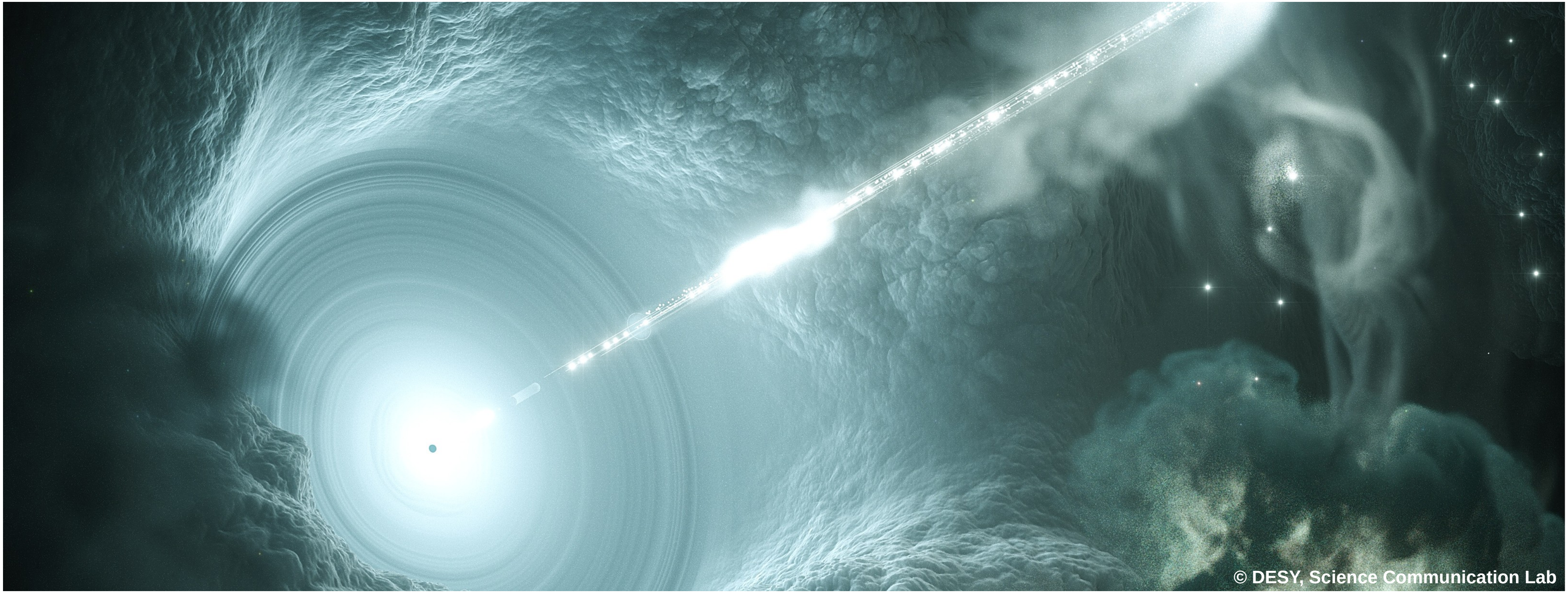
Facilitating multi-messenger modelling using Gammapy

Lea Heckmann, Matteo Cerruti, Bruno Khélifi, Justin Albinet



Current AGN modelling

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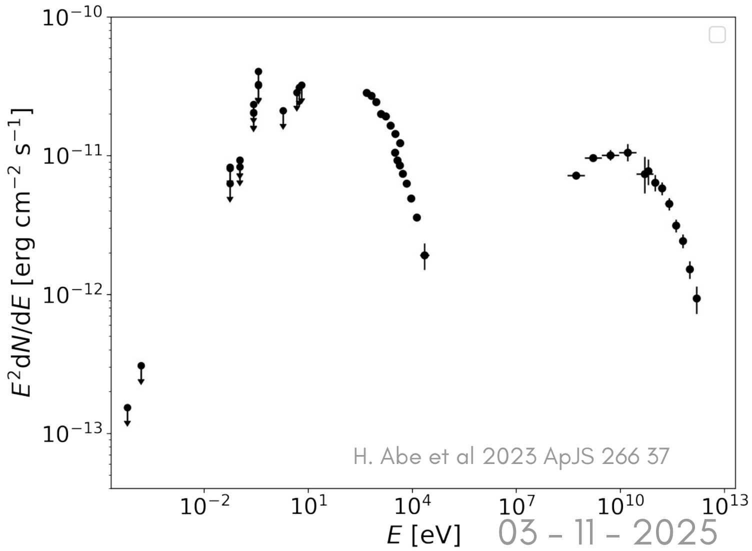

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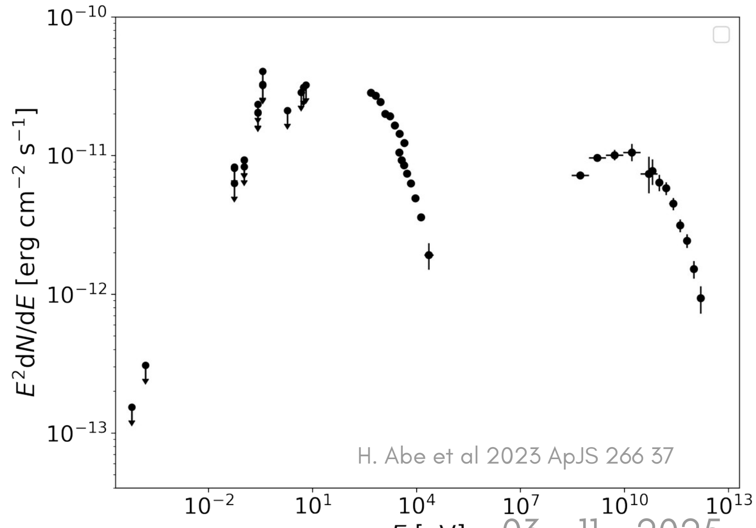
- Combining MWL data on flux point level:
    - We construct flux points for single instruments separately
        - using different frameworks for different instruments
        - assuming simplistic models (e.g. power-law) – single instruments cannot constrain physical models (e.g. SSC)



H. Abe et al 2023 ApJS 266 37

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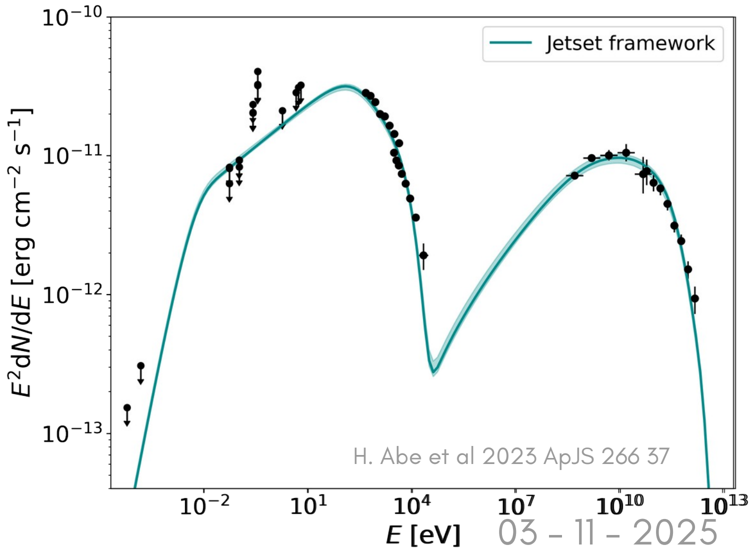

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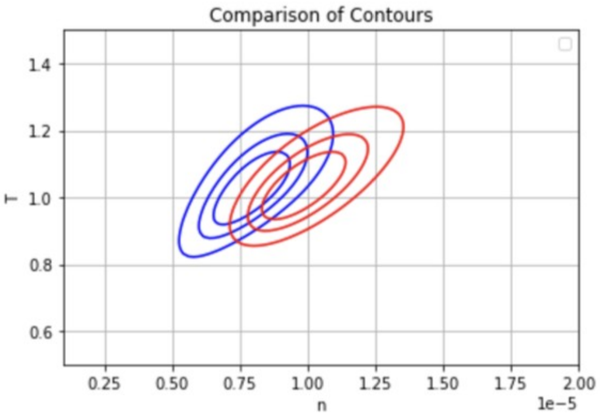

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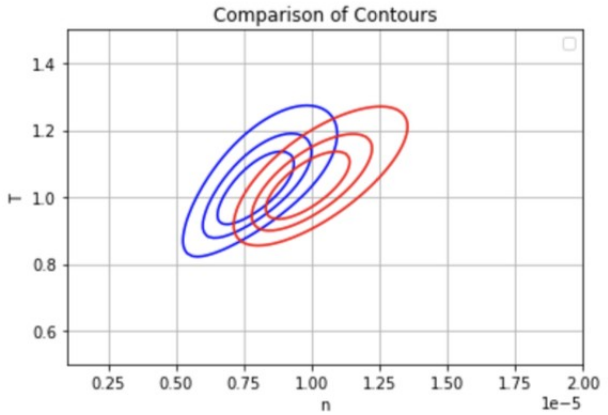

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- **Long-term goal: Enable event-based multi-messenger fits in Gammapy**
    - We start with blazars and JetSet as an example here

A new approach

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

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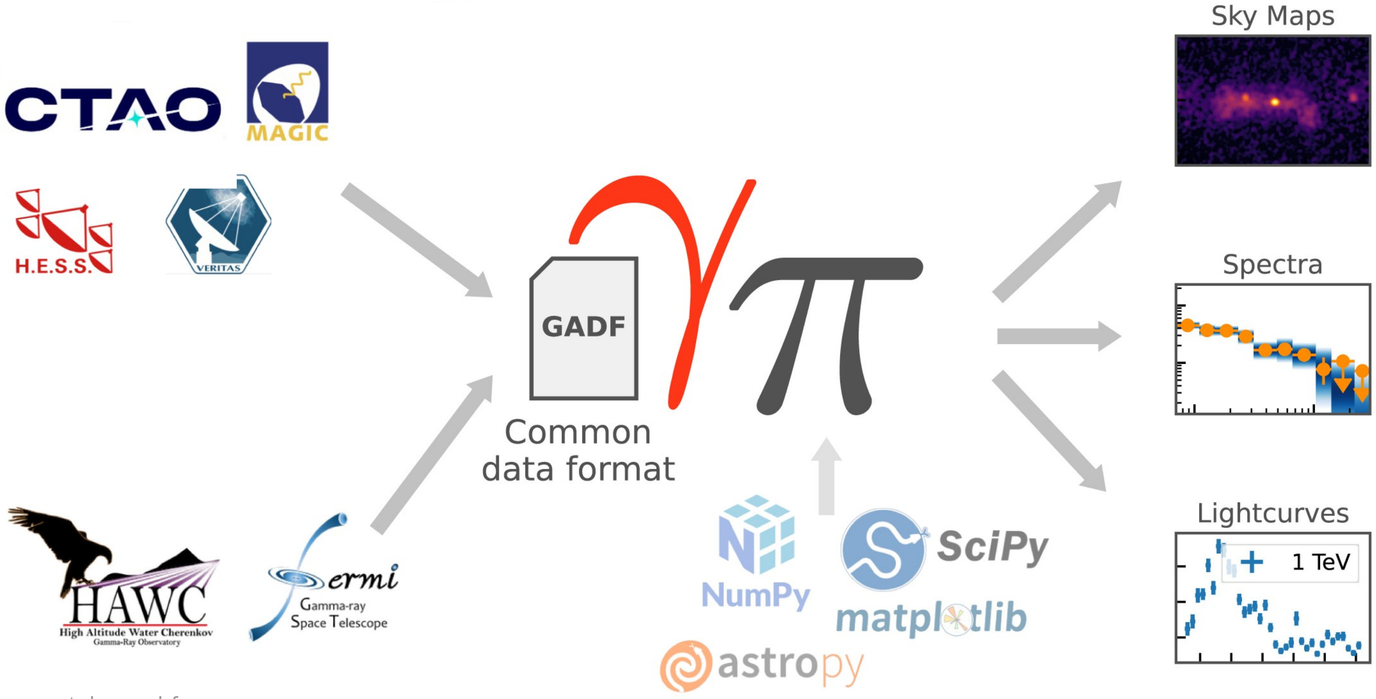
- Joined MWL fit on event basis using Gammapy
- Gammapy:
  - Python package for gamma-ray astronomy



Adapted from:
A. Donath et al. 2023, A&A, 678, A157

Gammapy

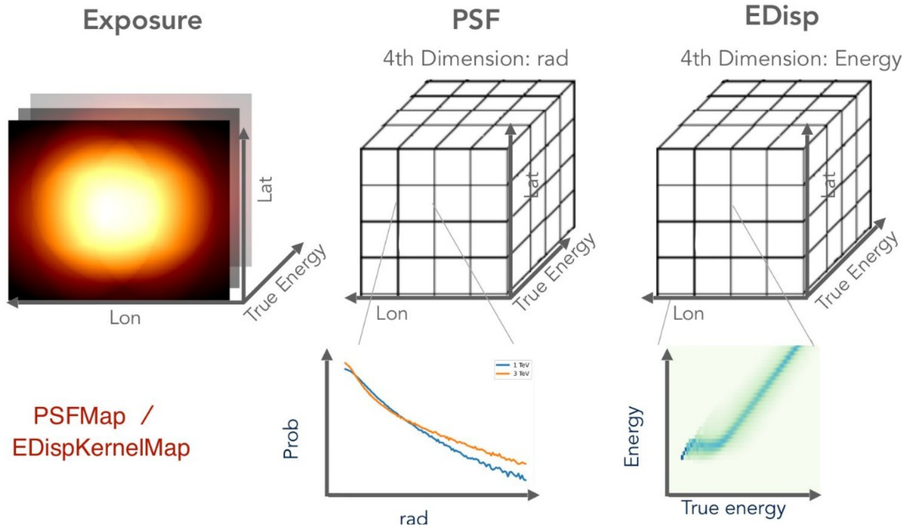
DL3

γ-like events

Time	RA	DEC	Energy	...
...				
...				

+

instruments response functions (IRFs)



Gammapy

DL3 → DL4

γ-like events

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...				
...				

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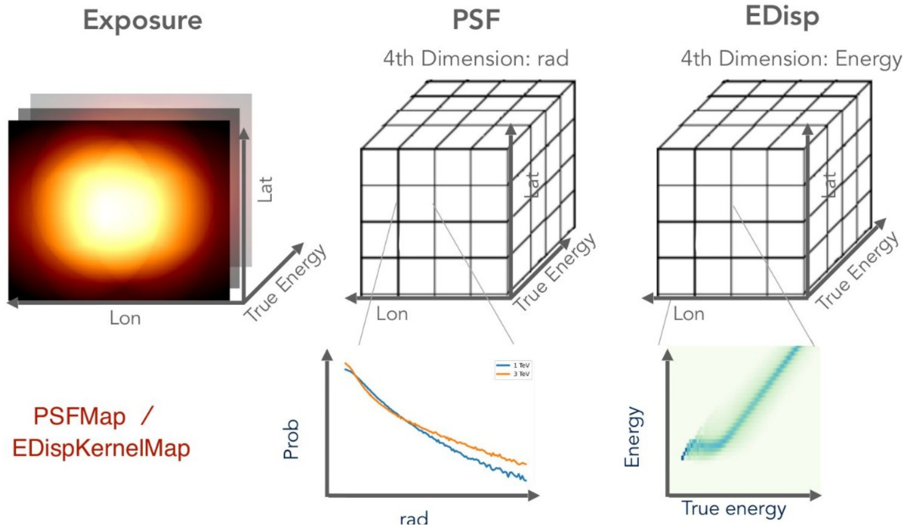
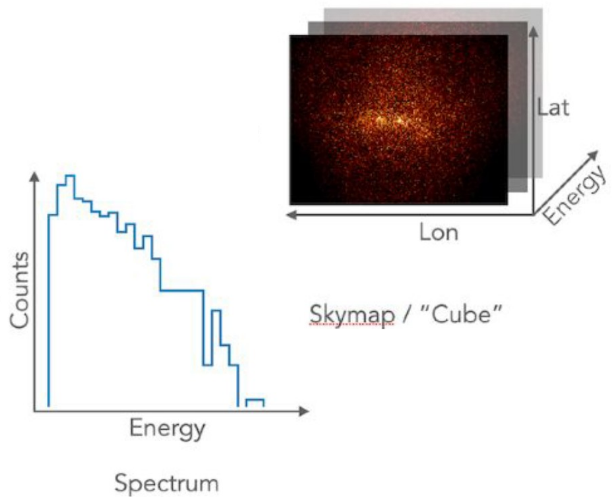


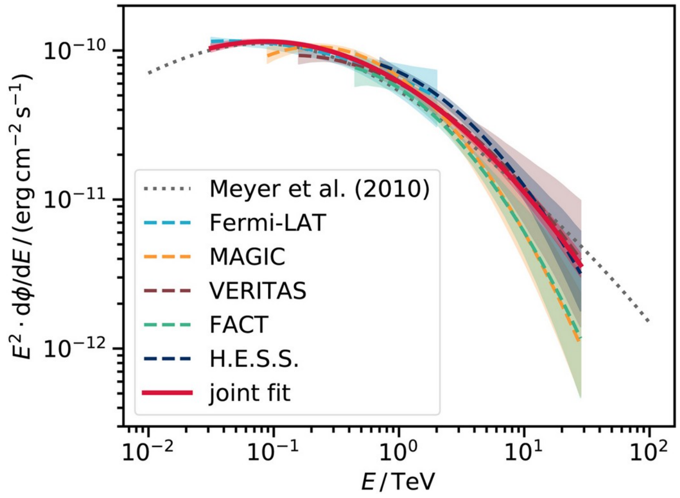
Binned data datasets:



Gammapy & MWL data

- Works nicely for gamma-ray data and joint instrument fits:

C. Nigro et al. 2019, A&A 625, A10



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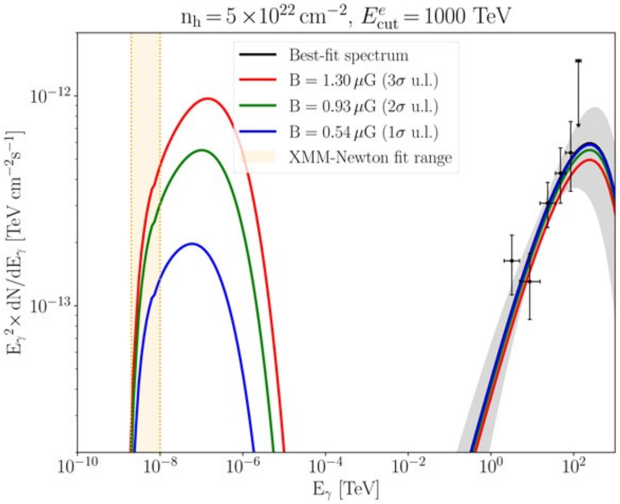
- Extension to X-rays:

  https://github.com/registerrier/gammapy-ogip-spectra



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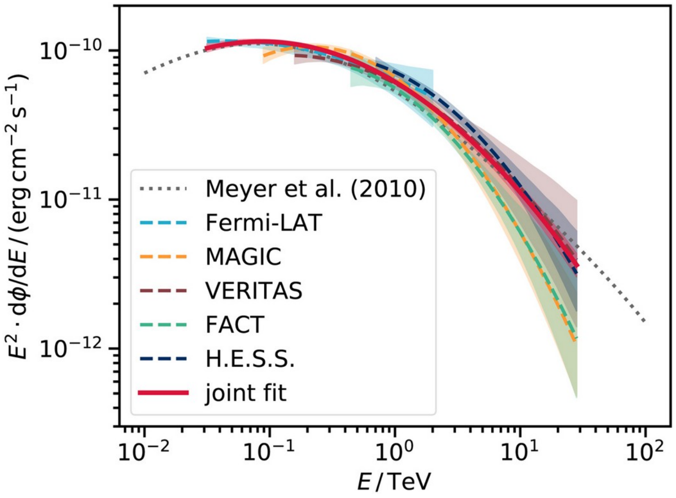

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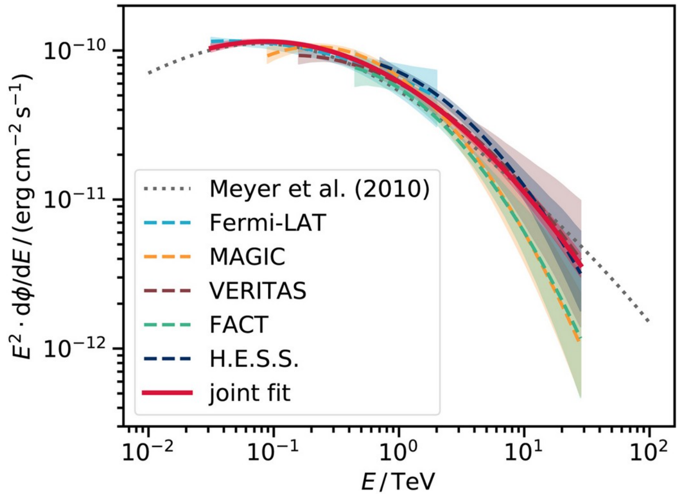

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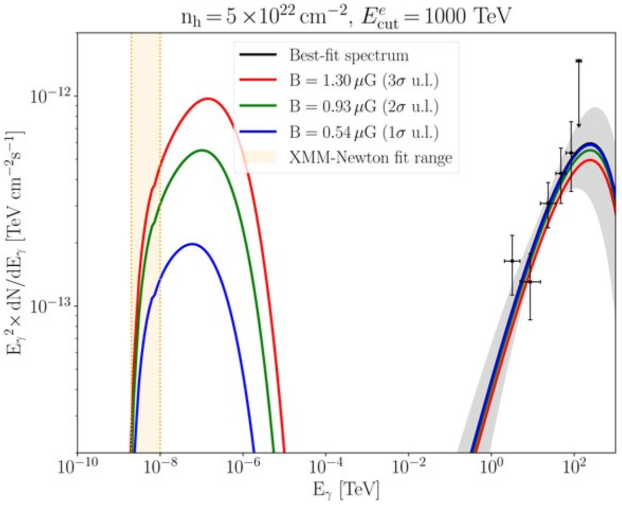
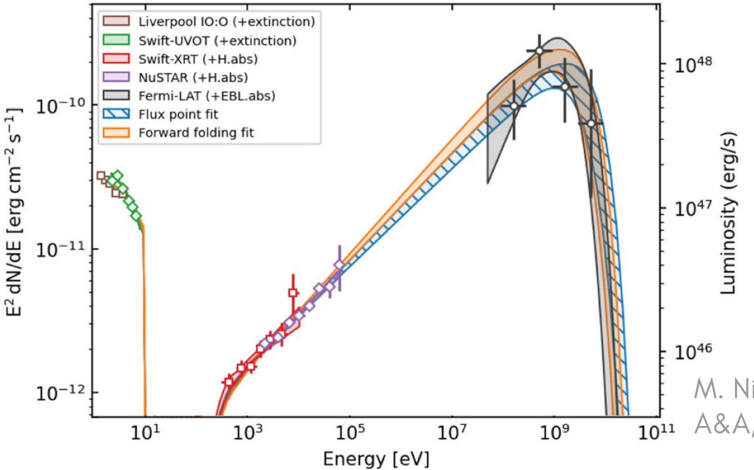


L. Giunti et al. 2022, A&A 667, A130

- Extension to UV/ optical:

https://github.com/mireianievas/gammapy_mwl_workflow



M. Nievas Rosillo et al. 2025,
A&A, 693, A287

New AGN modelling approach with Gammapy

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  - Simulations from CTAO (Very-high-energy gamma-rays)

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- Simulation of MWL data based on these IRFs using Gammapy:
- Physical model:
  - Leptonic Self-Synchrotron (SSC) model with EBL absorption
    - JetSeT (2020ascl.soft09001T) with its Gammapy plugin

+ Systematics for different bands

+ Absorption processes via the sherpa (10.5281/zenodo.593753.) module

Gammapy & SSC

- We produce 2 MWL Gammapy datasets:
  1) Event data (DL3) set with event lists and IRFs
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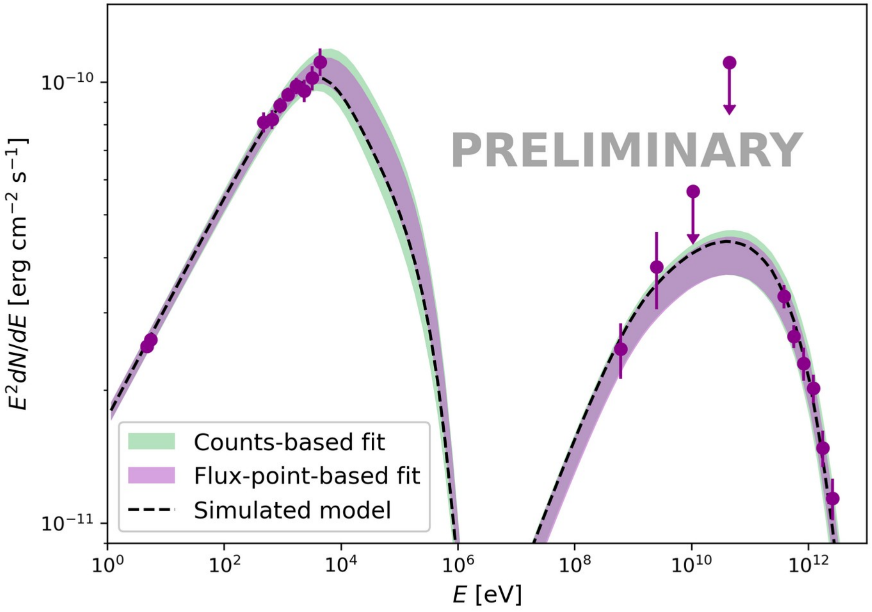
- We fit both datasets with a SSC model using JetSeT



Facilitating multi-messenger modelling using Gammapy

- Works quite well and events fit shows
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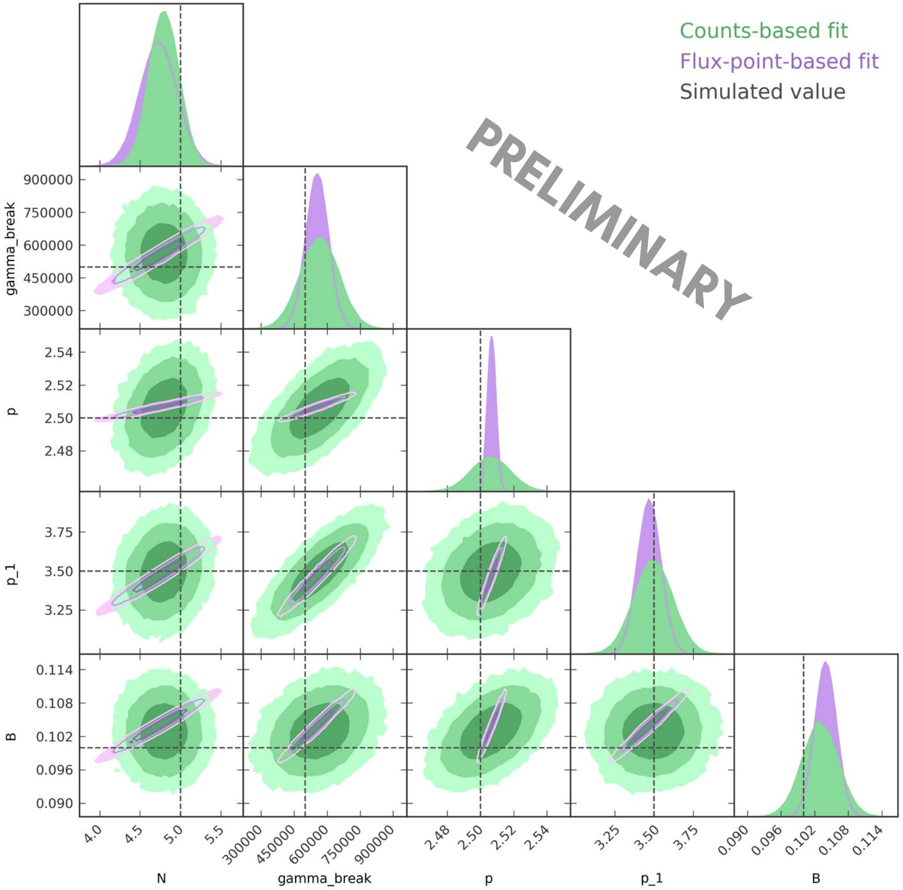

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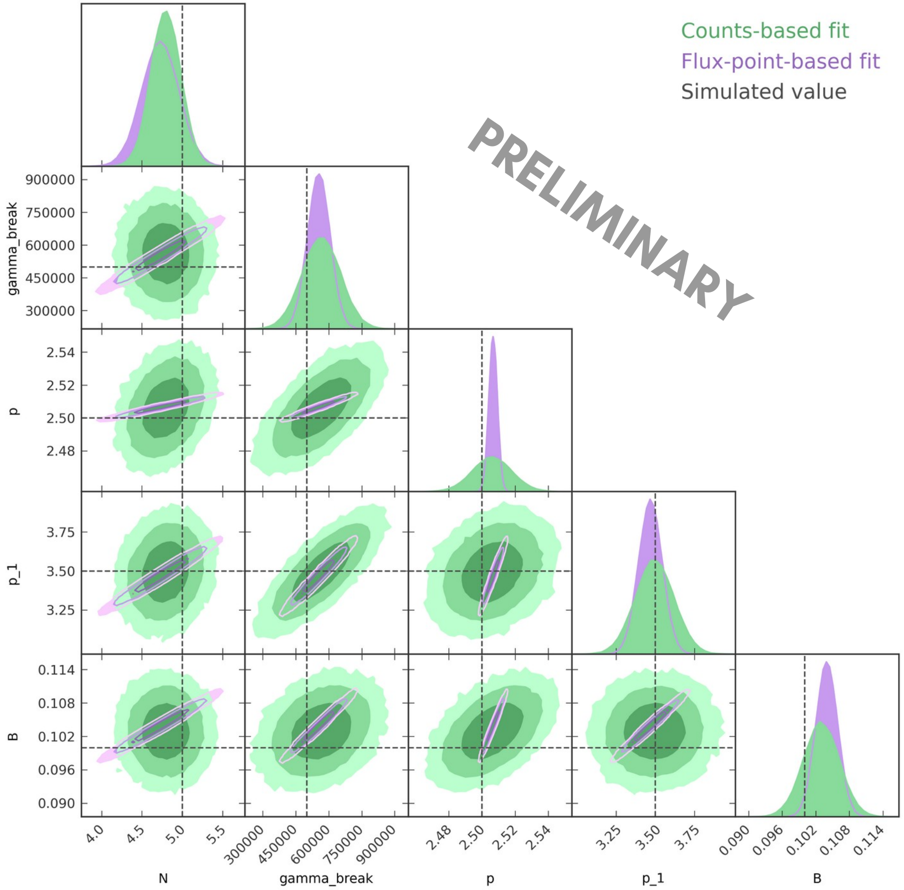
- But events fit takes longer (5-10x), e.g. 35 vs 10 min for 3, 190 vs. 50 min for 5 free parameters
  - JetSet timing inside Gammapy at one E: 0.02 sec
  - More complex models (e.g. hadronic ones) > 1 min

    → cannot be run on the fly



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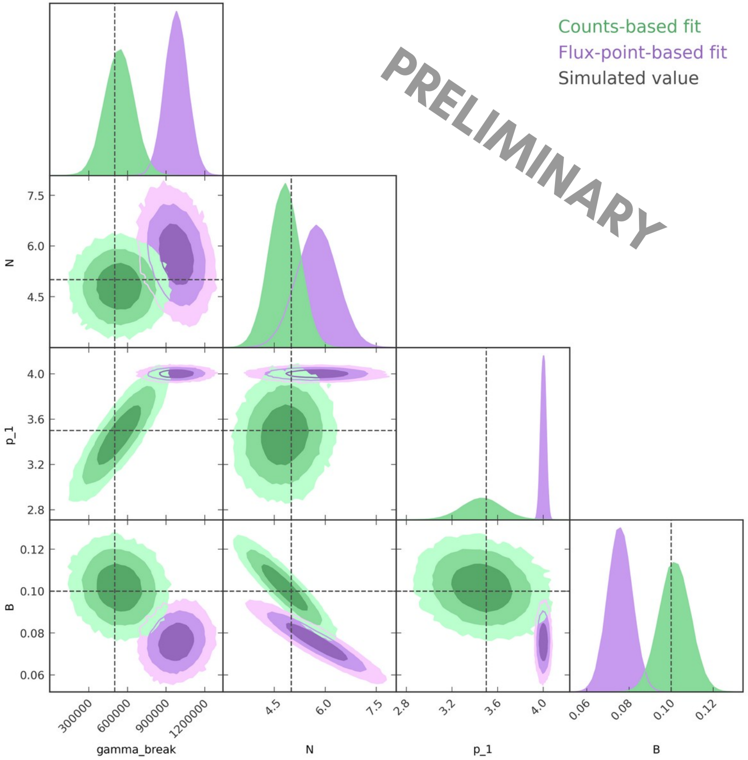

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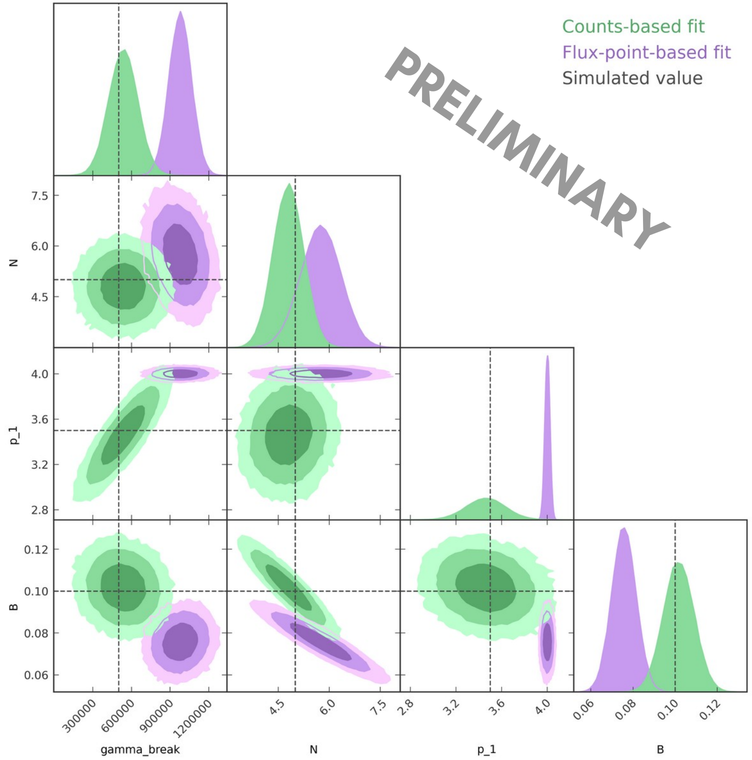
  - BUT e.g. overloads memory for a high number of paramters



Lessons learnt so far

- **Gammapy** enables us to **fit physical models directly on event basis**
  - Reducing biases and assumptions
  - Taking into account absorption, systematics or e.g. also ULs naturally
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- For **slow models (e.g. hadronic ones)** – **multimessenger fitting**
  - We are currently investigating **grid models + interpolation** methods
  - **Neural networks** and other machine learning methods might be a promising alternative

Thank you
for your attention!