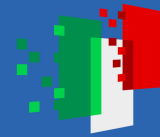




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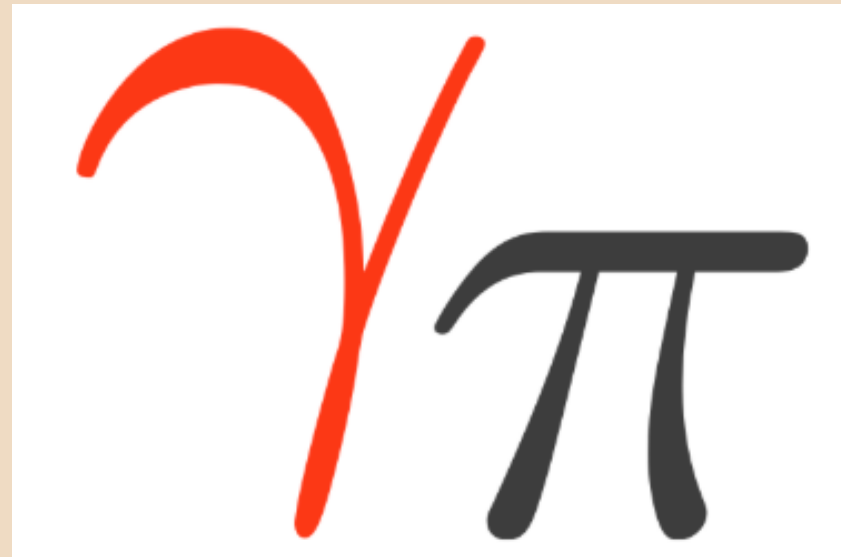
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Gammapy

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



*2nd VHEGAM meeting, Bari
May 26-28, 2025*

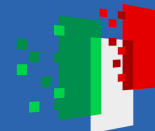
Fabio Pintore (INAF/IASF Palermo), on behalf of the Gammapy team
fabio.pintore@inaf.it



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Gammapy

Gammapy was born with the idea to develop an open-source software for the very high energy (VHE) data analysis;

This was intended to overpass the proprietary software philosophy and provide an observatory-independent data-analysis tool;

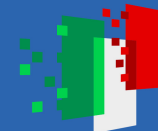
Since 2013 (with a 1st release - v0.1 - on Aug. 2014), a team is working on an independent open library to analyse VHE data formatted following a community-accepted format ([GADF](#));



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 π A Python package for
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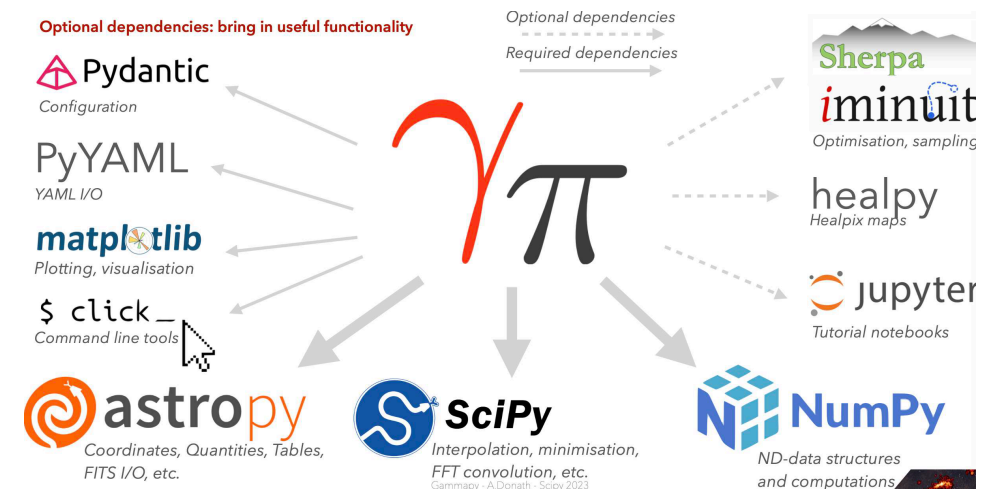
Gammapy

On 2021, Gammapy was selected as the official data-analysis tool of CTAO

However, it is currently adopted by a wider community and several facilities (*HESS, MAGIC, HAWC, ASTRI...*)

Gammapy is a Python based package, which lives in a Python ecosystem comprising *Numpy*, *Astropy*, *Scipy*...

<https://gammapy.org/>

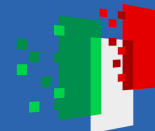




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Gammapy organization

The gammapy organization is well structured (<https://gammapy.org/team.html>):

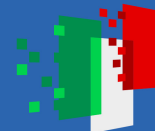




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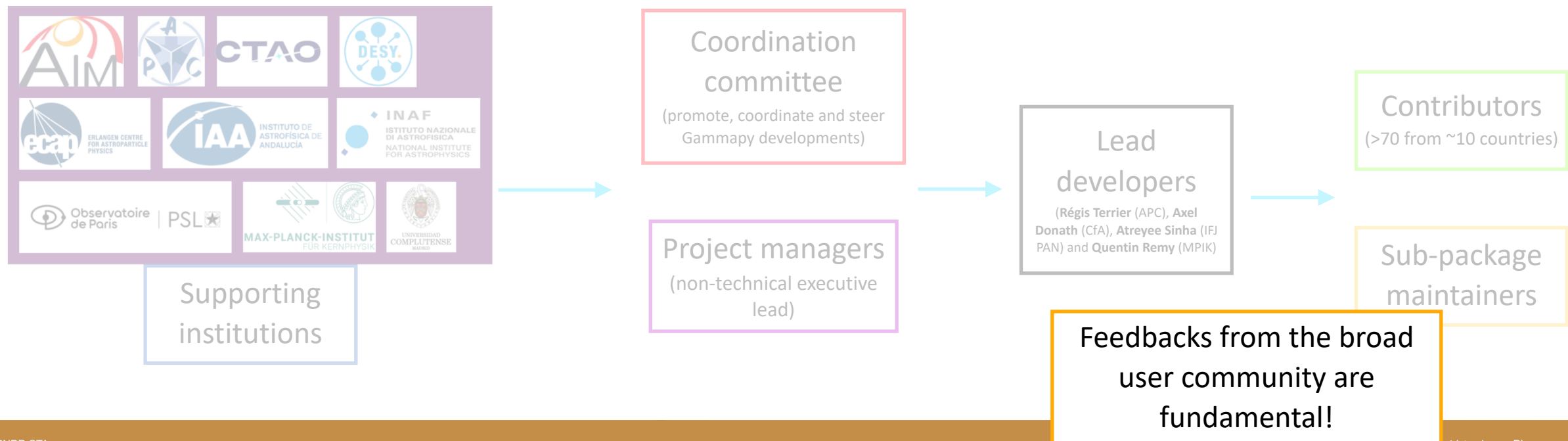


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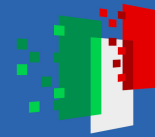




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Gammapy helpdesk

Gammapy offers several media to contact developers, ask questions, pose doubts or request new features!

- Gammapy *help* channel, on [slack](#)



- A dedicated git repository:

<https://github.com/gammapy/gammapy/discussions/categories/help>

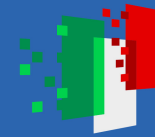
- The developer calls, every Friday at 2pm



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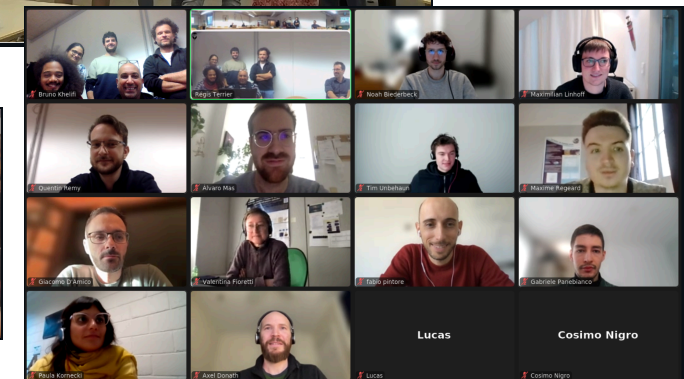
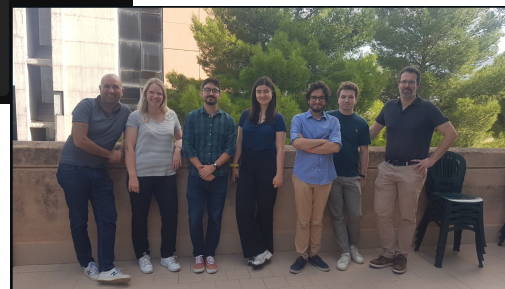
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Coding sprints

Coding sprints are meetings which aim at working together for a full week on the development of Gammapy. They are usually organised about one or twice per years



La Laguna- 2025
Heidelberg -2024
Palermo - 2023
Madrid - 2023
Paris - 2022

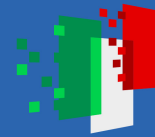




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Gammapy version release

The first Long Stable release (v1.0) was made public on November 2022;

Intermediate, stable versions are released about every six months;

The current Gammapy version is v1.3, released on November 26th, 2024;

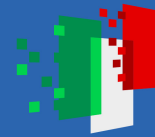
A development version is always available!



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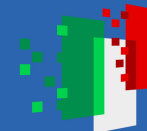


Gammapy installation

Installation can be done through *Anaconda/Miniconda*, *Mamba*, *pip*, *sudo apt-get*;

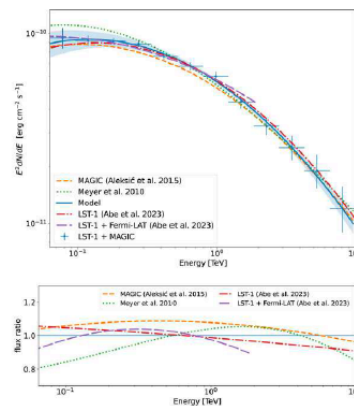
<https://docs.gammapy.org/1.3/getting-started/index.html>

A repository of data is also available: it can be used for tests, data-analysis and Gammapy developments



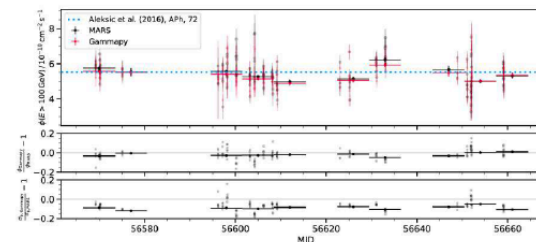
Gammapy validation

LST-1 and MAGIC with the Crab Nebula

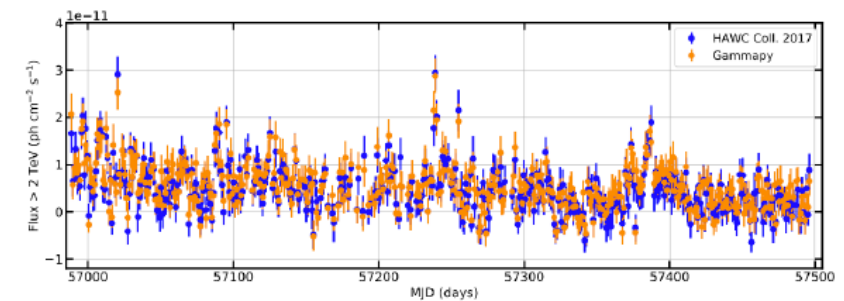


[Abe H. et al., A&A 680 A66 \(2023\)](#)

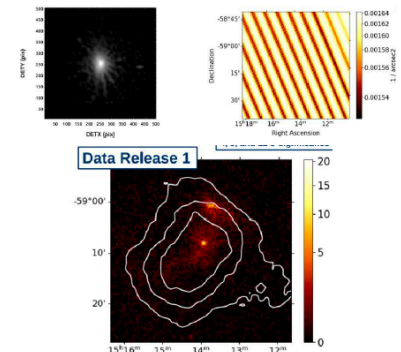
Gammapy vs MARS (MAGIC) on the Crab



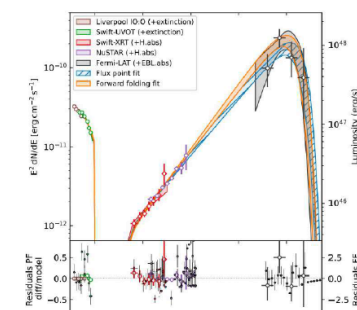
[Abe S. et al., JHEAP 44, 266-278 \(2024\)](#)

HAWC [Albert et al \(2022\)](#)

H.E.S.S. and eROSITA on MSH15-52

K. Egg et A. Mitchell ([Gamma 2024](#))

OP 313 detected by LST-1:
Joint forward fitting fit (eV $\rightarrow$ 10^{10} eV)

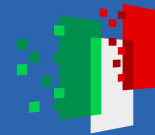
M. Nievas Rosillo et al. ([arXiv:2409.20487](https://arxiv.org/abs/2409.20487))



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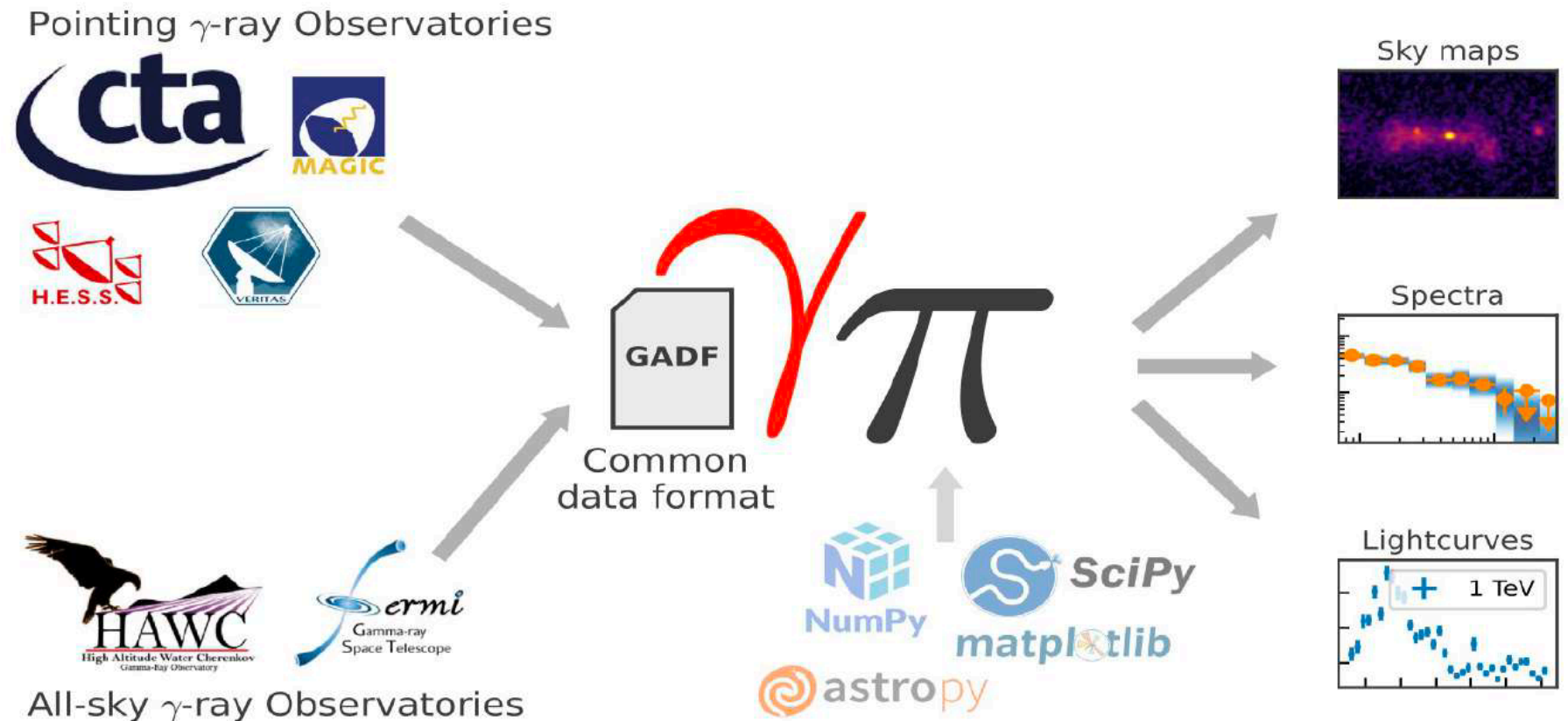


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Multi-instrument analysis

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Gammapy is designed to
handle data from different
observatories

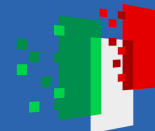




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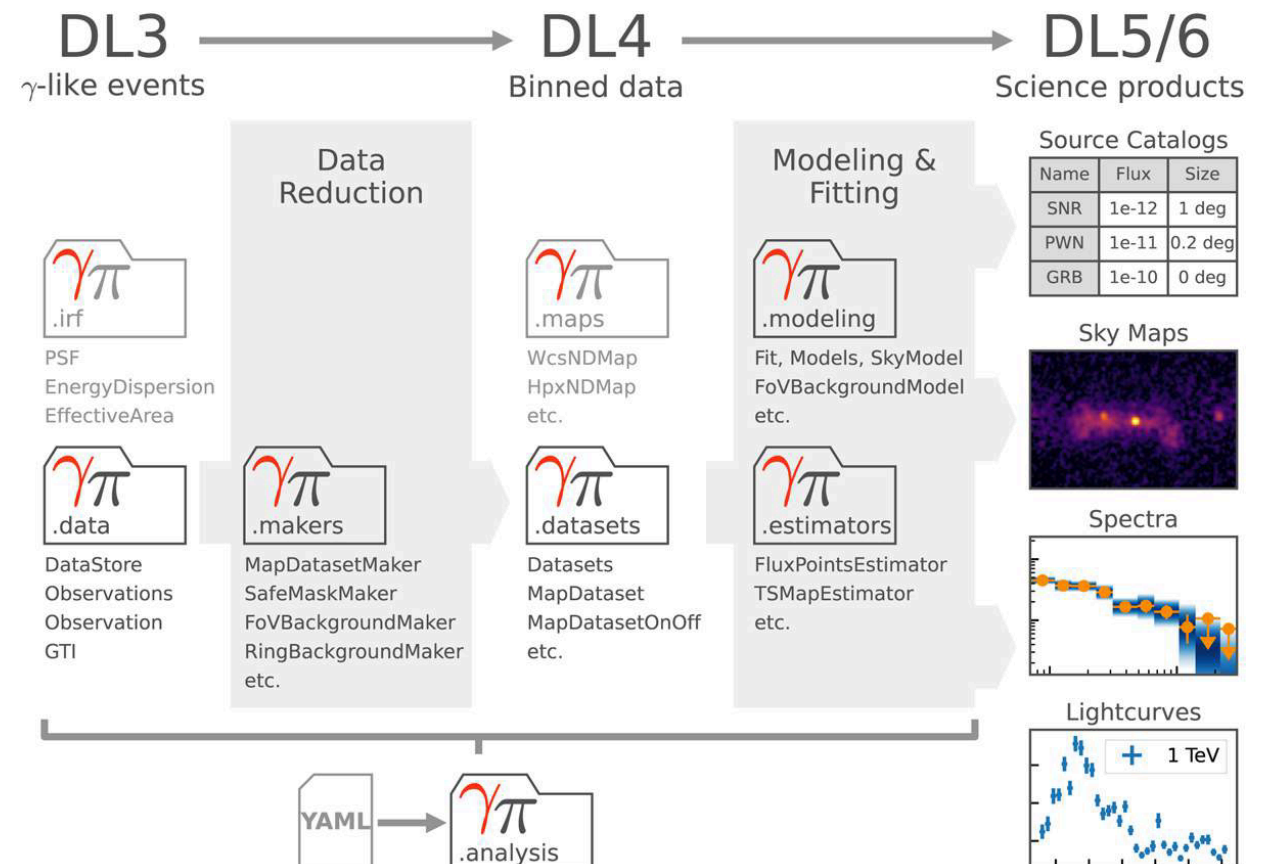
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$\gamma\pi$ A Python package for
gamma-ray astronomy

Gammapy workflow

The main Gammapy workflow aims at a data-reduction from a data level (DL)3 to a binned DL4. The latter are then analysed to extract science products (DL5).

A number of classes and different data-reduction/analysis approaches are available.

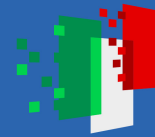




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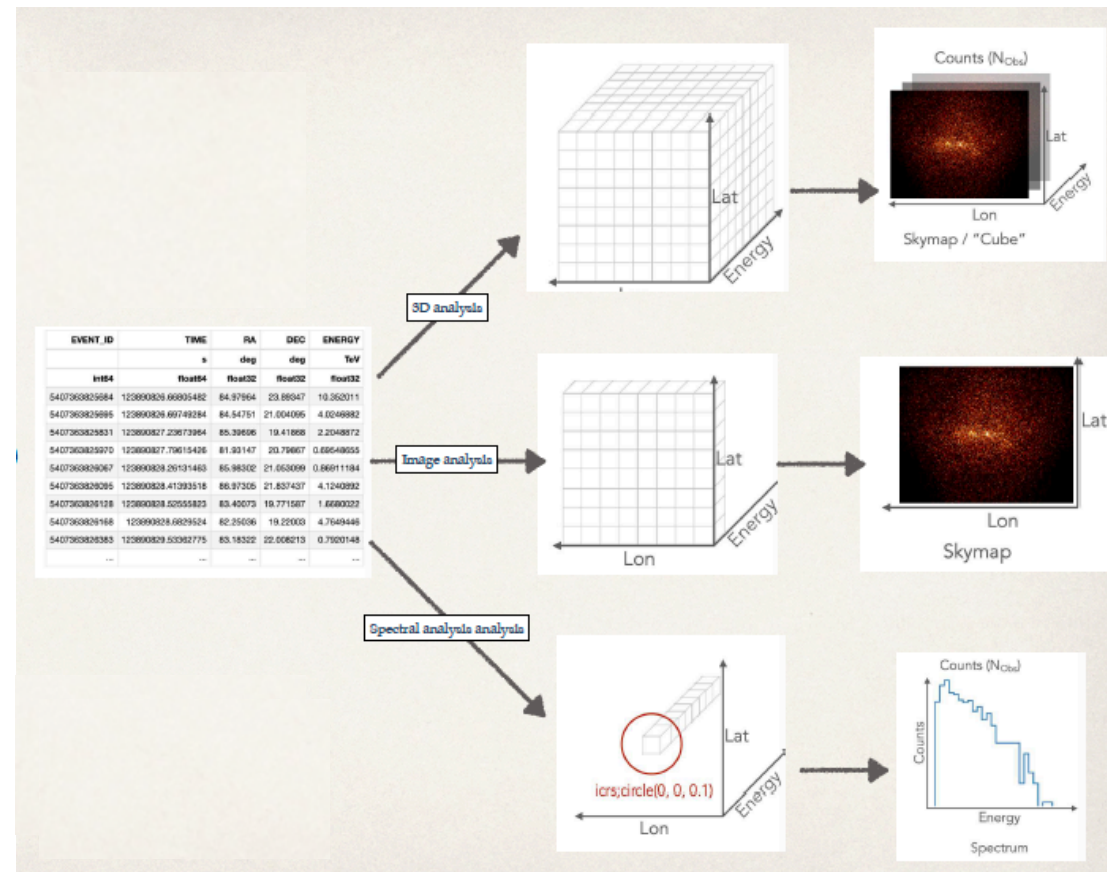
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Gammapy workflow

Gammapy adopts a binned approach (energetic and spatial axes) for both data and IRFs;

Events can be selected from coordinates, energies and time;

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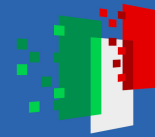




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Functionalities

Gammapy offers a wide range of different tools and kinds of data-analysis. Just a few examples:

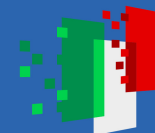
- Data-handling from different facilities and multiple observations
- IRF access and manipulation
- Multi-instrument joint analysis
- Imaging (sky, counts, flux, exposure, excess... maps)
- Spectral analysis (1D/3D) of point-like and extended sources
- Source detection
- Temporal analysis
- Model fitting
- Background estimation (reflected regions, ring, FoV background)
- High-level interface
- Catalogues



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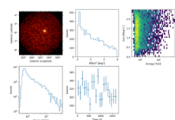
$\gamma\pi$ A Python package for
gamma-ray astronomy

A number of tutorials is available!

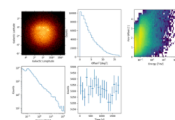
<https://docs.gammapy.org/1.3/tutorials/index.html>

Data exploration

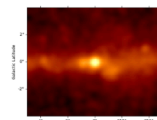
These tutorials show how to perform data exploration with Gammapy, providing an in-depth look at HAWC, H.E.S.S. and Fermi-LAT data and instrument response functions (IRFs). You can filter event lists according to different criteria, as well as to get a quick look of the multi-wavelength sky maps.



H.E.S.S. with
Gammapy



CTAO with Gammapy

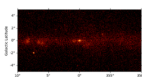


Fermi-LAT with
Gammapy

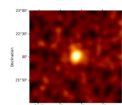
Introduction

The following three tutorials show the workflow from data selection to data reduction.

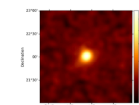
The first tutorial is an overview of the configuration-driven approach, showing what is happening under the hood. The second tutorial shows how to work with data structures like event lists, source catalogs, sky maps, spectral models and flux points tables.



Data structures



High level interface

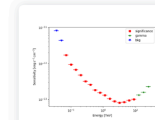


Low level API

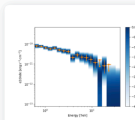
Data analysis

The following set of tutorials are devoted to data analysis, and grouped according to the specific covered use cases in spectral analysis and flux fitting, image and cube analysis modelling and fitting, as well as time-dependent analysis with light-curves.

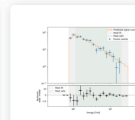
1D Spectral



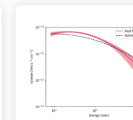
Point source sensitivity



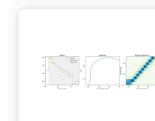
Spectral analysis



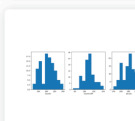
Spectral analysis with
the HLI



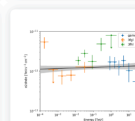
Spectral analysis with
energy-dependent
directional cuts



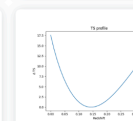
Spectral analysis of
extended sources



1D spectrum
simulation

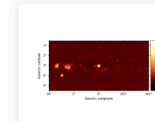


Flux point fitting

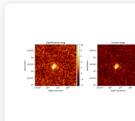


Account for spectral
absorption due to the
EBL

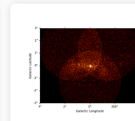
2D Image



Source detection and
significance maps



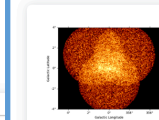
Ring background map



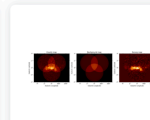
2D map fitting

↑ Back to top

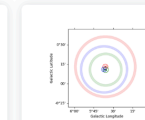
3D Cube



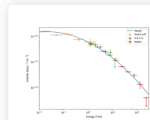
3D detailed analysis



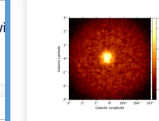
Basic image
exploration and fitting



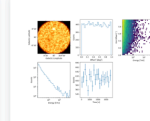
Morphological energy
dependence estimation



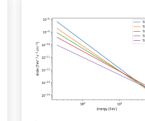
Multi instrument joint
3D and 1D analysis



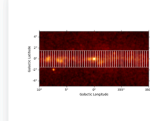
3D map simulation



Event sampling

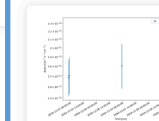


Sample a source with
energy-dependent
temporal evolution

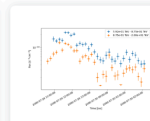


Flux Profile Estimation

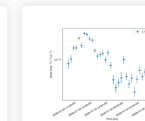
Time



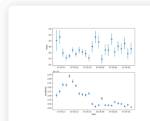
Light curves



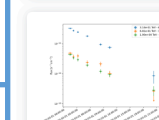
Light curves for flares



Estimation of time
variability in a
lightcurve



Time resolved
spectroscopy estimator



Simulating and fitting a
time varying source



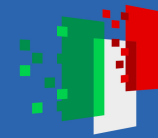
Pulsar analysis



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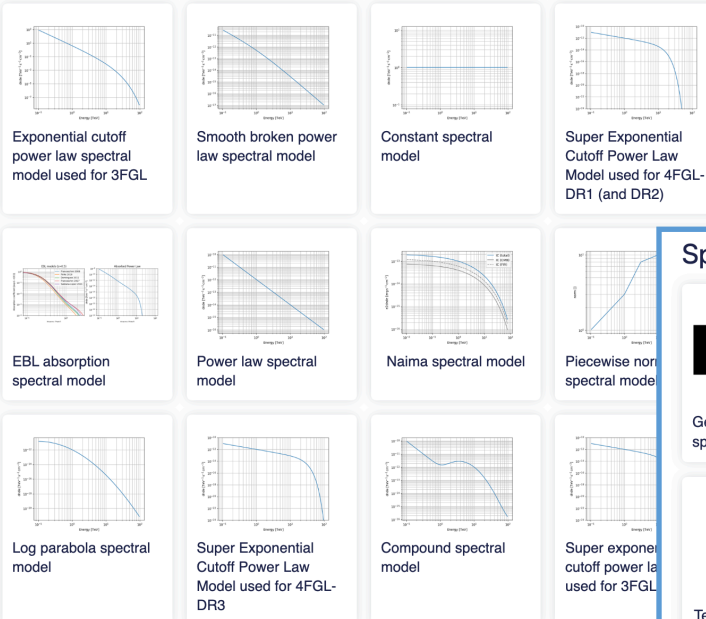


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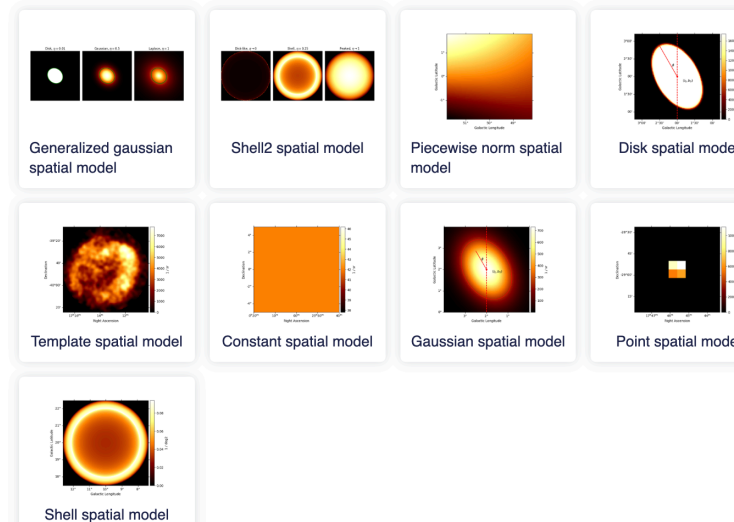
 A Python package for
gamma-ray astronomy

Gammapy model gallery (spectral, spatial and temporal)

Spectral models



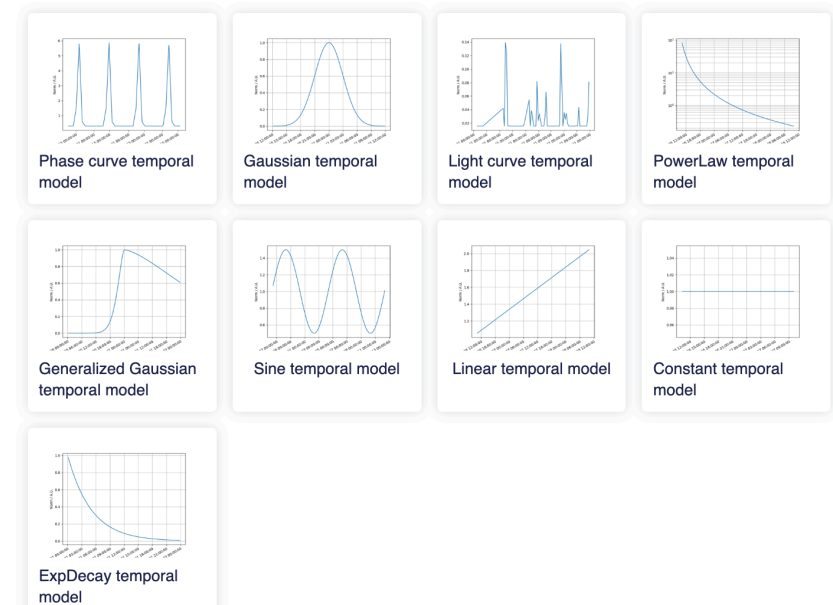
Spatial models



<https://docs.gammapy.org/dev/tutorials/api/models.html>

<https://docs.gammapy.org/dev/user-guide/model-gallery/index.html#model-gallery>

Temporal models

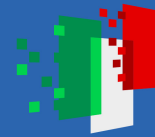




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The application programming interface (API) is well organised and detailed:

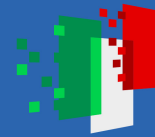
<https://docs.gammapy.org/1.3/api-reference/index.html>



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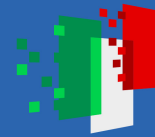
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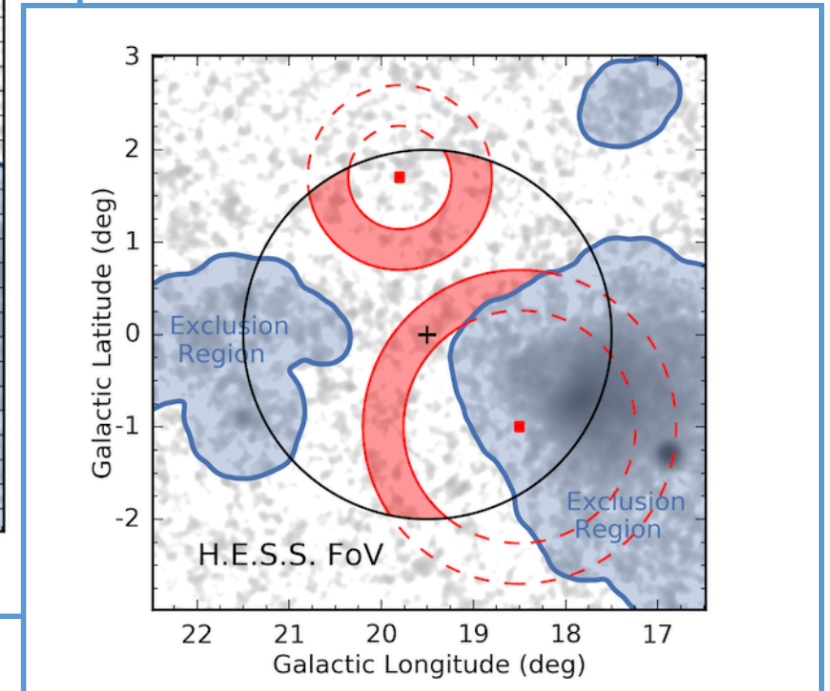
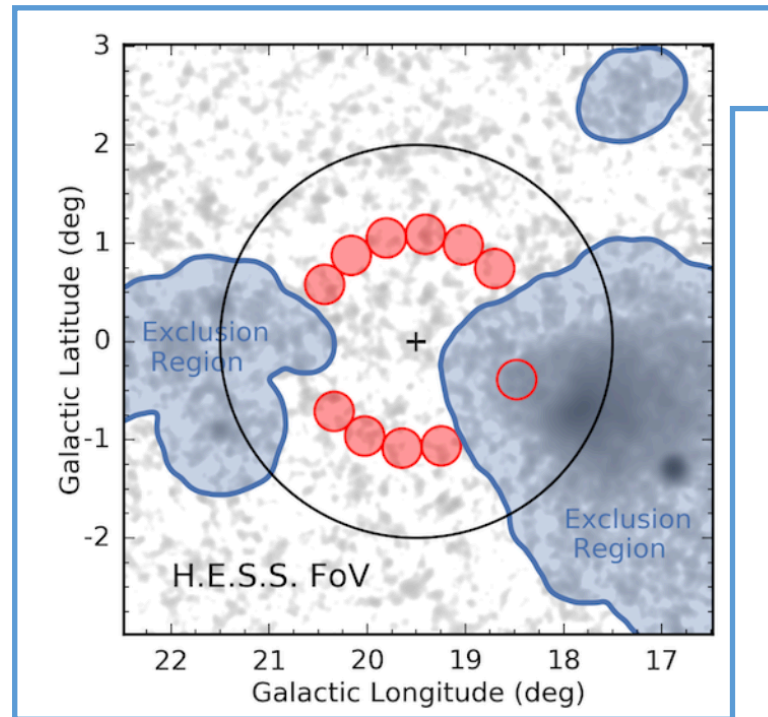
Scientific analysis with Gammapy

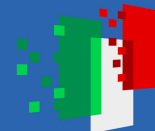


Background estimation

Background can be estimated following different methods:

- Reflected regions
- Ring background
- FoV background





Fitting approaches are based on a forward folding with maximum likelihood estimation.
The predicted events are a convolution of source and background events.

- Cash statistics

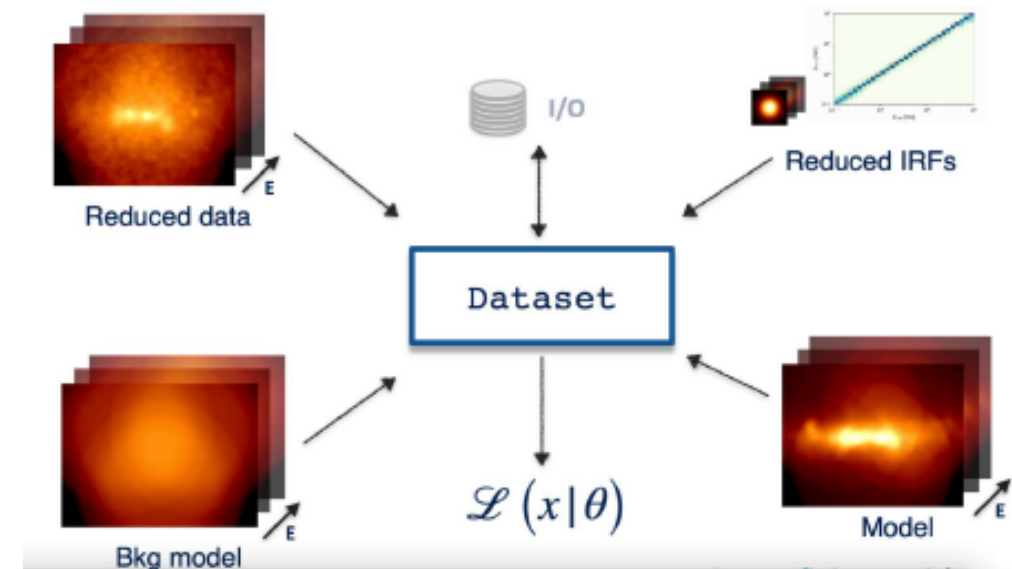
The background model is known:

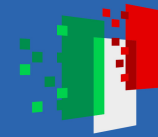
$$C = 2 \times (\mu_{\text{sig}} + \mu_{\text{bkg}} - n \times \log(\mu_{\text{sig}} + \mu_{\text{bkg}}))$$

- Wstat statistics

The background is estimated from the data:

$$W = 2(\mu_{\text{sig}} + (1 + 1/\alpha)\mu_{\text{bkg}} - n_{\text{on}} \log(\mu_{\text{sig}} + \mu_{\text{bkg}}) - n_{\text{off}} \log(\mu_{\text{bkg}}/\alpha))$$

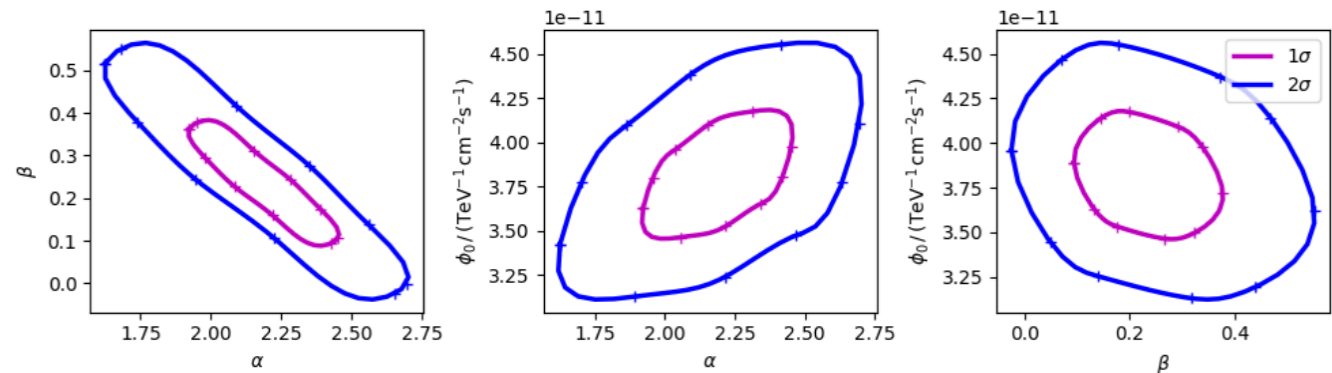
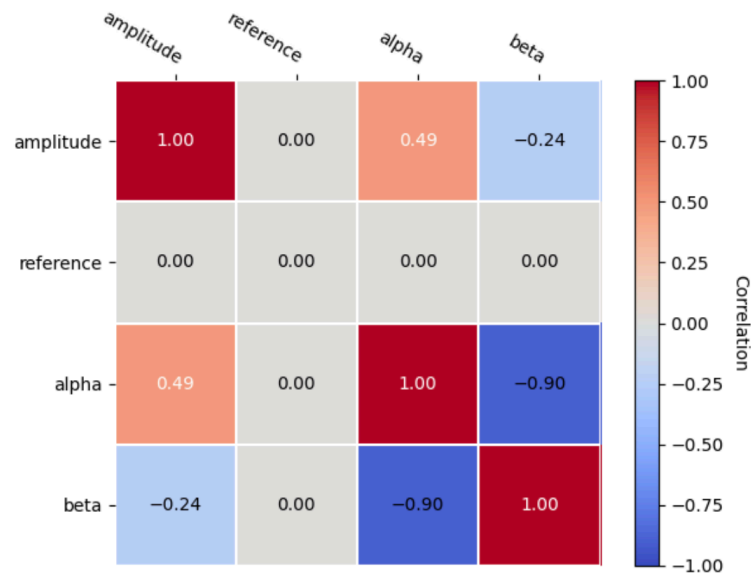




Fitting

Fitting can access different backends (*sherpa*, *iminuit*...) and optimisation algorithms (*Levenberg-Marquardt*, *Simplex*, *Monte Carlo*...).

Possibility to choose optimisation parameters and fitting strategy;

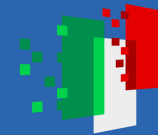




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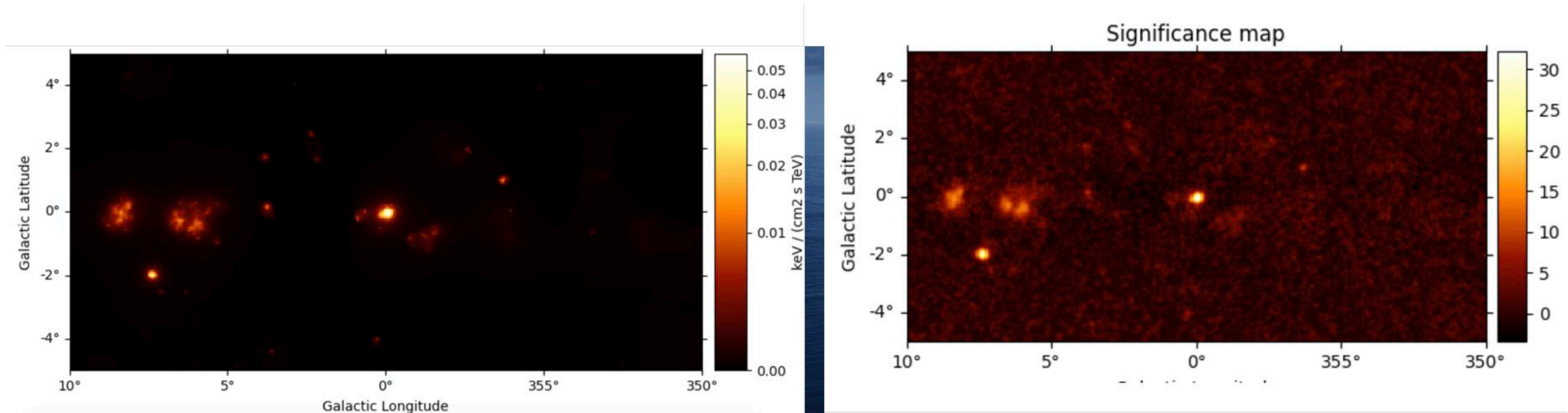
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Gammapy.maps



Maps can be created over arbitrary energies or spatial geometries;

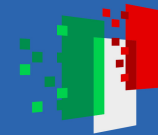
Possibility of reshape, downsample or upsample the geometries;



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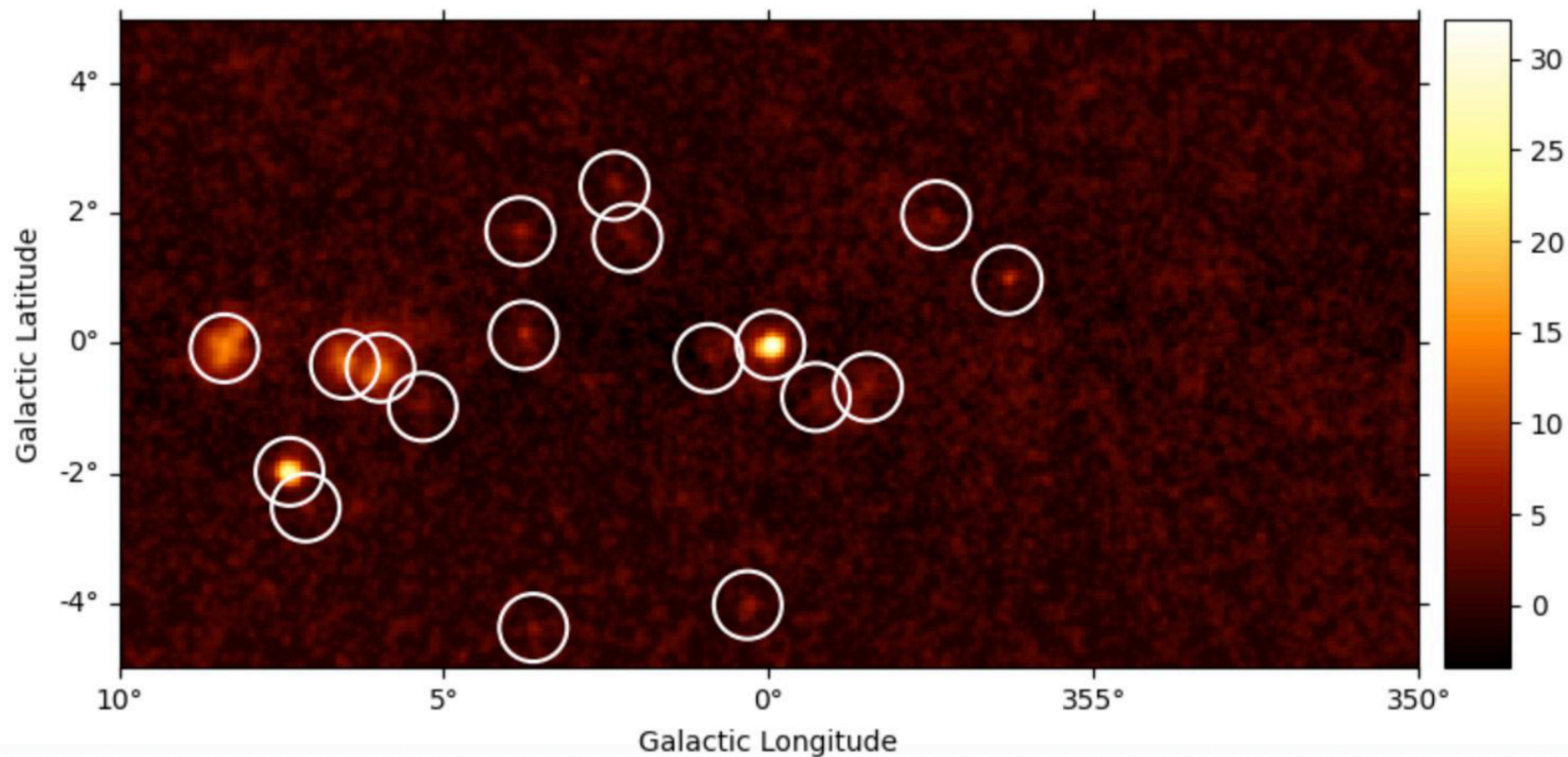
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Gammapy.maps + source detection



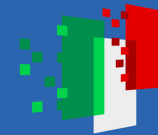
SOURCE DETECTION



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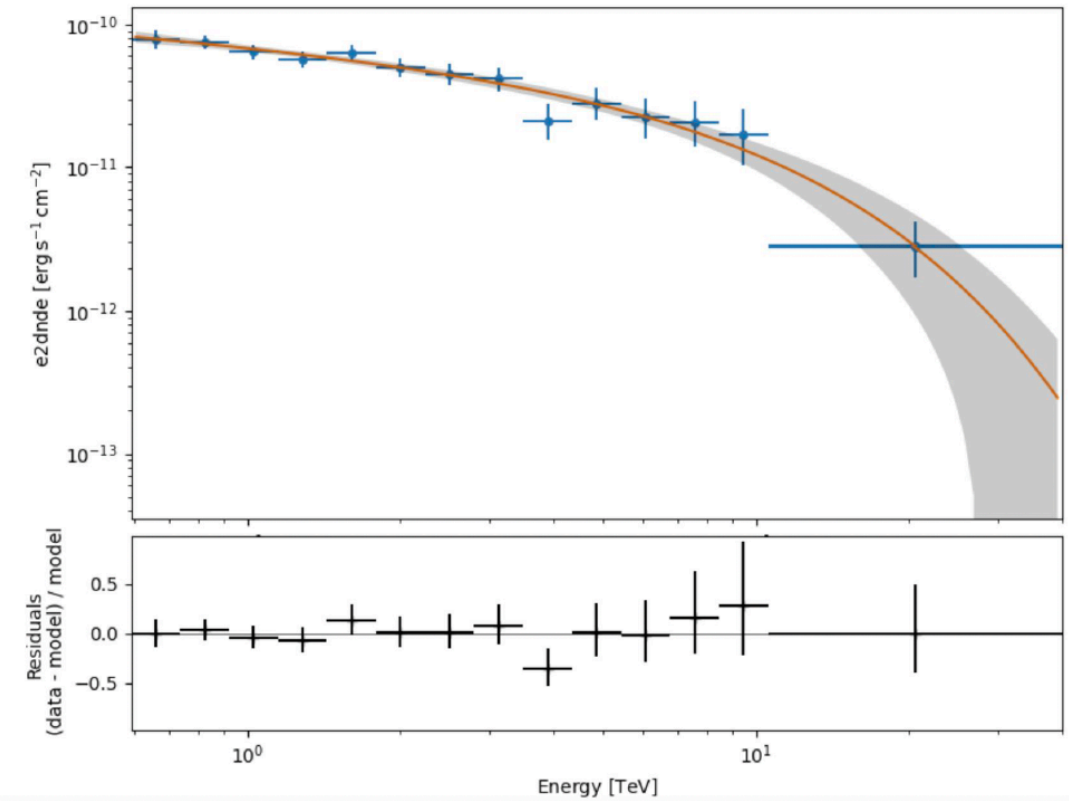
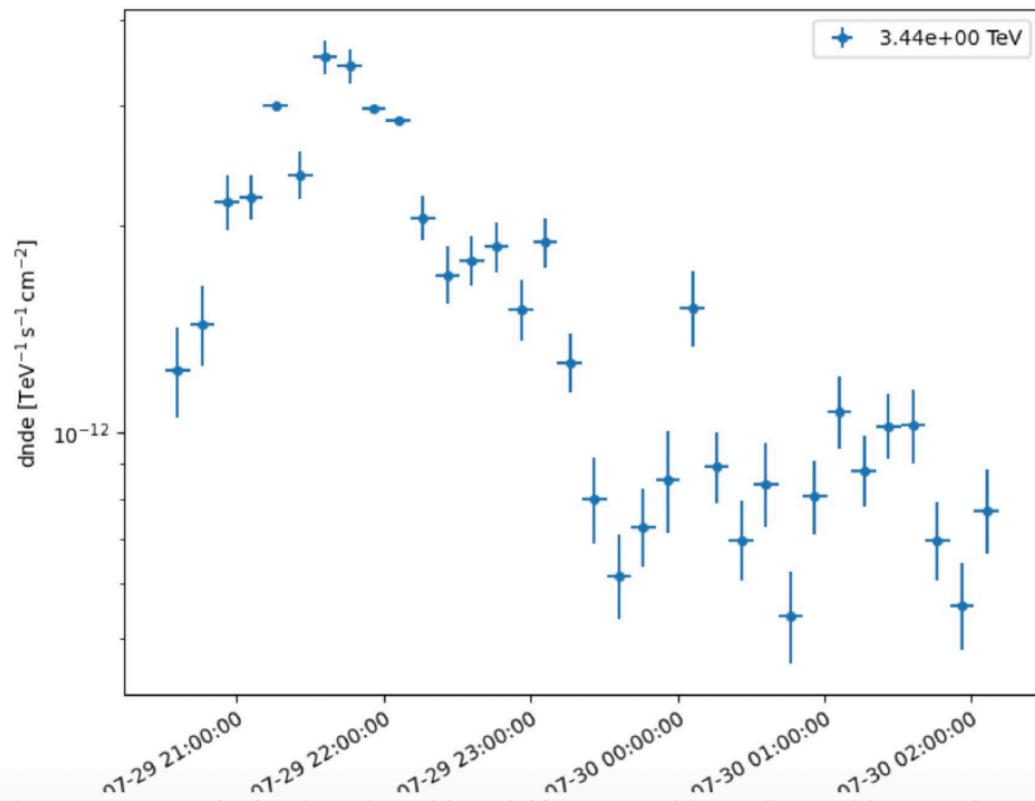
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Lightcurves and spectra

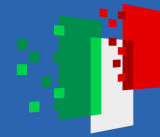




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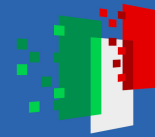
How to: simulate an observation event list with Gammapy



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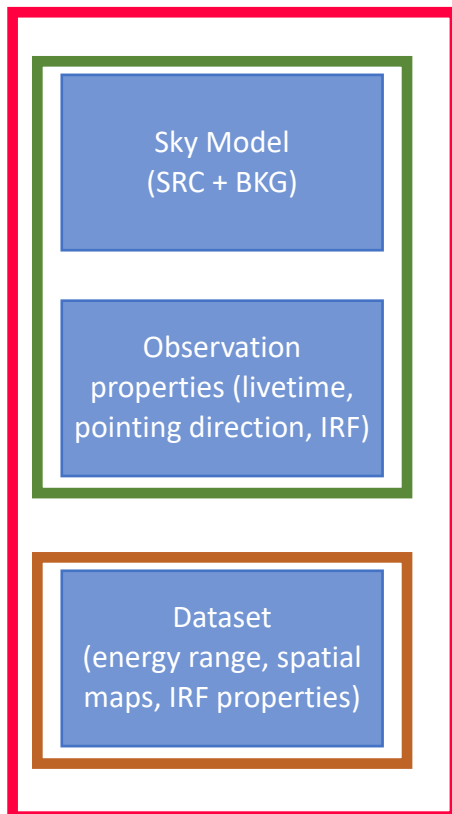


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Gammapy event sampling

MapDatasetMaker



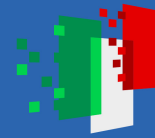
MapDatasetMaker applies a binning of the spatial and energy axes, and projects the IRF properties in the sky-direction!



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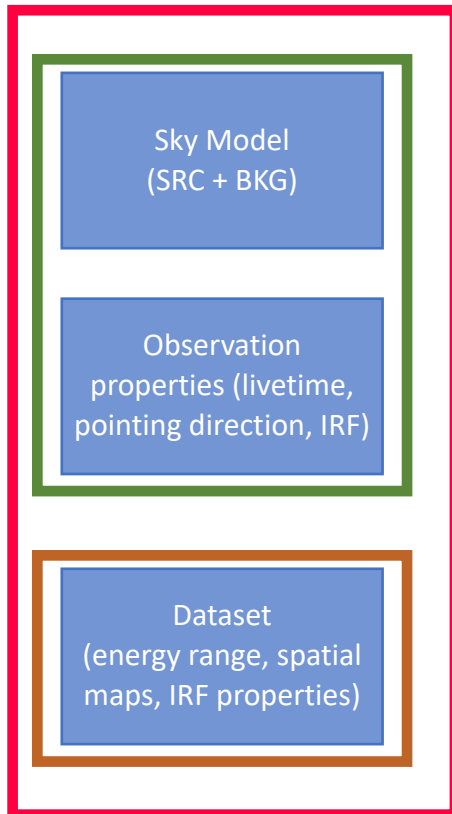


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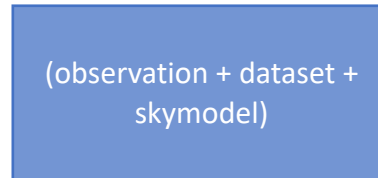
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Gammapy event sampling

MapDatasetMaker



MapDatasetEventSampler

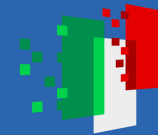




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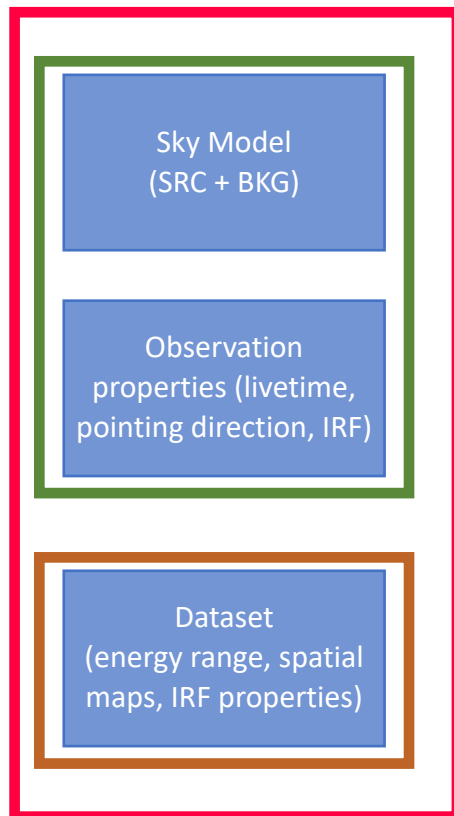


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Gammapy event sampling

MapDatasetMaker



MapDatasetEventSampler

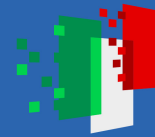




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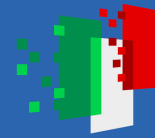
How to: source detection



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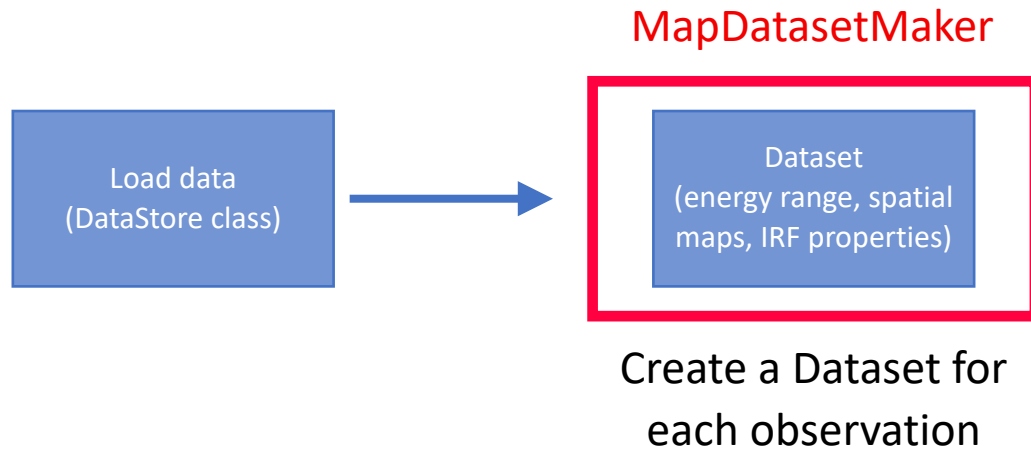
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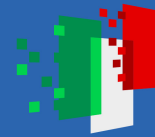




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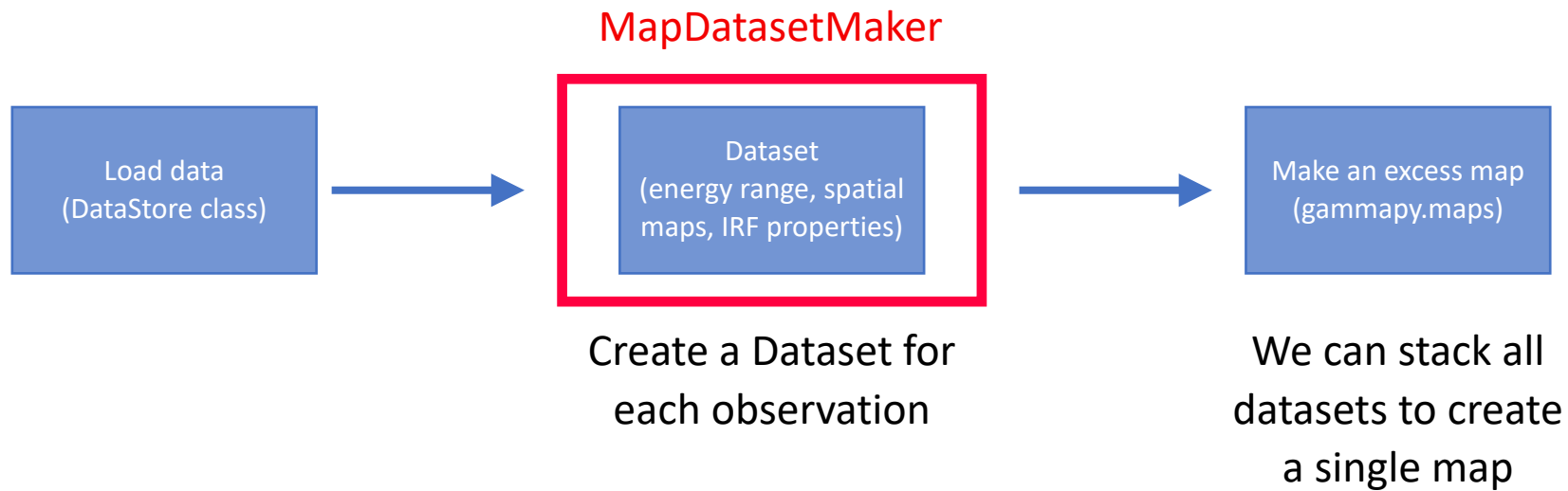
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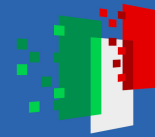




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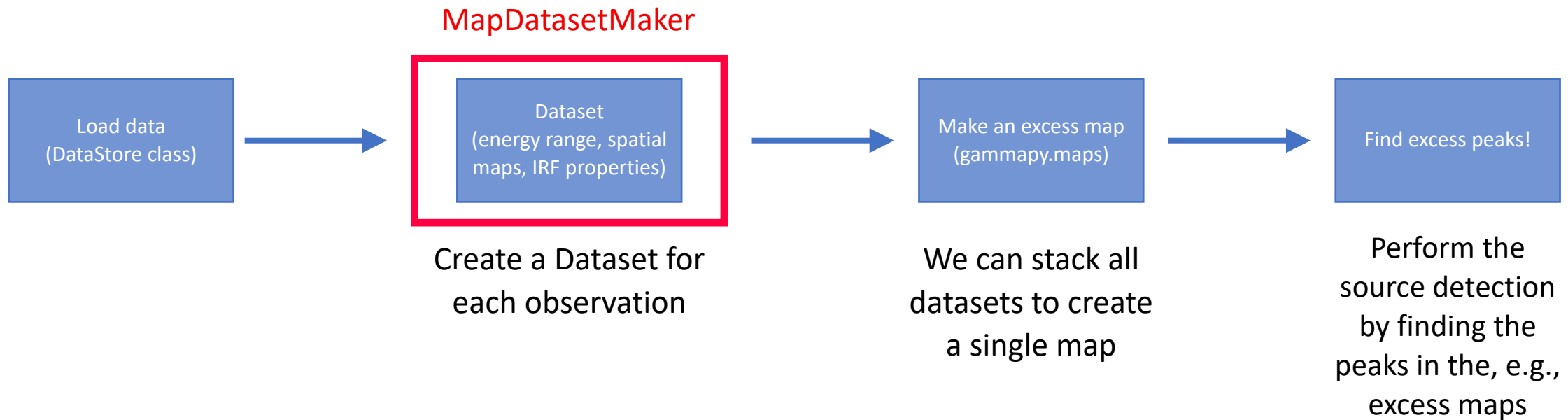
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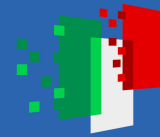




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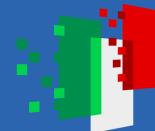
How to: 1D stacked spectral analysis



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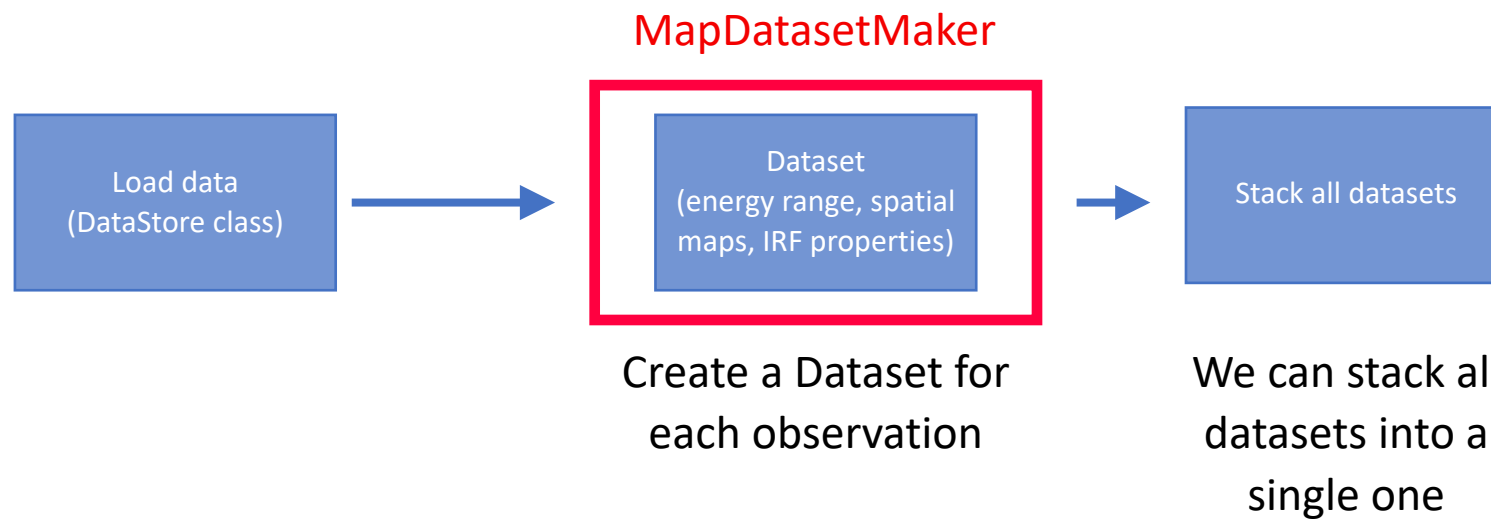
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Gammapy stacked spectral analysis: 1D

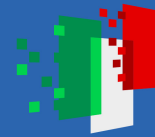




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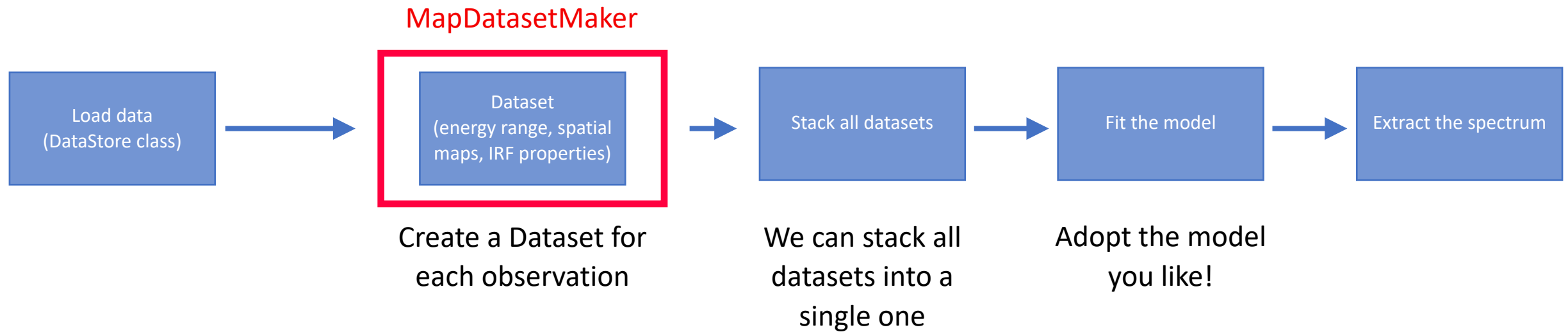
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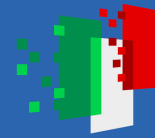




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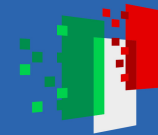
How to: extract a long-term lightcurve



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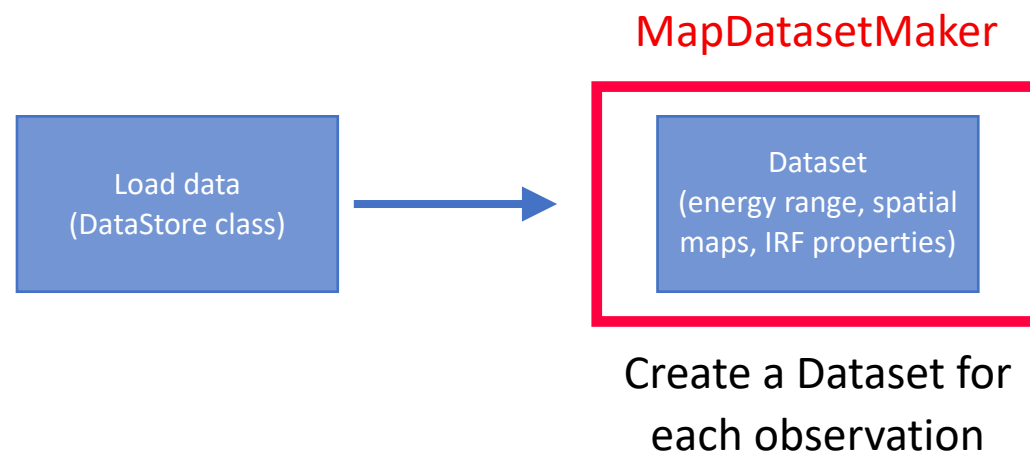
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Long-term lightcurve

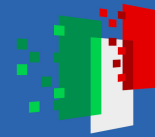




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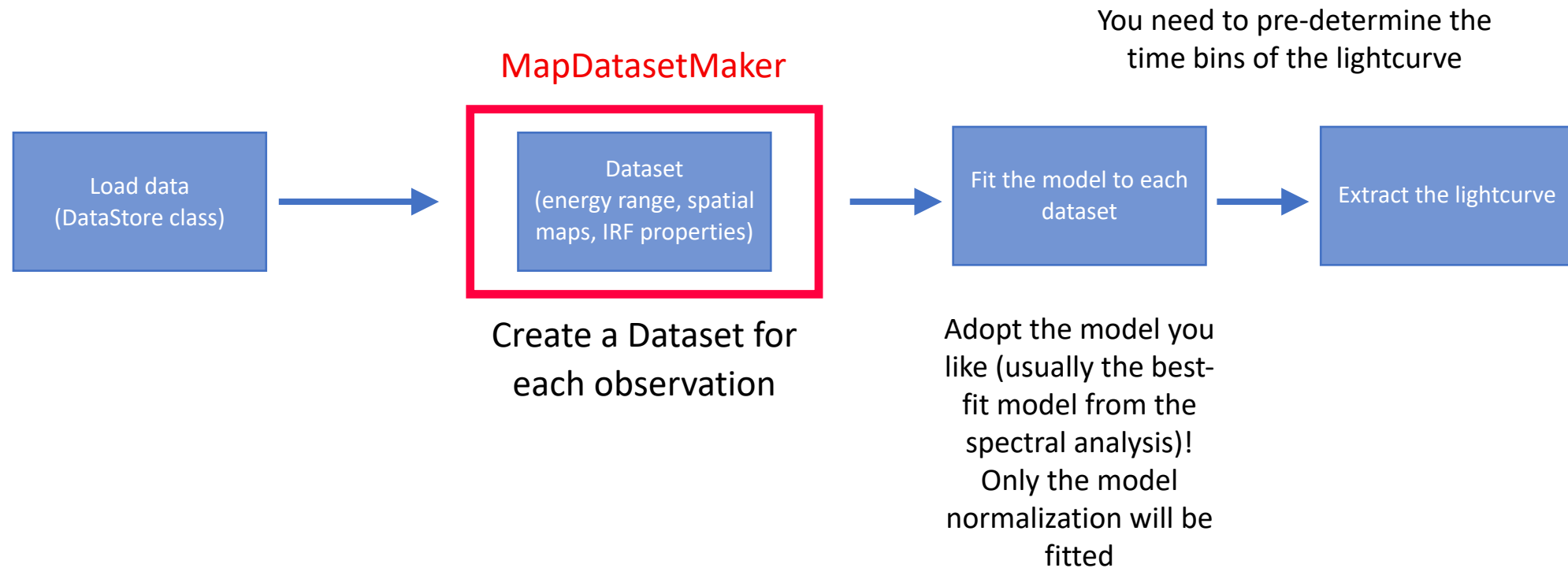
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Long-term lightcurve

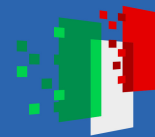




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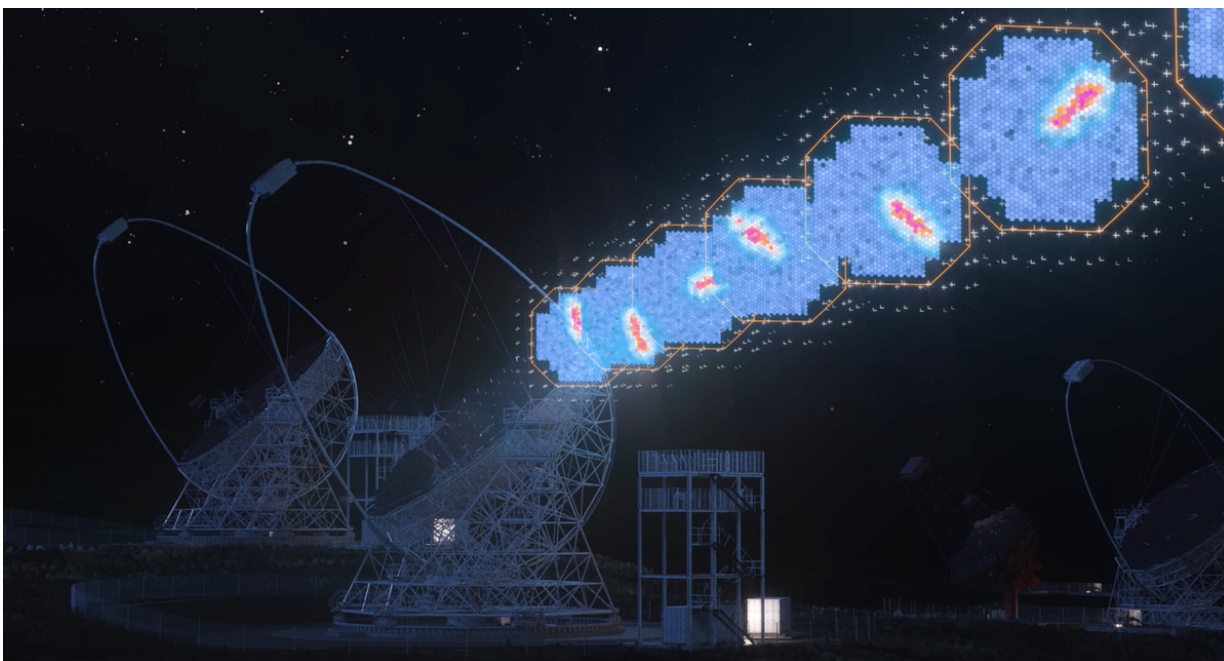


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Thanks for the attention!