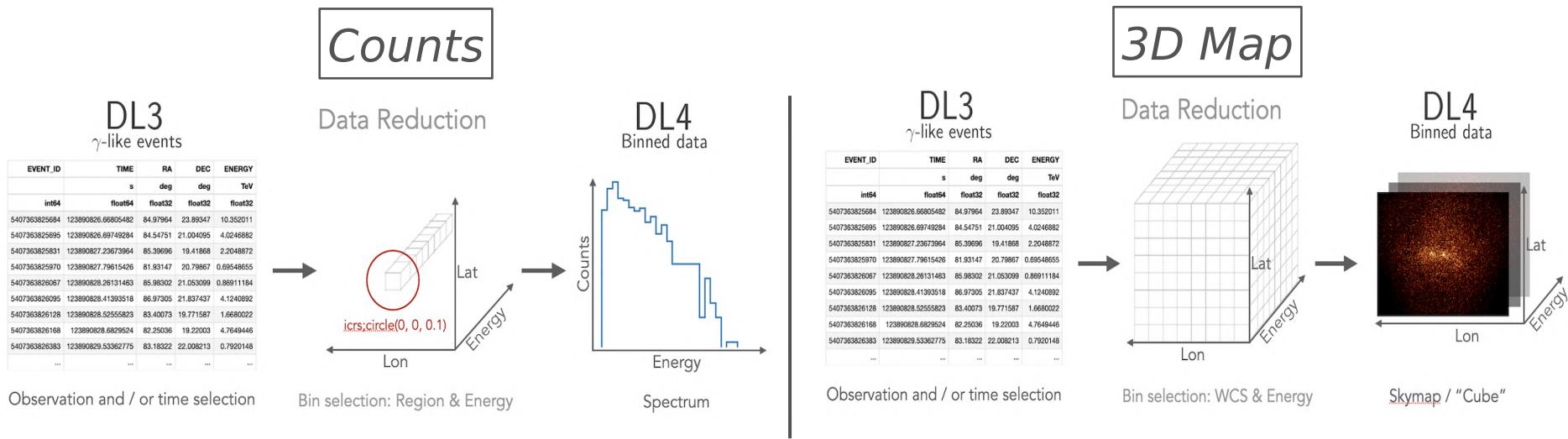
DL3 to DL4

1. Select and retrieve observations
2. Define the reduced dataset geometry
3. Initialize the data reduction methods ([makers](#))
 - Data and IRFs projection
 - Safe Mask determination
 - Background estimation

DL4 to DL5



Data and IRF re-projection

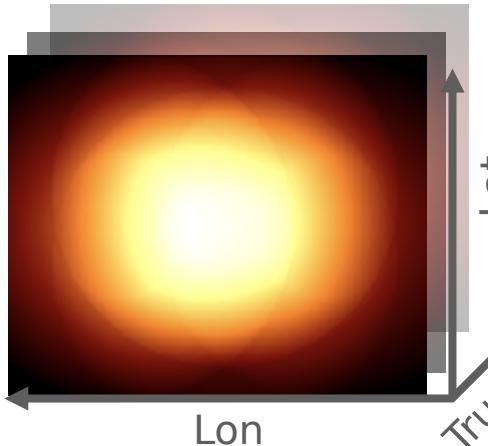


```
empty = MapDataset.create(  
    geom,  
    energy_axis_true=energy_true,  
    name="my-dataset")  
maker = MapDatasetMaker(selection=["exposure", "background", "psf", "edisp"])  
dataset = maker.run(empty, observation)
```

Reduced IRFs

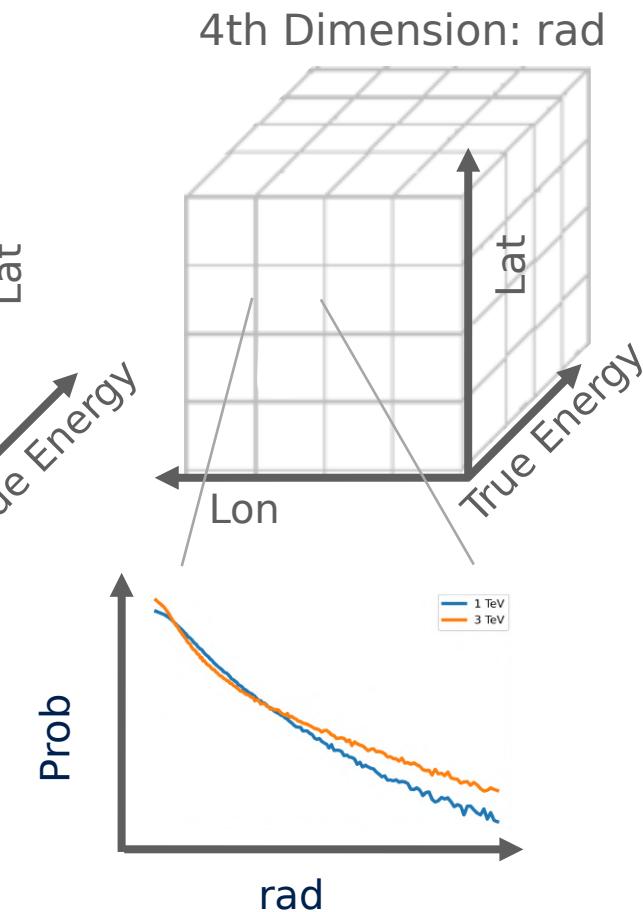
- DL3 IRFs are reprojected by the `DatasetMaker` on the target geometry

Exposure

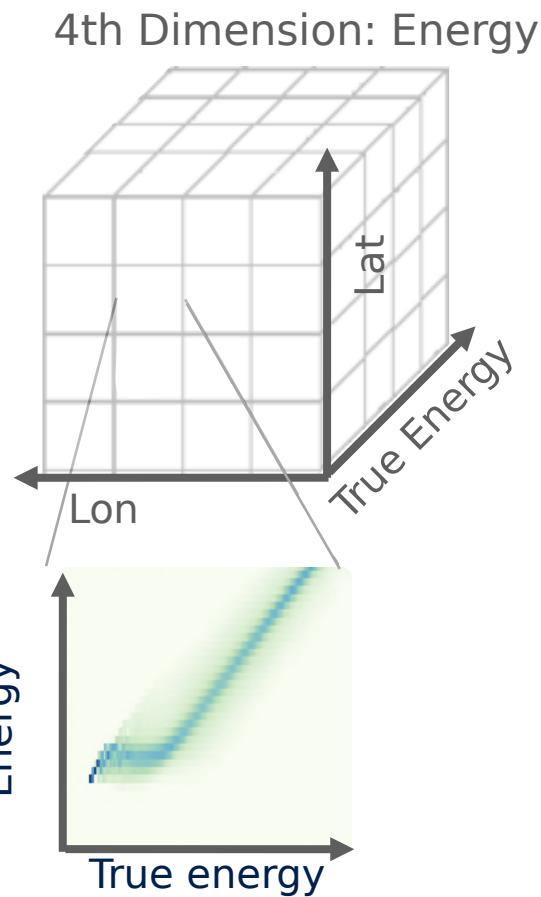


PSFMap /
EDispKernelMap

PSF



EDisp





The basic analysis steps



DL3 to DL4

1. Select and retrieve observations
2. Define the reduced dataset geometry
3. Initialize the data reduction methods ([makers](#))
 - Data and IRFs projection
 - Safe Mask determination
 - Background estimation

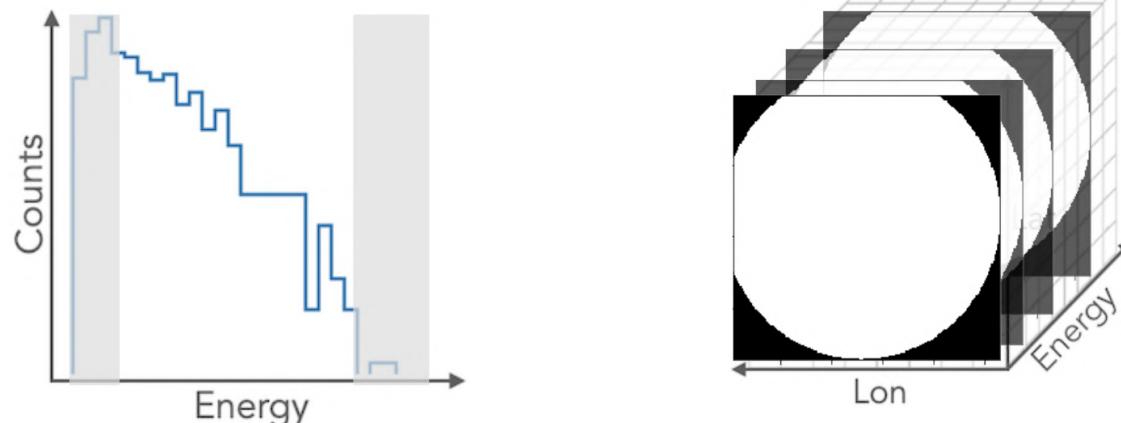
DL4 to DL5

It allows to restrict the analysis bins because of any of these reasons:

- restriction the phase space (statistics, sources)
- validity range of the IRFs (systematics)
- scaling of the bkg model to the data

SafeMaskMaker

SafeMask





The basic analysis steps



DL3 to DL4

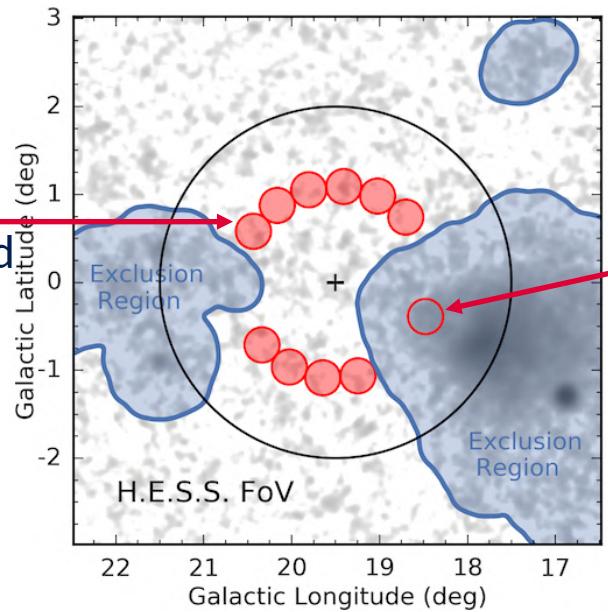
1. Select and retrieve observations
2. Define the reduced dataset geometry
3. Initialize the data reduction methods ([makers](#))
 - Data and IRFs projection
 - Safe Mask determination
 - Background estimation

DL4 to DL5

Correcting background from data

- To further reduce systematics or for the 1D analysis (spectrum), the background is sometimes measured directly in the data, e.g. in regions of the FoV where the background is assumed to be identical
 - Common approach used for 1D spectral analysis
 - e.g. reflected regions or wobble regions background

OFF regions
containing only background



ON region
containing signal and background

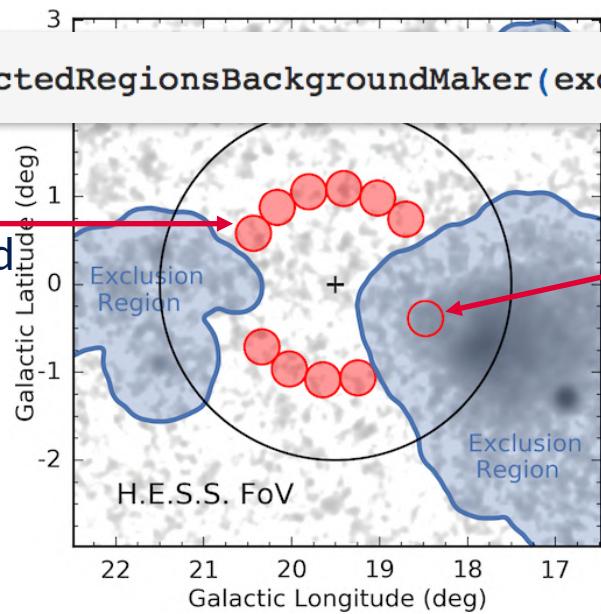
Correcting background from data

- To further reduce systematics or for the 1D analysis (spectrum), the background is sometimes measured directly in the data, e.g. in regions of the FoV where the background is assumed to be identical
 - Common approach used for 1D spectral analysis
 - e.g. reflected regions or wobble regions background

```
bkg_maker = ReflectedRegionsBackgroundMaker(exclusion_mask=exclusion_mask)
```

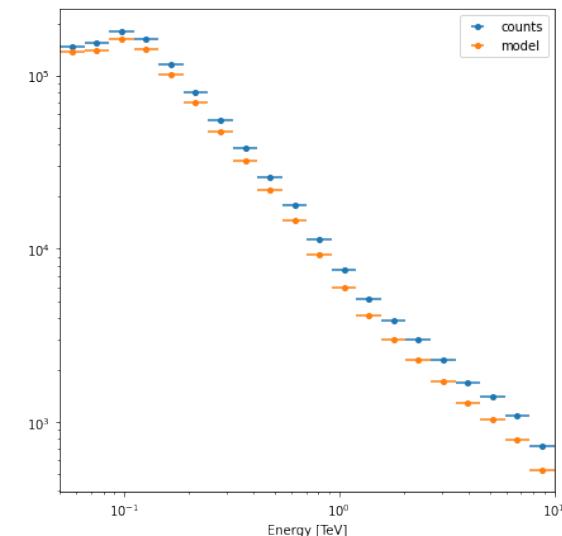
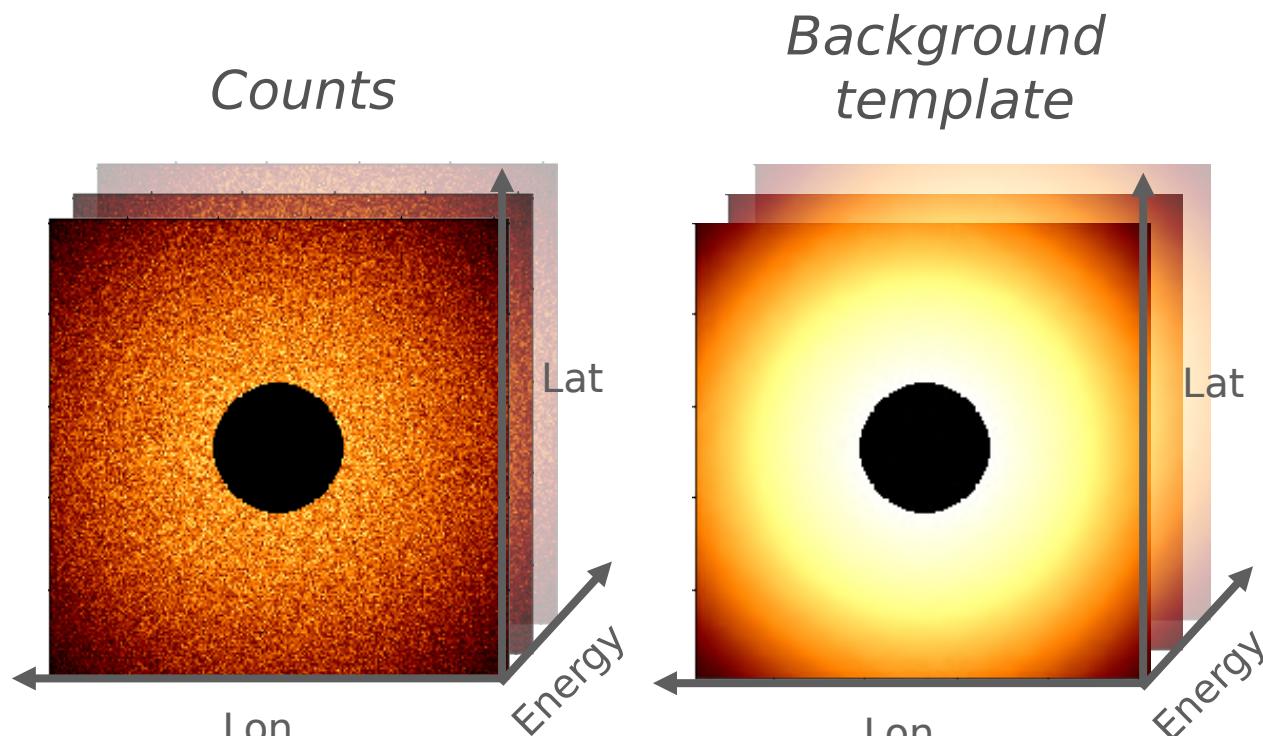
OFF regions containing only background

ON region containing signal and background



Correcting background from data

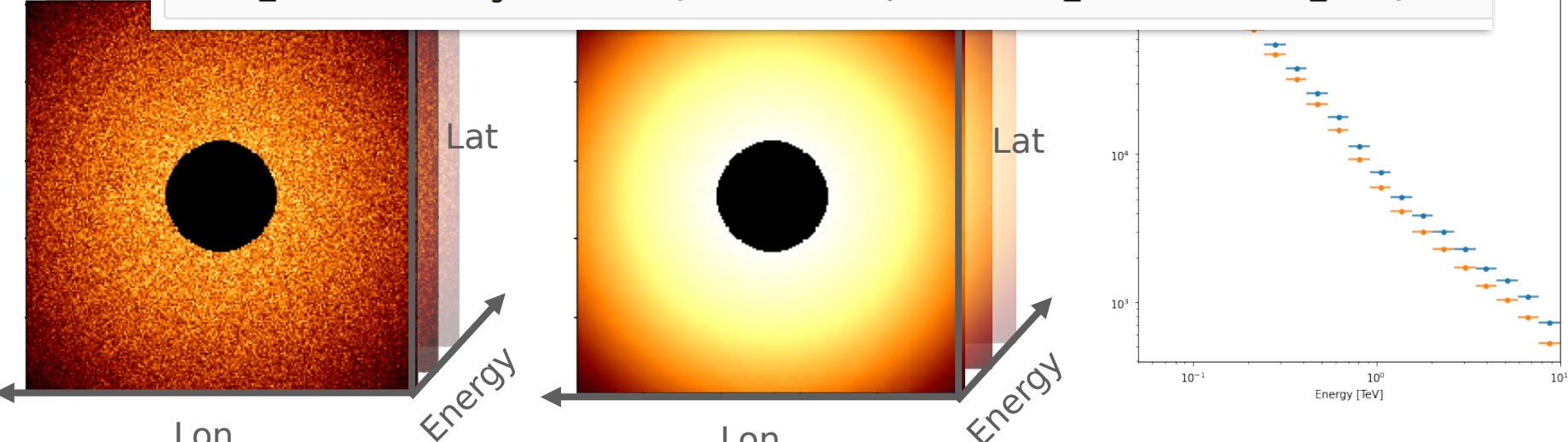
- $BKG(p, E)$ is usually corrected on the observed data themselves.
 - Field of View (FoV) background estimation: `FoVBackgroundModel` adjusted with the `FoVBackgroundMaker`
 - $BKG(p, E)$ is normalized in regions devoid of signal



Correcting background from data

- $BKG(p, E)$ is usually corrected on the observed data themselves.
 - Field of View (FoV) background estimation
 - $BKG(p, E)$ is normalized in regions devoid of signal

```
circle = CircleSkyRegion(
    center=SkyCoord("83.63 deg", "22.14 deg"), radius=0.2 * u.deg
)
exclusion_mask = ~geom.region_mask(regions=[circle])
maker_fov = FoVBackgroundMaker(method="fit", exclusion_mask=exclusion_mask)
```





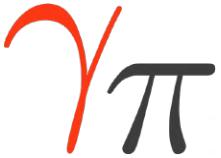
The basic analysis steps



DL3 to DL4

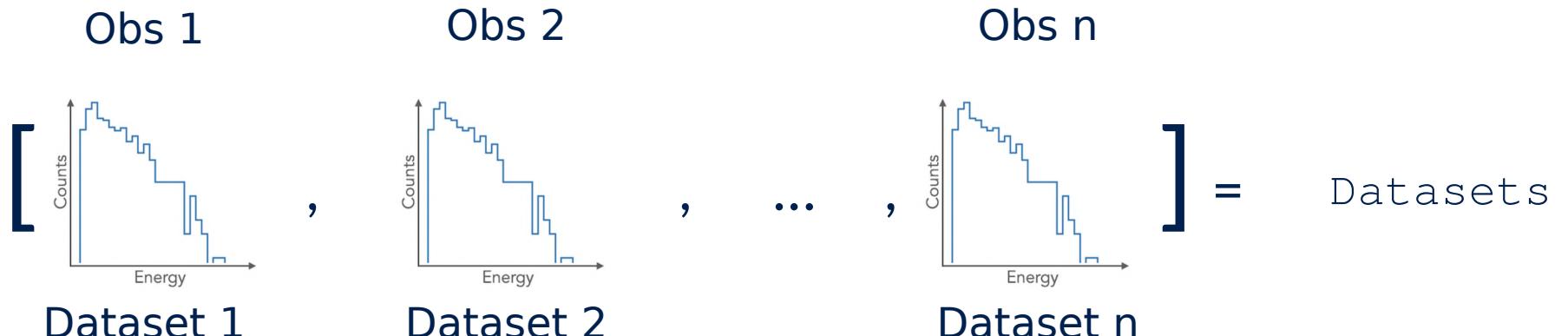
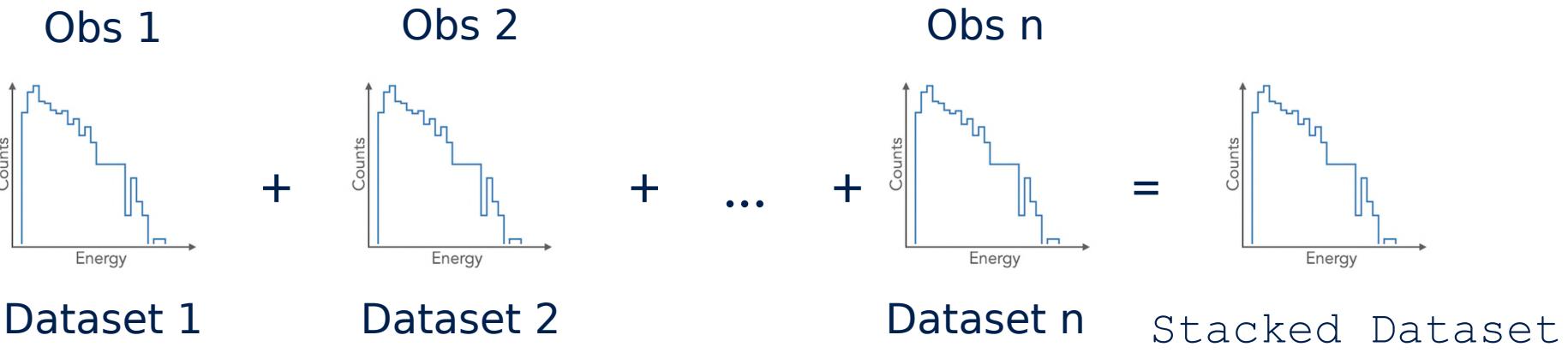
1. Select and retrieve observations
2. Define the reduced dataset geometry
3. Initialize the data reduction methods ([makers](#))
4. Loop over selected observations
 - Apply makers to produce [reduced datasets](#)
 - Combine them for [stacked](#) or [joint analysis](#)

DL4 to DL5



Loop over observations

- Apply makers to produce reduced datasets
- Combine them for stacked or joint analysis





The basic analysis steps: overview of the Data Reduction

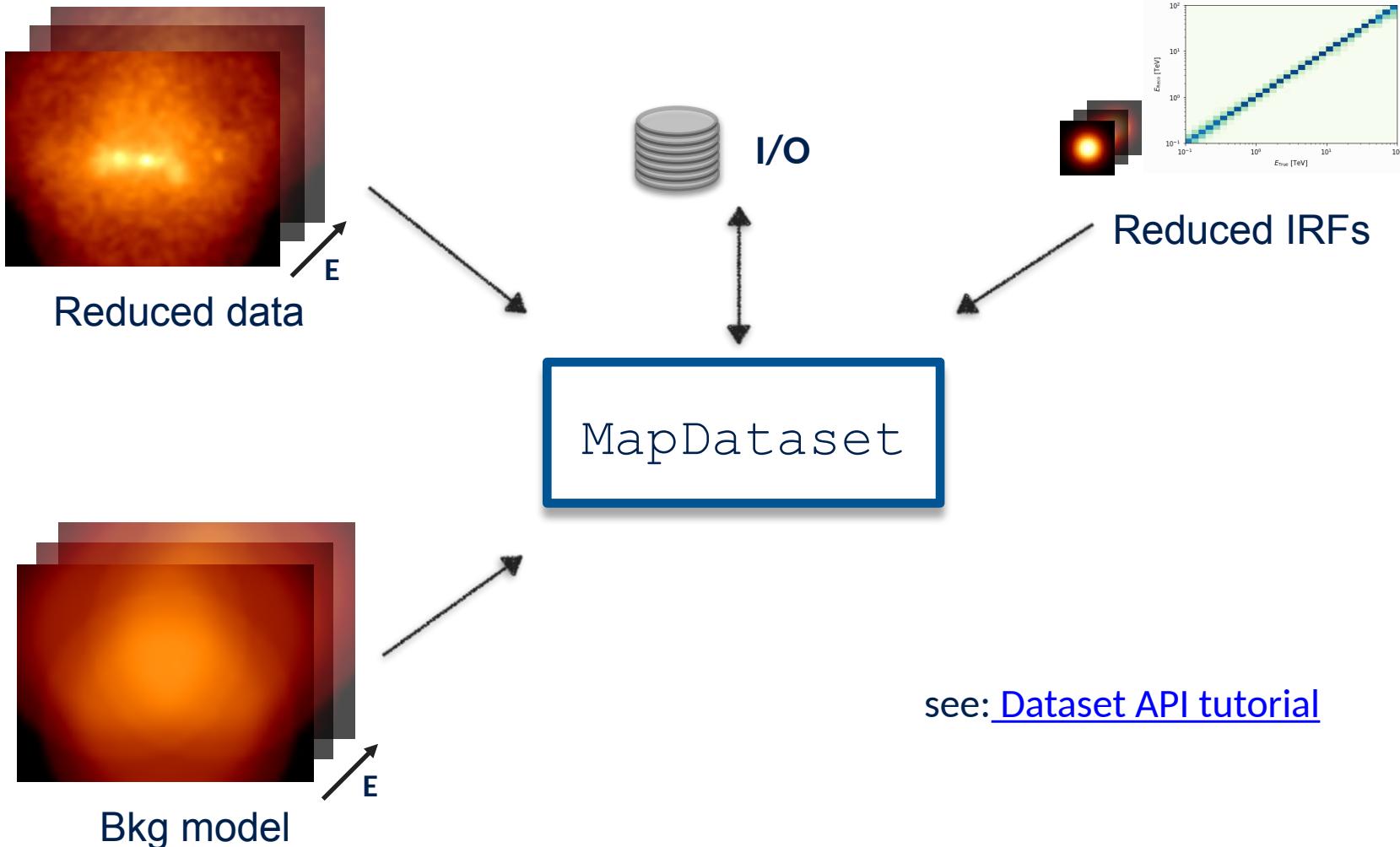


DL3 to DL4

1. Select and retrieve observations
 - Datastore → list of Observation
2. Define the reduced dataset geometry
 - Is the analysis 1D or 3D?
 - Define target binning and projection
3. Initialize the data reduction methods ([makers](#))
 - Data and IRF projection
 - Safe Mask determination
 - Background estimation
4. Loop over selected observations
 - Apply makers to produce [reduced datasets](#)
 - Combine them for [stacked](#) or [joint analysis](#)

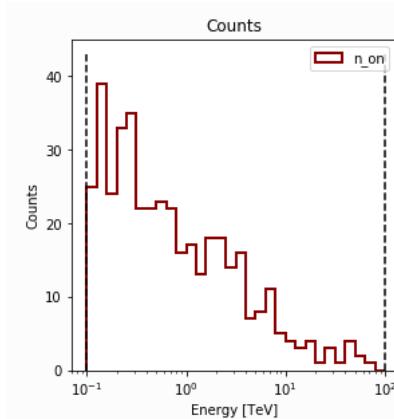


DL4 structures: Datasets

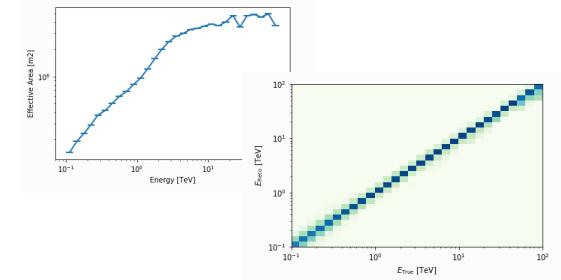
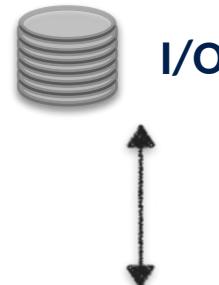




DL4 structures: Datasets

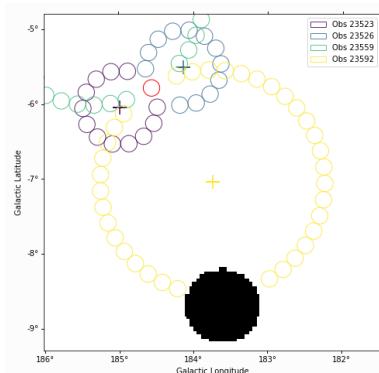


Reduced data



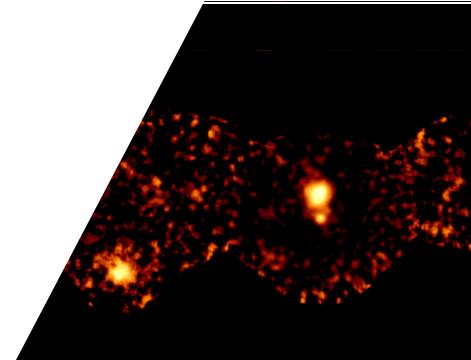
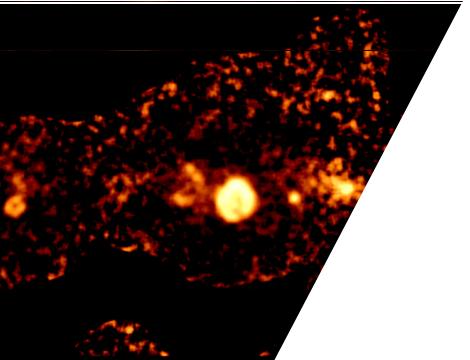
Reduced IRFs

SpectrumDataset

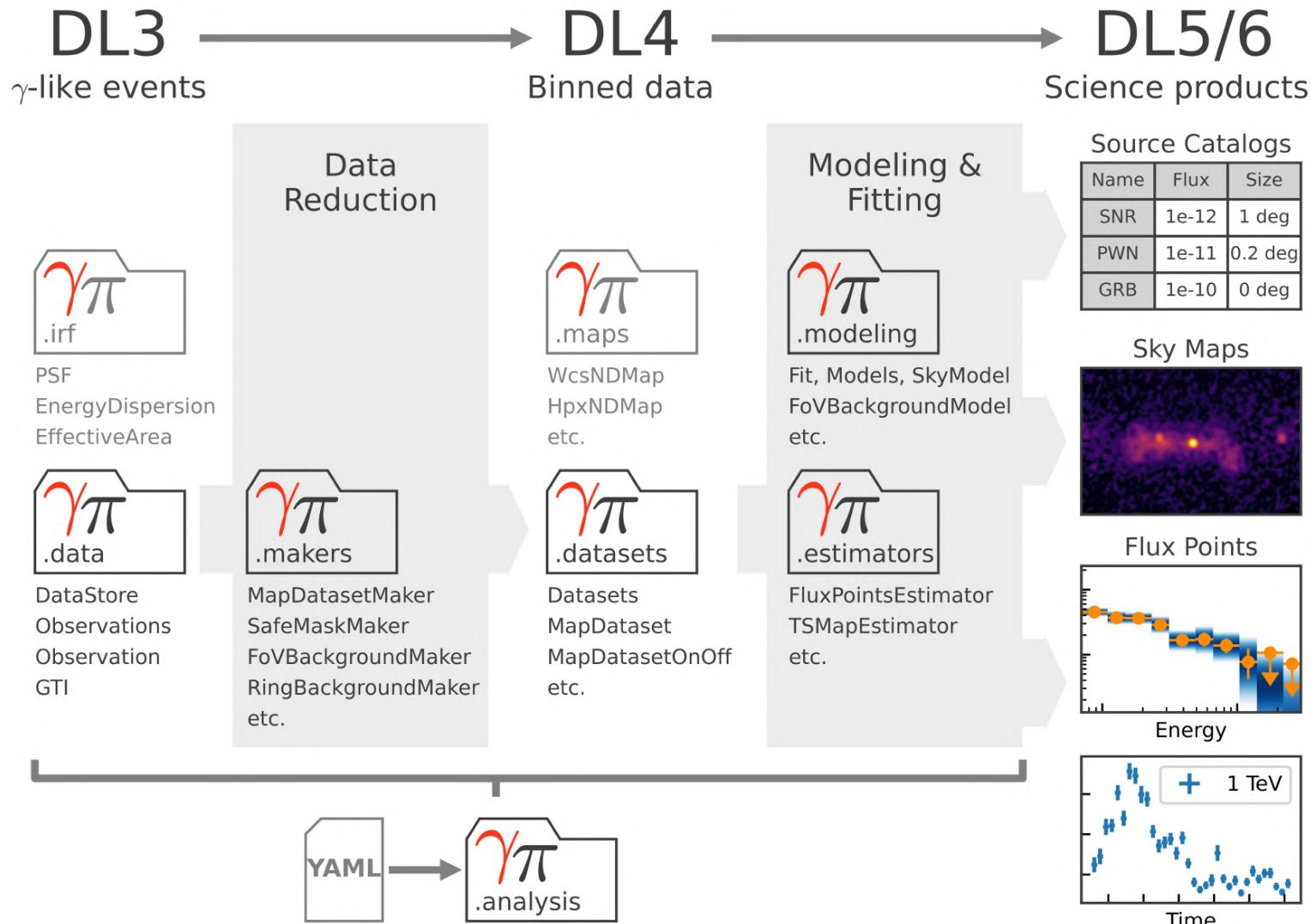


Bkg data or model

see: [Dataset API tutorial](#)



From DL4 to DL5

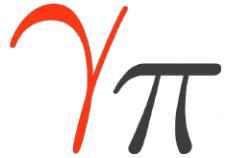




DL4 to DL5: Modelling and fitting



- For modelling and fitting, Gammipy relies on ***forward-folding***:
 - Measured counts is compared to predicted counts
- Model parameter estimation is performed through maximum likelihood technique:
 - Cash statistics is used for counts data with a known background
 - Wstat statistics is used for counts data with a measured background



The basic analysis steps

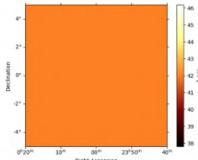
DL3 to DL4

1. Select and retrieve observations
2. Define the reduced dataset geometry
3. Initialize the data reduction methods ([makers](#))
4. Loop over selected observations

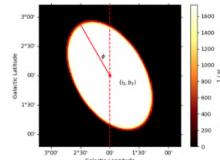
DL4 to DL5

1. Modelling
 - Define your model(s)
 - For the 3D analysis, add a final FoVBackgroundModel
 - Associate them/it to the correct dataset (or several)

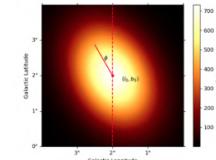
Datasets modelling and fitting



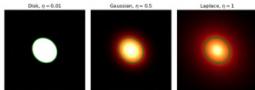
Constant spatial model



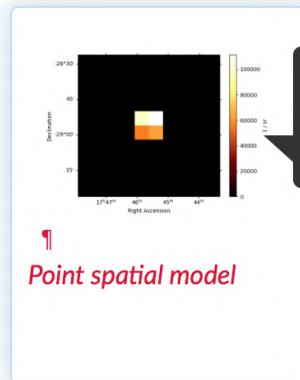
Disk spatial model



Gaussian spatial model



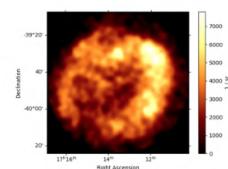
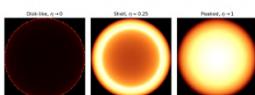
Generalized gaussian spatial model



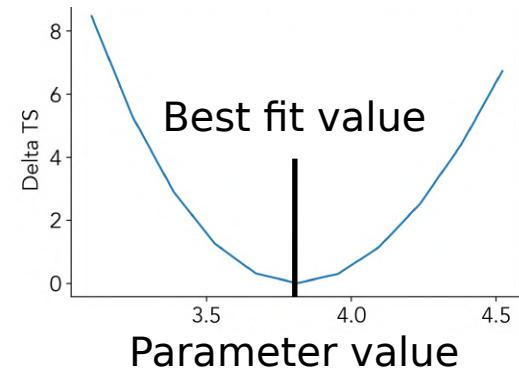
Point spatial model

This model is a delta function centered in *lon_0* and *lat_0* parameters provided:

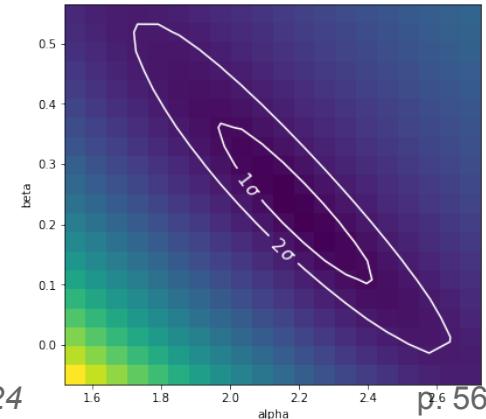
Shell spatial model



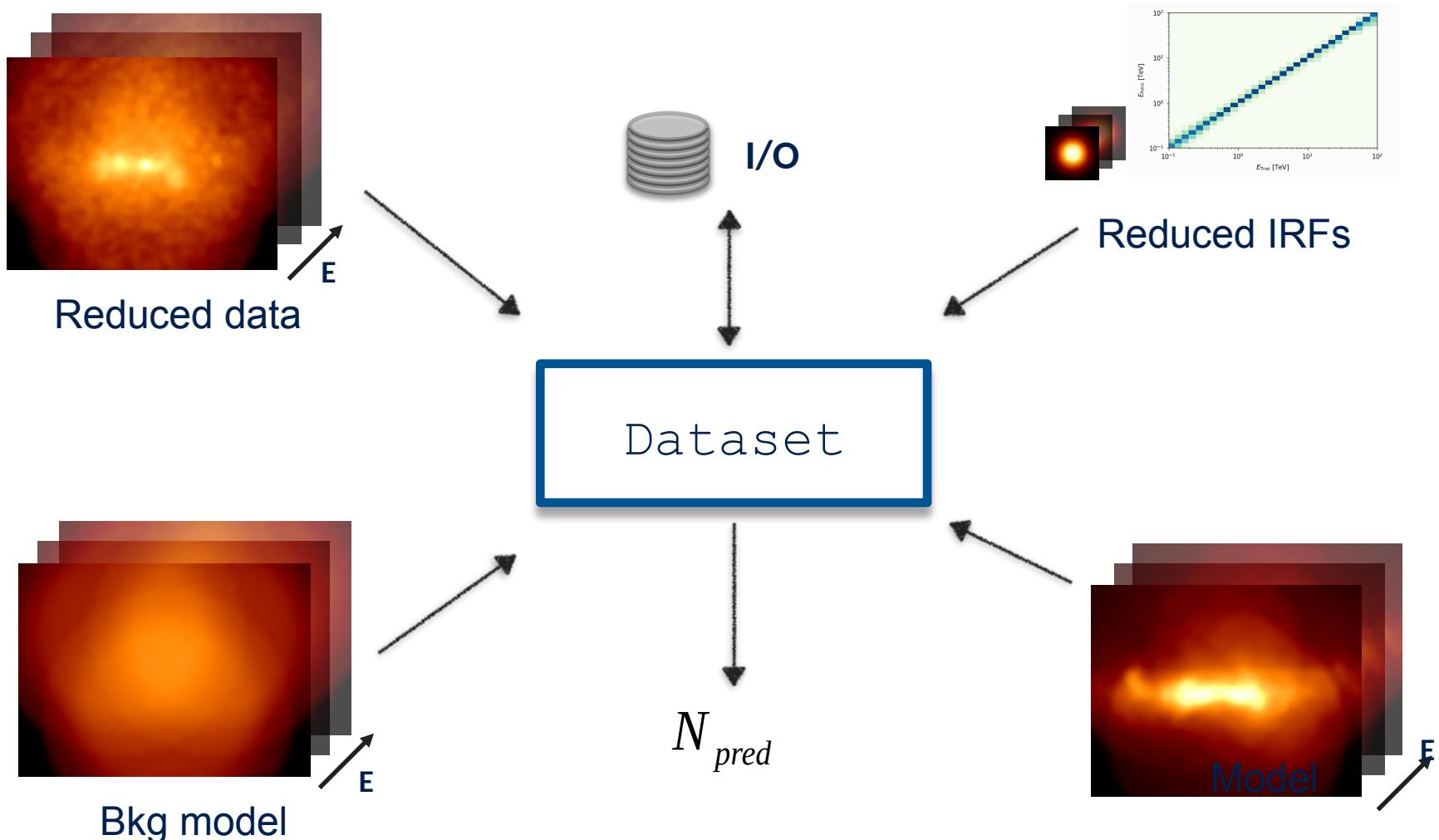
A library of models and a Fitting interface



Parameter value

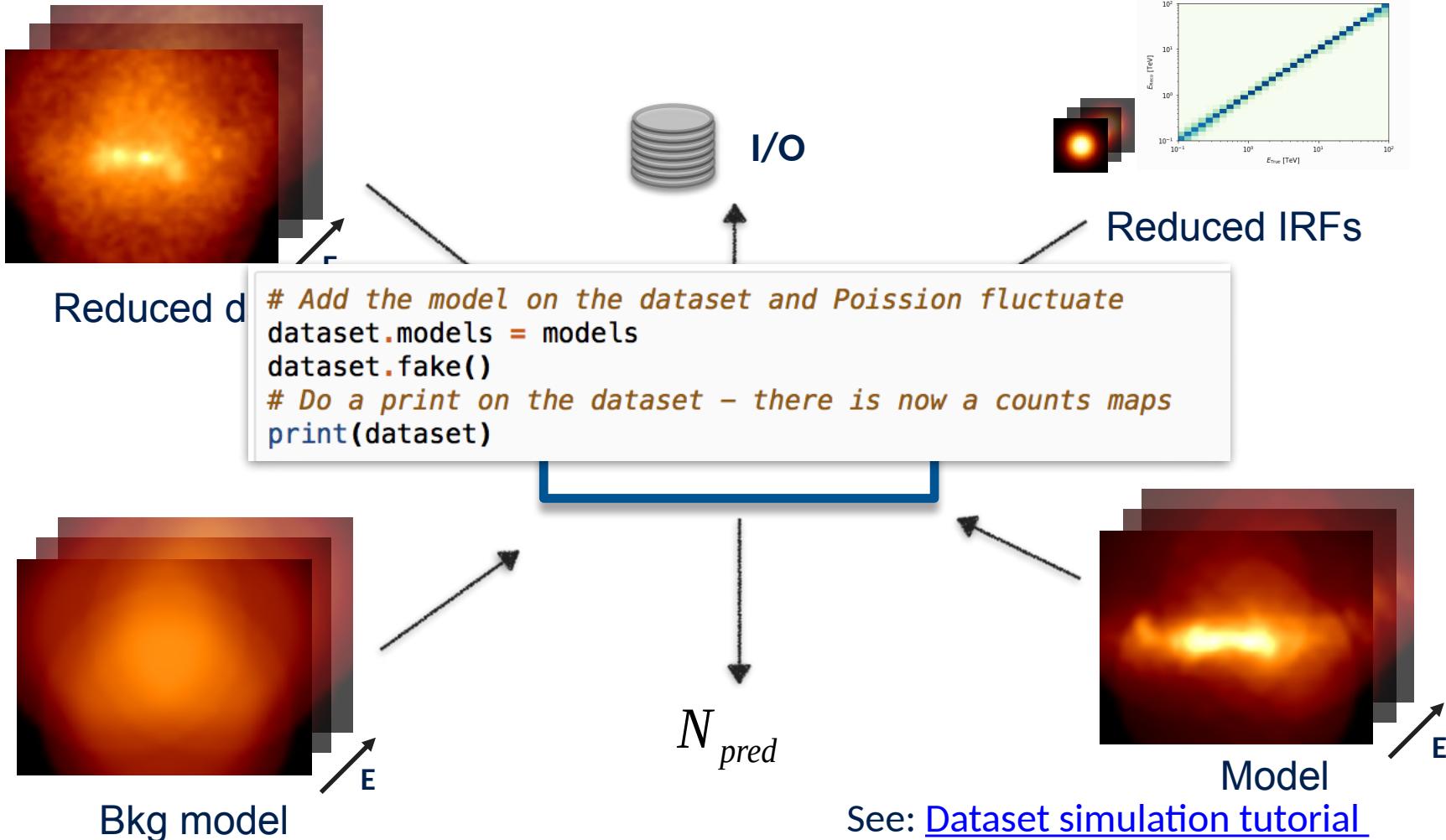


Datasets modelling and fitting

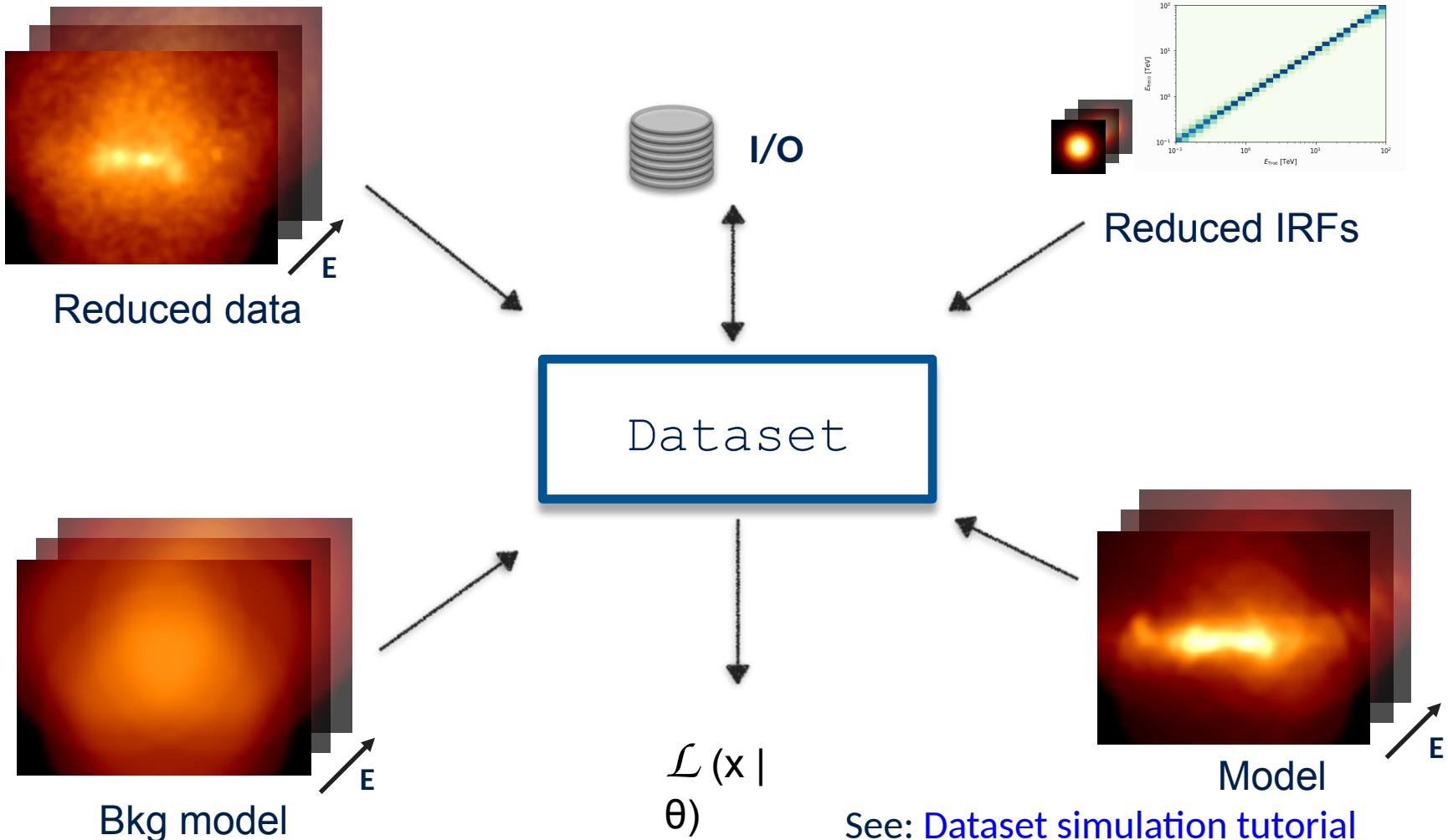


See: [Dataset simulation tutorial](#)

Datasets modelling and fitting



Datasets modelling and fitting





The basic analysis steps



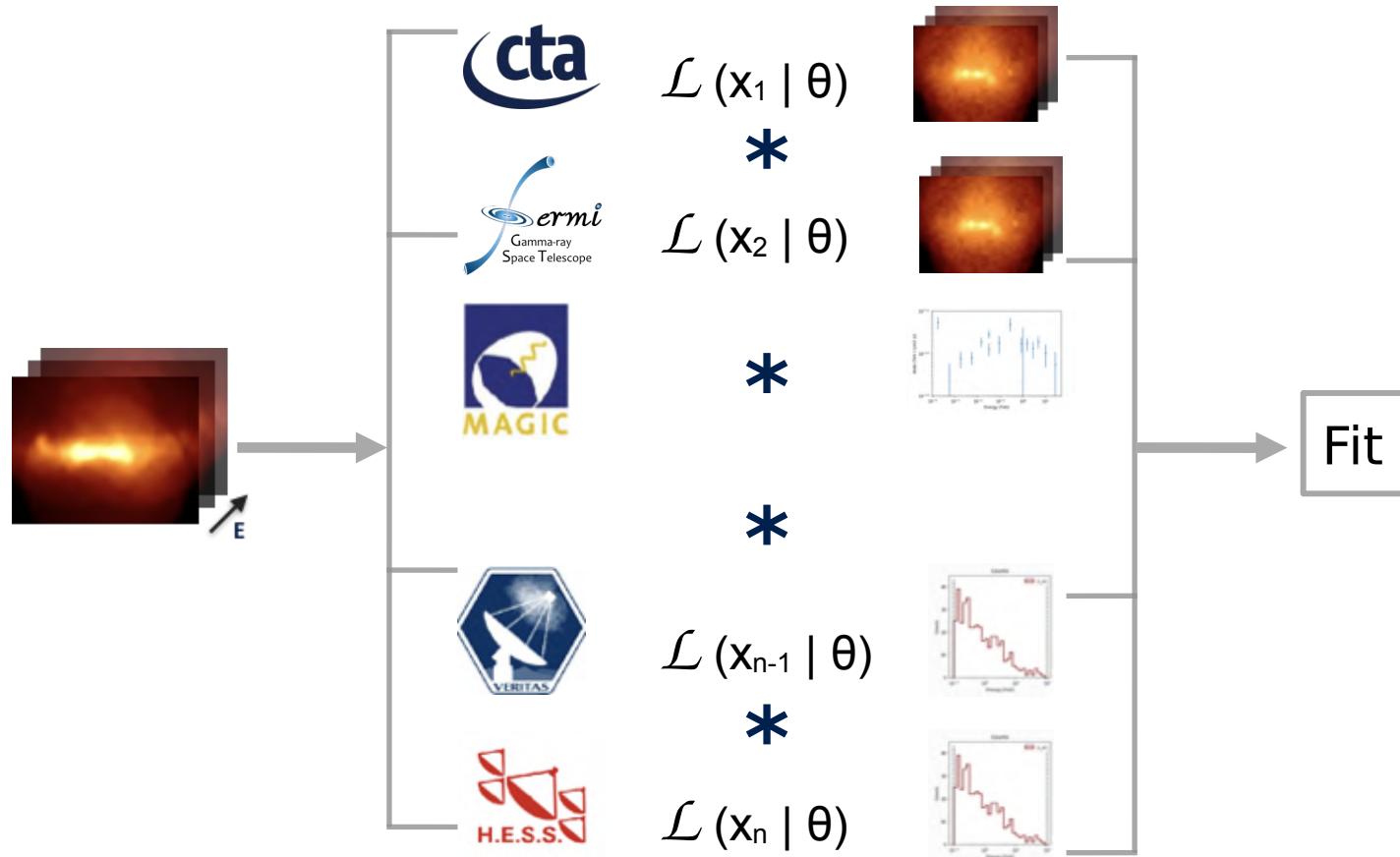
DL3 to DL4

1. Select and retrieve observations
2. Define the reduced dataset geometry
3. Initialize the data reduction methods ([makers](#))
4. Loop over selected observations

DL4 to DL5

1. Modelling
2. Do the fit
 - Choose your minimization parameters (optional)
 - Make the control plots, compute significance

DL4 to DL5 : Joint fitting



Gammapy Dataset structure allows heterogeneous data modelling and fitting: see [joint fit tutorial](#)



The basic analysis steps

DL3 to DL4

1. Select and retrieve observations
2. Define the reduced dataset geometry
3. Initialize the data reduction methods ([makers](#))
4. Loop over selected observations

DL4 to DL5

1. Modelling
2. Do the fit
3. Run the DL5 estimators ([estimators](#))
 - Initialisation of the geometry
 - Creation of the estimator(s)
 - Run them of the dataset(s)



The basic analysis steps: Overview of the modelling and fitting



DL4 to DL5

1. Modelling

- Define your model(s)
 - For the 3D analysis, add a final `FoVBackgroundModel`
 - Associate them/it to the correct dataset (or several)

2. Do the fit

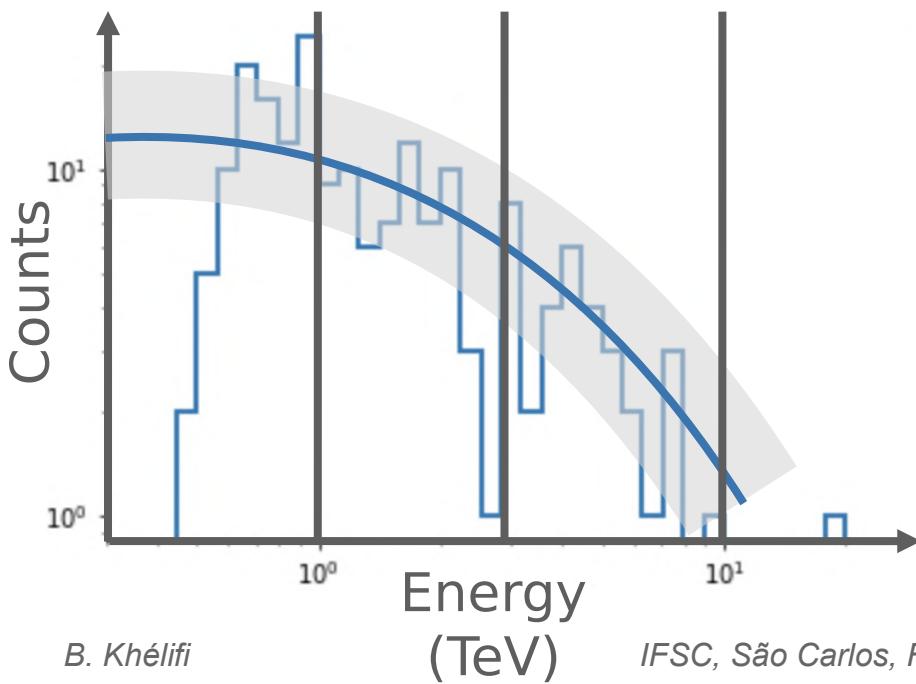
- Choose your minimization parameters (optional)
- Make the control plots, compute significance

3. Run the DL5 estimators ([estimators](#))

- Initialization of the geometry
- Creation of the estimator(s)
- Run it/them on dataset(s)

DL5: estimating fluxes

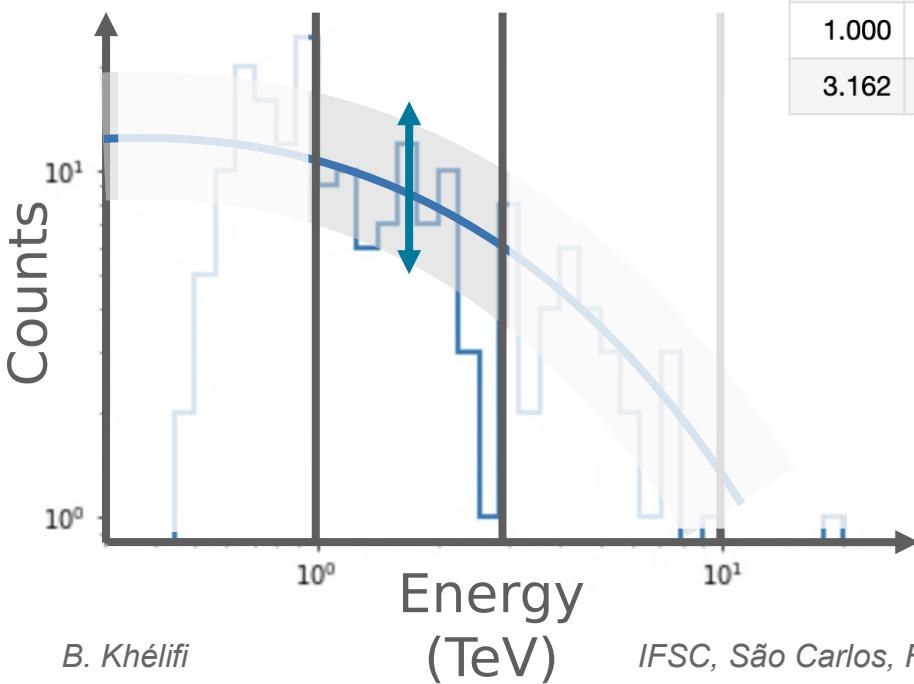
- Gammapy provides a set of estimator objects which create DL5 data products based on a model assigned to one or more datasets.



DL5: estimating fluxes

- Gammapy provides a set of estimator objects which create DL5 data products based on a model assigned to one or more datasets.

e_min	e_max	ref_flux	ref_eflux	norm	norm_err	norm_ul
TeV	TeV	1 / (cm ² s)	TeV / (cm ² s)			
float64	float64	float64	float64	float64	float64	float64
0.300	1.000	1.699e-10	8.184e-11	nan	nan	nan
1.000	3.162	2.433e-11	3.845e-11	1.032	0.058	1.152
3.162	10.000	3.847e-12	1.923e-11	0.879	0.103	1.099



FluxPointsEstimator
 LightCurveEstimator
 TSMapEstimator
 ExcessMapEstimator

DL3 → DL4 → DL5/6
 γ -like events Binned data Science products

Support for two analysis workflows:

- config-driven high-level interface
- advanced user library



DataStore
Observations
Observation
GTI

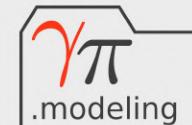


MapDatasetMaker
SafeMaskMaker
FoVBackgroundMaker
RingBackgroundMaker
etc.



Datasets
MapDataset
MapDatasetOnOff
etc.

Modeling & Fitting



Fit, Models, SkyModel
FoVBackgroundModel
etc.

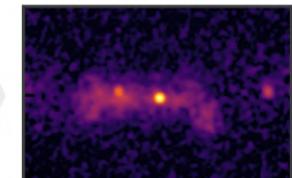


FluxPointsEstimator
TSMapEstimator
etc.

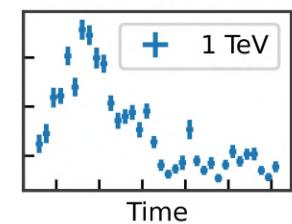
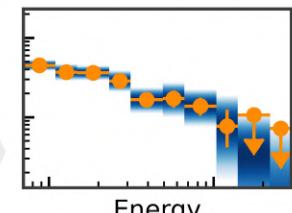
Source Catalogs

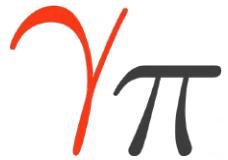
Name	Flux	Size
SNR	1e-12	1 deg
PWN	1e-11	0.2 deg
GRB	1e-10	0 deg

Sky Maps



Flux Points





Config-file driven analysis

The YAML configuration file

```
general:
  log: {level: info, filename: null, filemode: null, format: null, datefmt: null}
  outdir: .
observations:
  datastore: $GAMMAPY_DATA/hess-dl3-dr1
  obs_ids: []
  obs_file: null
  obs_cone: {frame: icrs, lon: 83.633 deg, lat: 22.014 deg, radius: 5.0 deg}
  obs_time: {start: null, stop: null}
  required_irf: [aeff, edisp, bkg]
datasets:
  type: 1d
  stack: true
  geom:
    axes:
      energy: {min: 0.2 TeV, max: 30.0 TeV, nbins: 15}
      energy_true: {min: 0.1 TeV, max: 60.0 TeV, nbins: 30}
  map_selection: [counts, exposure, edisp]
background:
  method: reflected
  exclusion: null
safe_mask:
  methods: [aeff-default, aeff-max]
  parameters: {aeff_percent: 10}
on_region: {frame: icrs, lon: 83.63 deg, lat: 22.01 deg, radius: 0.11 deg}
containment_correction: true
fit:
  fit_range: {min: 0.6 TeV, max: 20.0 TeV}
flux_points:
  energy: {min: 0.4 TeV, max: 20.0 TeV, nbins: 10}
  source: Crab
  parameters: {selection_optional: all}
```

```
config = AnalysisConfig.read(f"{estimate}/config.yaml")
analysis = Analysis(config)
analysis.get_observations()
analysis.get_datasets()
```

```
models = Models.read(f"{estimate}/models.yaml")
analysis.set_models(models)
analysis.run_fit()
```

Select observations

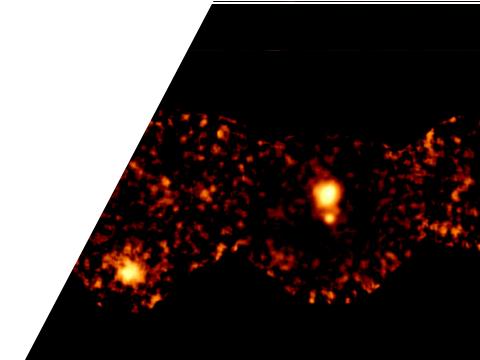
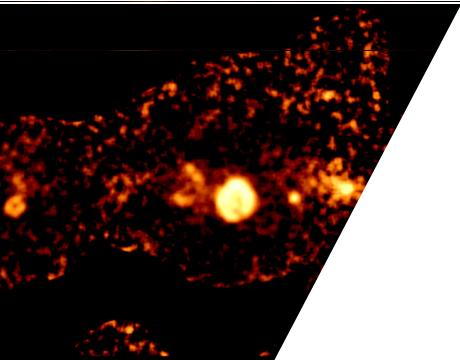
Define target Dataset geometry

Define data reduction methods

Define Fit configuration

Define high level estimators config.

See [High Level Interface tutorial](#)



Next sessions...



Next sessions: hands-on



We have prepared three specific analysis tutorials:

- I. Basics of the analysis: 1D (spectrum) and 3D
- II. Realization of simulations: impact of the statistics on results
- III. Study of instrument systematics

Conduct of the sessions:

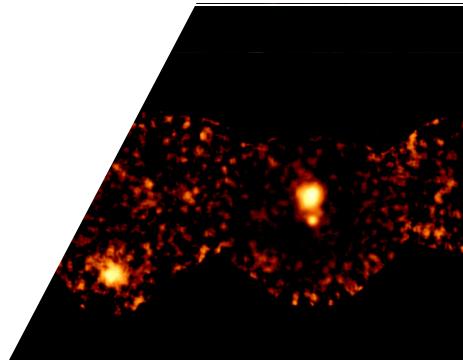
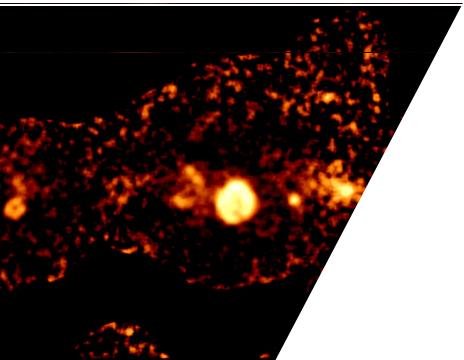
Tutorial as a demo (by me) → Exercise (for you)

You can retrieve them with:

```
git clone https://github.com/bkhelifi/Brazil_2024.git
```

Contact point: khelifi@in2p3.fr

Backup slides





Getting the software



- **Recommended gammapy installation**

```
curl -O https://gammapy.org/download/install/gammapy-1.1-environment.yml
```

```
conda env create -f gammapy-1.1-environment.yml  
conda activate gammapy-1.1
```

- **Download tutorials & associated data**

```
gammapy download notebooks
```

```
gammapy download datasets
```

```
export GAMMAPY_DATA=$PWD/gammapy-datasets/1.1
```

Note: mamba might prove a better/faster package manager

See: <https://docs.gammapy.org/1.1/getting-started/index.html#quickstart-setup>



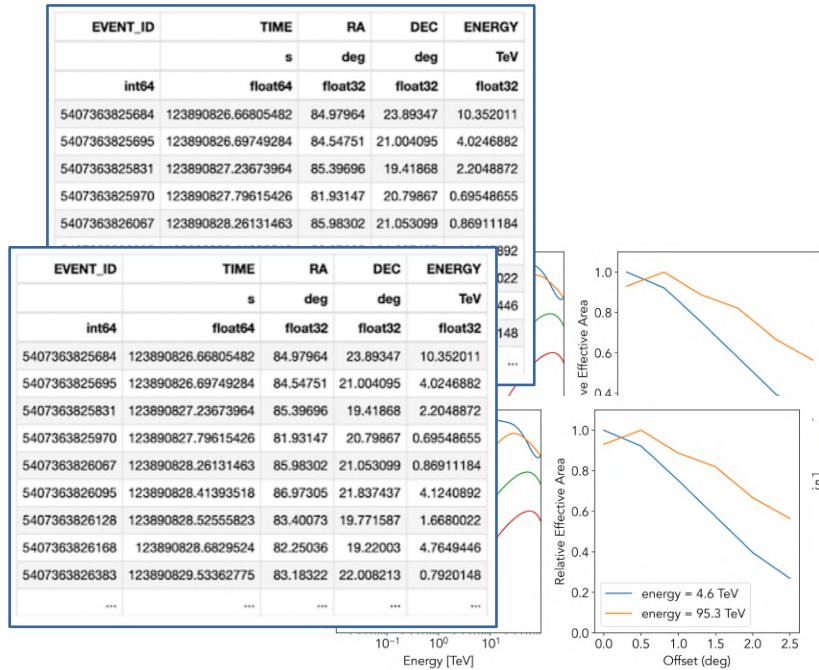
DL3 to DL4: data reduction

DL3
 γ -like events

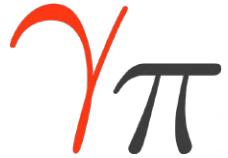
1. Select and retrieve relevant observations

EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
int64	float64	float32	float32	float32
5407363825684	123890826.66805482	84.97964	23.89347	10.352011
5407363825695	123890826.69749284	84.54751	21.004095	4.0246882
5407363825831	123890827.23673964	85.39696	19.41868	2.2048872
5407363825970	123890827.79615426	81.93147	20.79867	0.69548655
5407363826067	123890828.26131463	85.98302	21.053099	0.86911184
5407363826095	123890828.41393518	86.97305	21.837437	4.1240892
5407363826128	123890828.52555823	83.40073	19.771587	1.6680022
5407363826168	123890828.6829524	82.25036	19.22003	4.7649446
5407363826383	123890829.53362775	83.18322	22.008213	0.7920148
...

DataStore



Observation / Observations



DL3 to DL4: data reduction

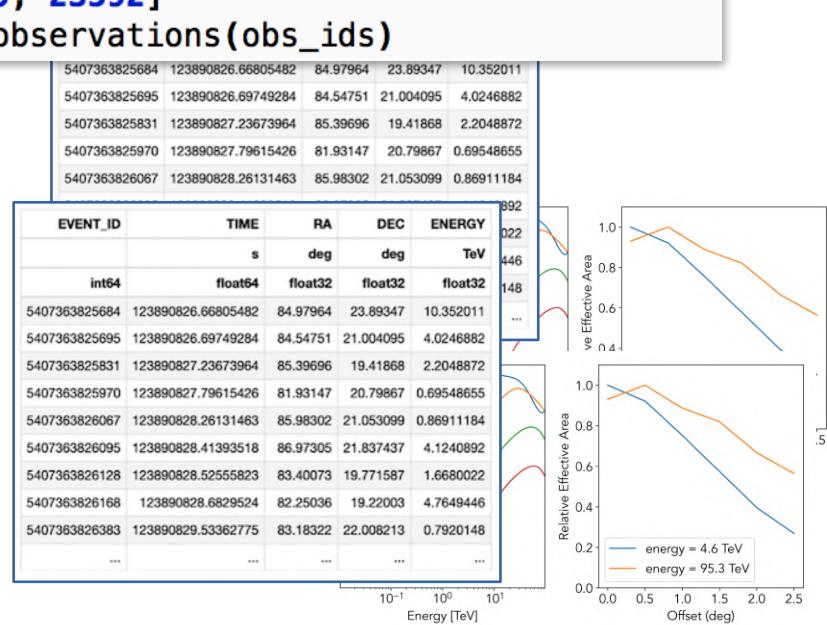
DL3
 γ -like events

1. Select and retrieve relevant observations

```
datastore = DataStore.from_dir("$GAMMAPY_DATA/hess-dl3-dr1/")
obs_ids = [23523, 23526, 23559, 23592]
observations = datastore.get_observations(obs_ids)
```

EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
EVENT_ID	TIME	RA	DEC	ENERGY
	s	deg	deg	TeV
int64	float64	float32	float32	float32
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...

DataStore



Observation / Observations

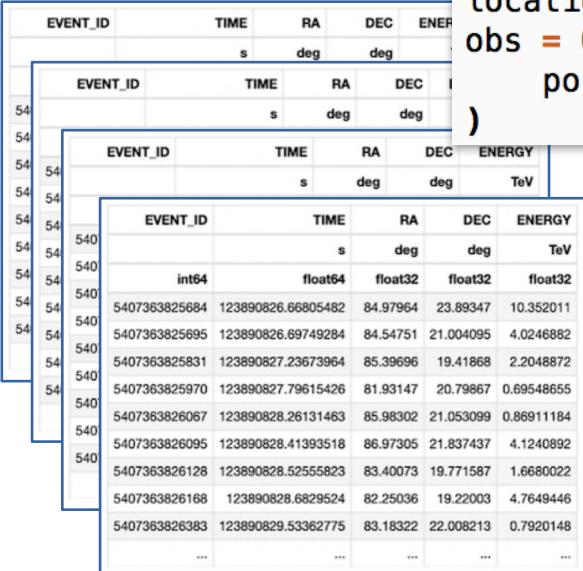


DL3 to DL4: data reduction

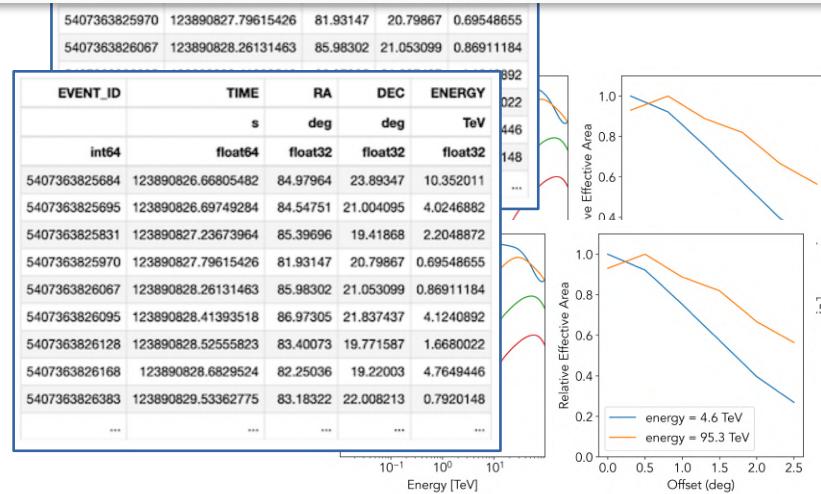
DL3
 γ -like events

1. Select and retrieve relevant observations

```
# Create an in-memory observation
location = observatory_locations["cta_south"]
obs = Observation.create(
    pointing=pointing, livetime=livetime, irfs=irfs, location=location
)
```

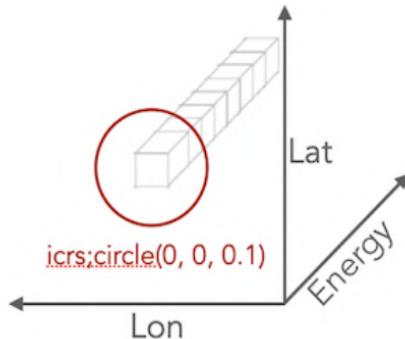


DataStore



Observation / Observations

DL3 to DL4: data reduction

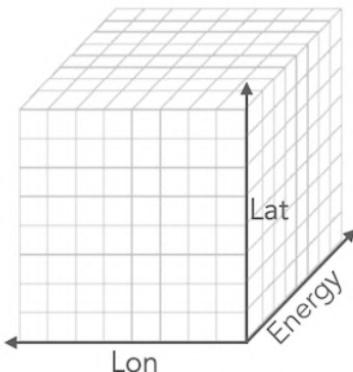


region & energy

1. Select and retrieve relevant observations

2. Define the reduced dataset geometry

- Is the analysis 1D (spectral only) or 3D?
- Define target binning and projection



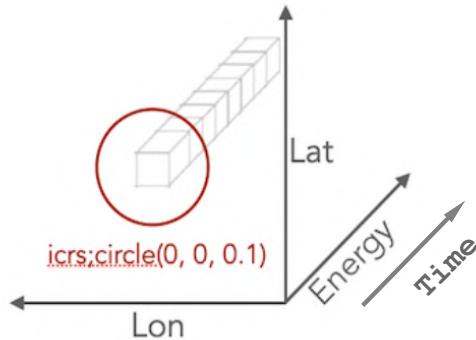
WCS & energy



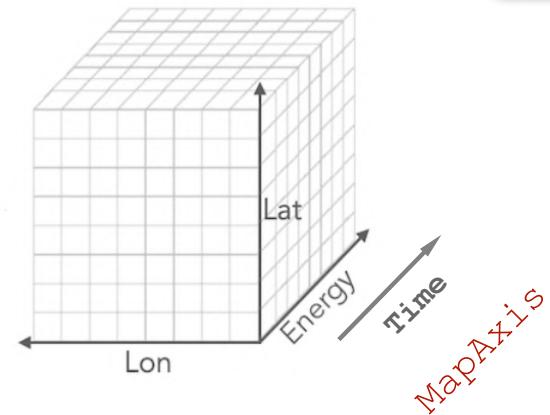
Geometry : multidimensional maps



- Gammapy maps represent data on the sky with non-spatial dimensions (in particular energy)
 - World Coord. System (WCS) for 3D analyses (lon, lat, E)
 - Region geometry for 1D analysis



RegionGeom / RegionNDMap



WcsGeom / WcsNDMap

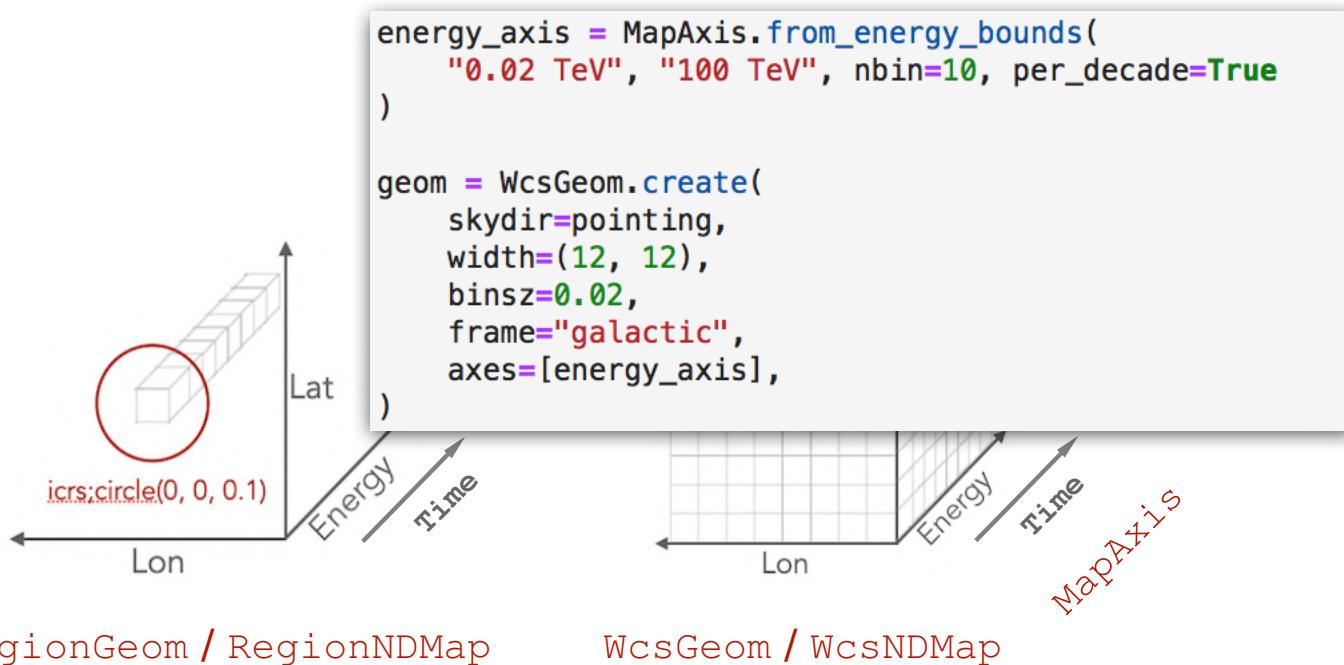
See : [working with maps](#)



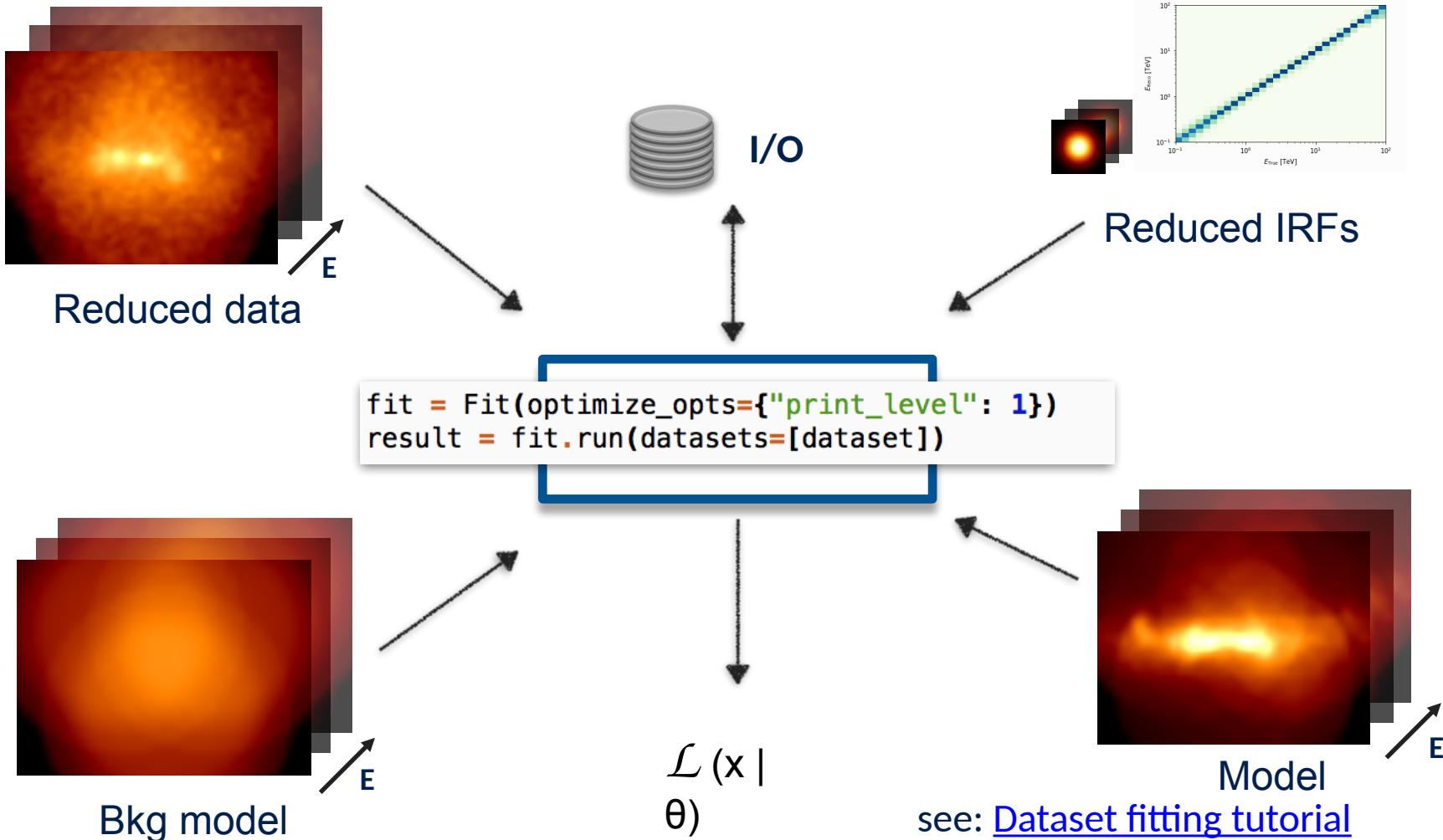
Geometry : multidimensional maps



- Gammapy maps represent data on the sky with non-spatial dimensions (in particular energy)
 - World Coord. System (WCS) for 3D analyses (lon, lat, E)
 - Region geometry for 1D analysis



Datasets modelling and fitting



- Gammapy provides a set of estimator objects which create DL5 data products based on a model assigned to one or more datasets.
 - Once a proper model is determined
 - In predefined energy intervals, estimators compute:
 - fluxes errors and associated significance
 - fit statistic scan etc.
 - They can produce flux points, light curves, flux maps

