COSI
Gamma-ray
Space Explorer

From Data Challenges to COSI Science

Chris Karwin
Clemson University

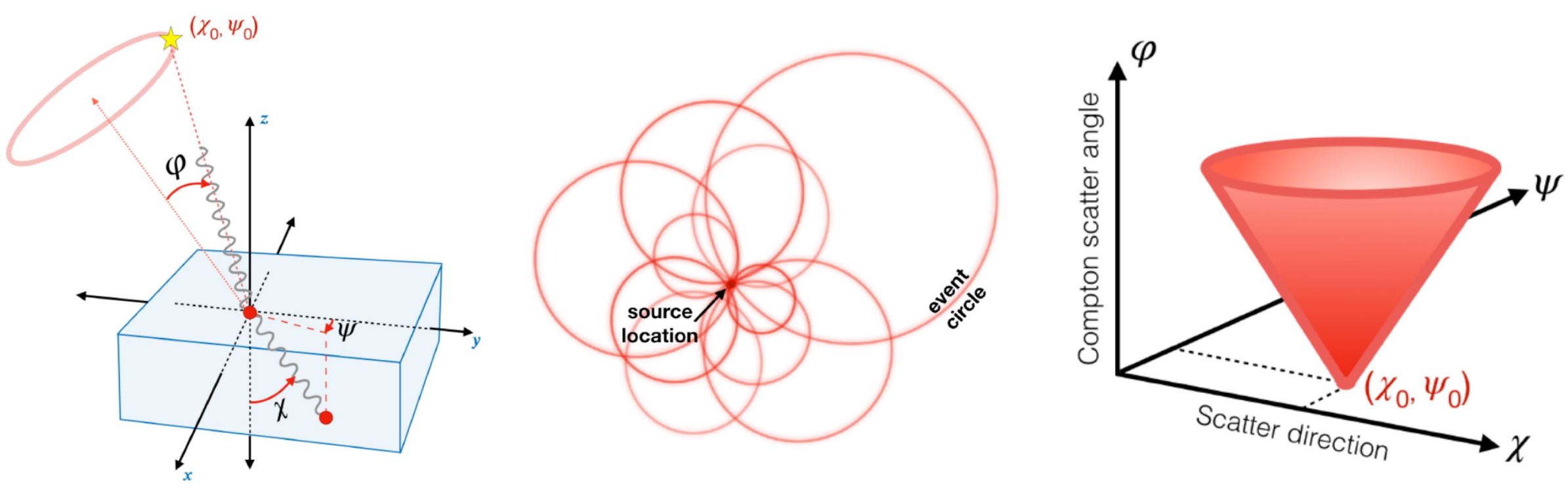
On behalf of the COSI Collaboration

Annual Meeting of the German Astronomical Society 2026

Sept 8, 2026

The Compton Data Space

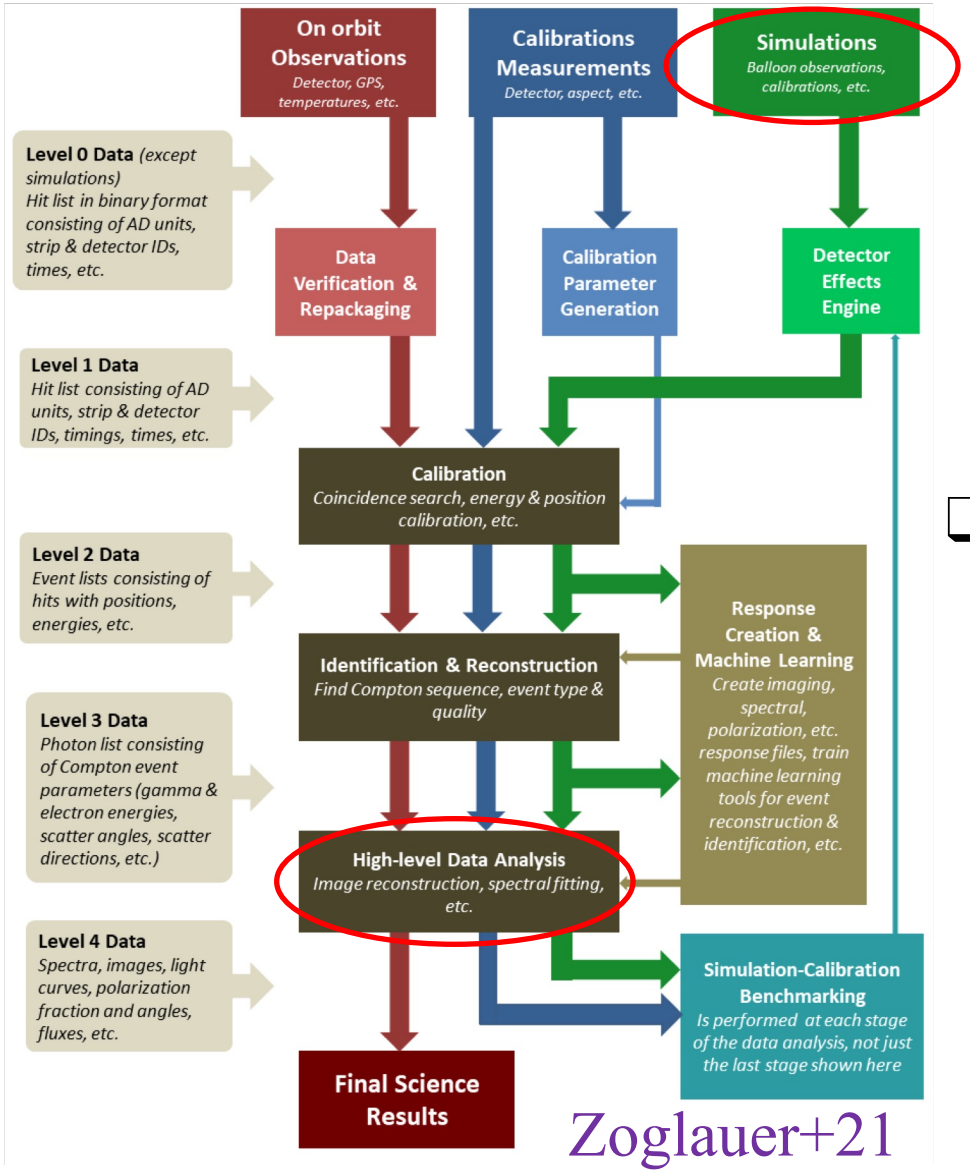
COSI
A Gamma-ray
Space Explorer



- The direction of an incident photon is constrained to an event circle, shown in red
- The overlap of multiple event circles allows for the localization and characterization of a source
- This is represented in a 3D Compton data space

The COSI Data Pipeline

COSI
A Gamma-ray
Space Explorer



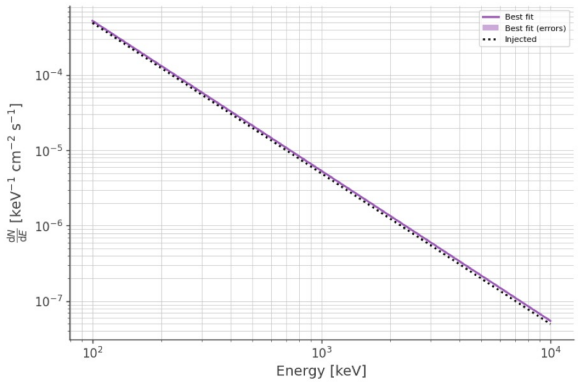
- Transforming reconstructed events into science-ready data products requires a well-characterized instrument and a multi-stage data analysis pipeline

COSIPy and the Data Challenges

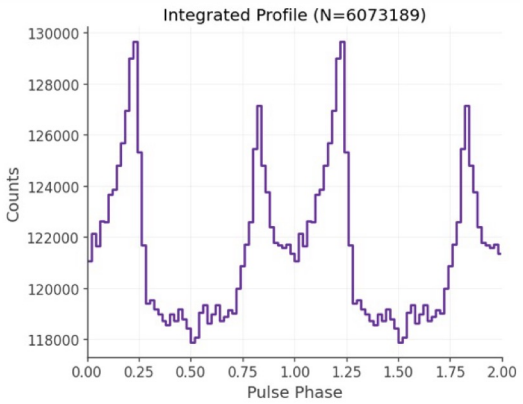
COSI
A Gamma-ray
Space Explorer

- COSIPy: open-source high-level analysis Python library for COSI
- Data Challenges: simulated data increasingly more realistic every year

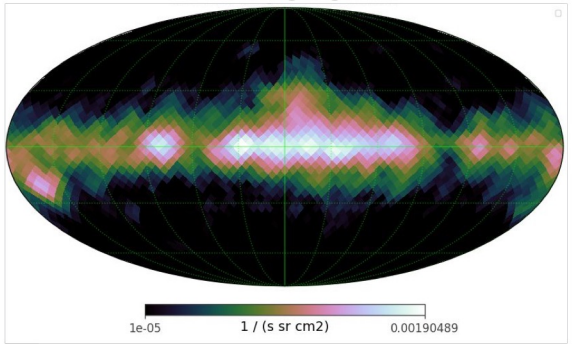
Spectral fits



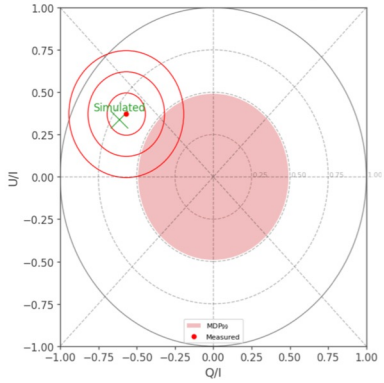
Phase-resolved analysis



Imaging



Polarization analysis



https://github.com/cositools/

cosipy

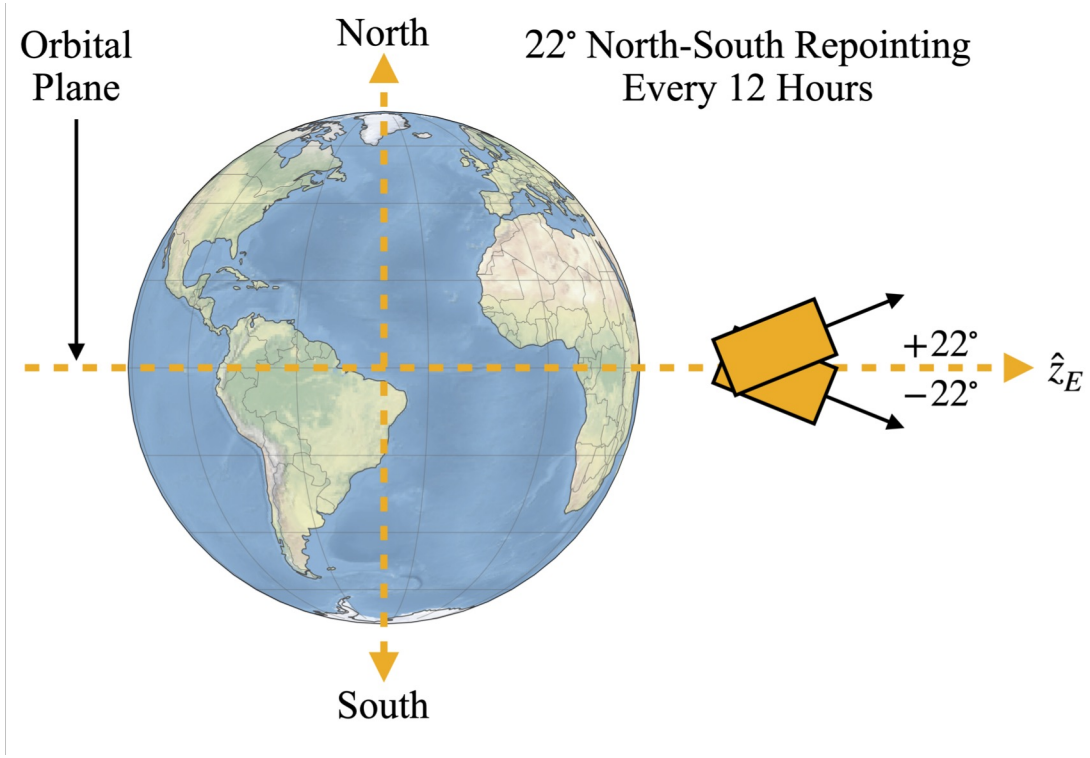
cosi-data-challenges

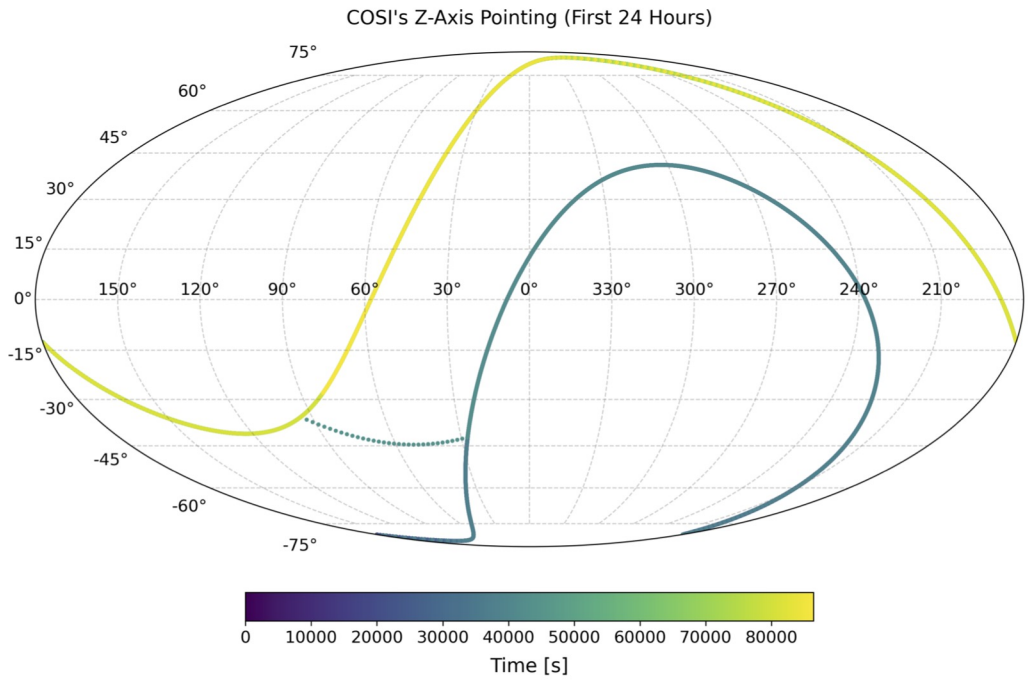
Latest release (DC4) now available!

and more!

Simulations: Orbit and Pointing

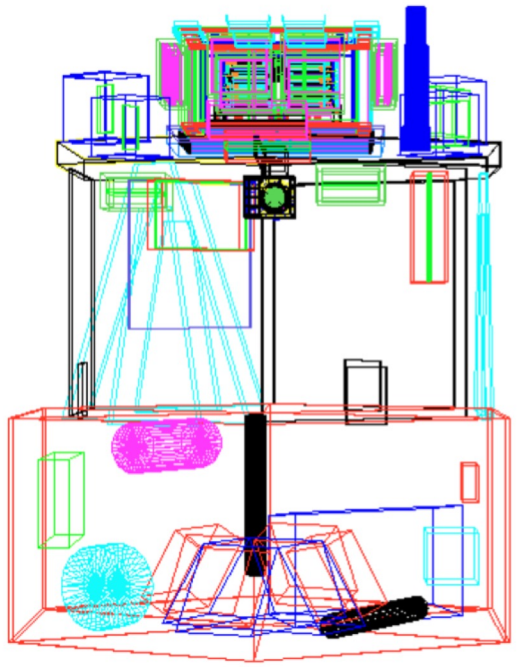
COSI
A Gamma-ray
Space Explorer

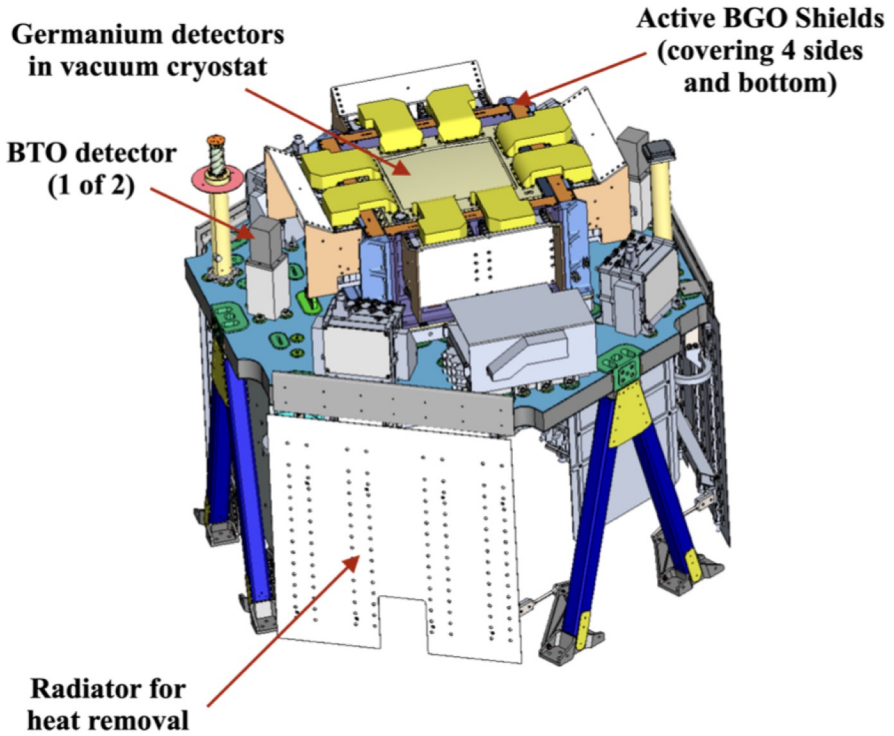


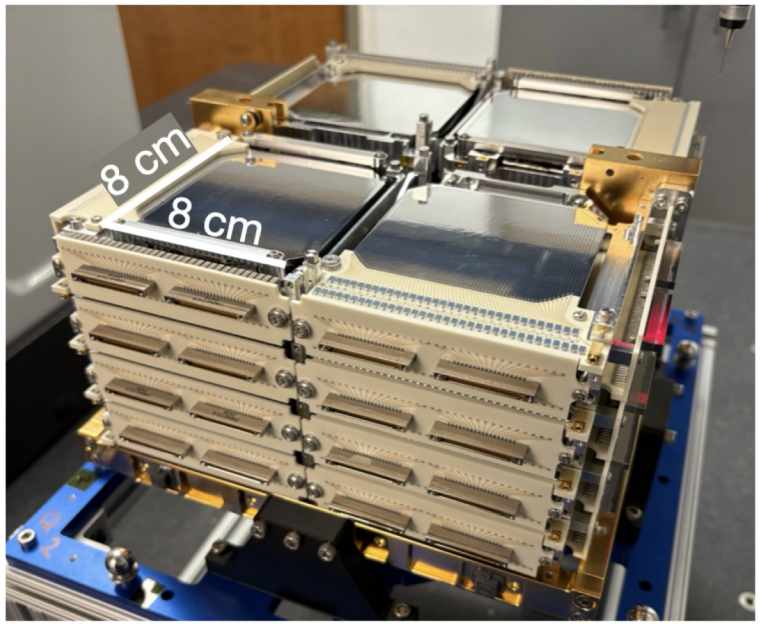


- ❑ Simulated 3 months of observations
- ❑ Simulations employ MEGALib
- ❑ DC4 uses an equatorial orbit at 530 km, with the instrument pointing rocking between $\pm 22^{\circ}$ from the Earth zenith every 12 hours (8-minute slew time)

Simulations: Mass Model



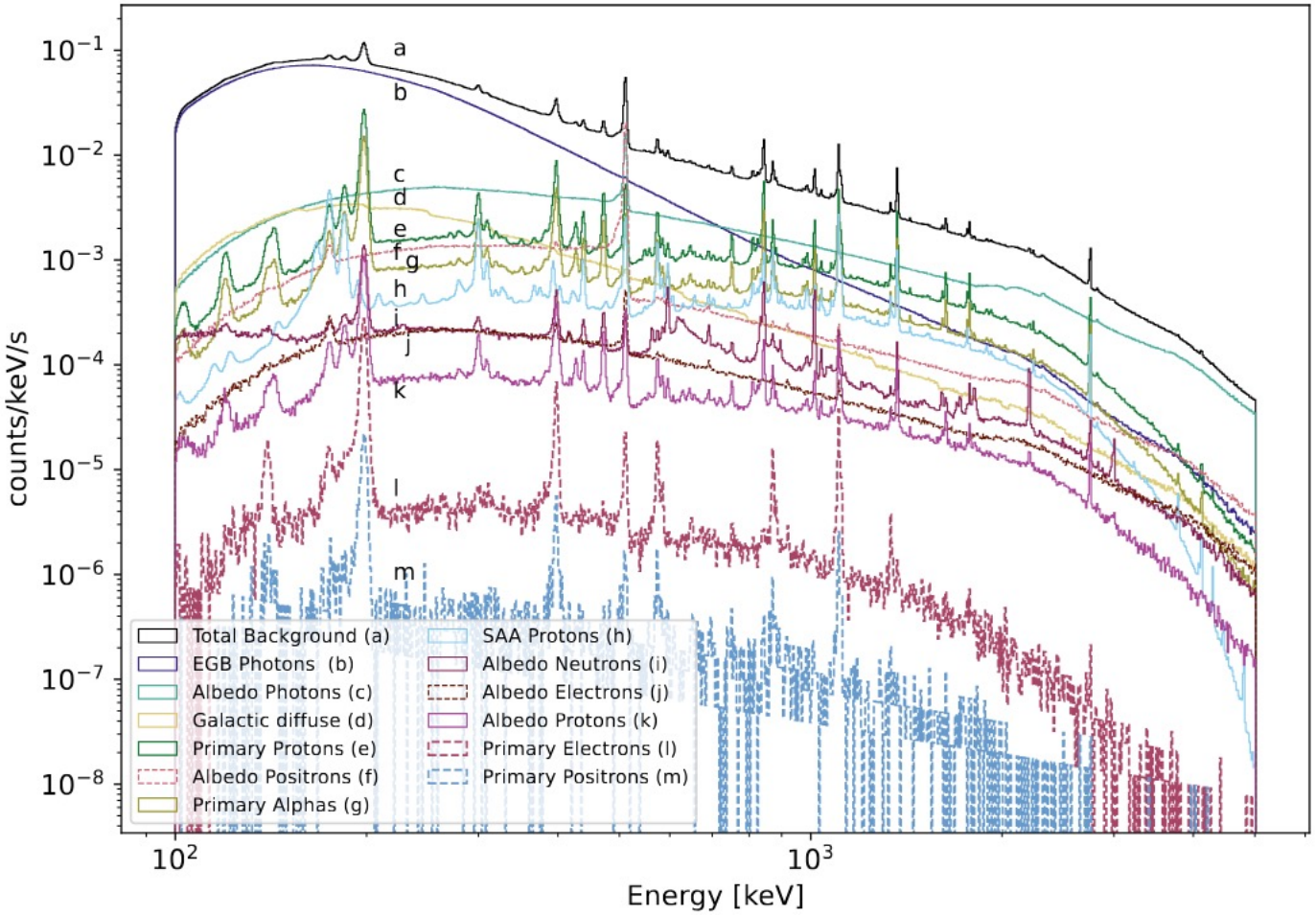




- MEGALib mass model shown on the left compared to payload schematic in the middle and the assembled flight model germanium detectors on the right

Simulations: Background Emission

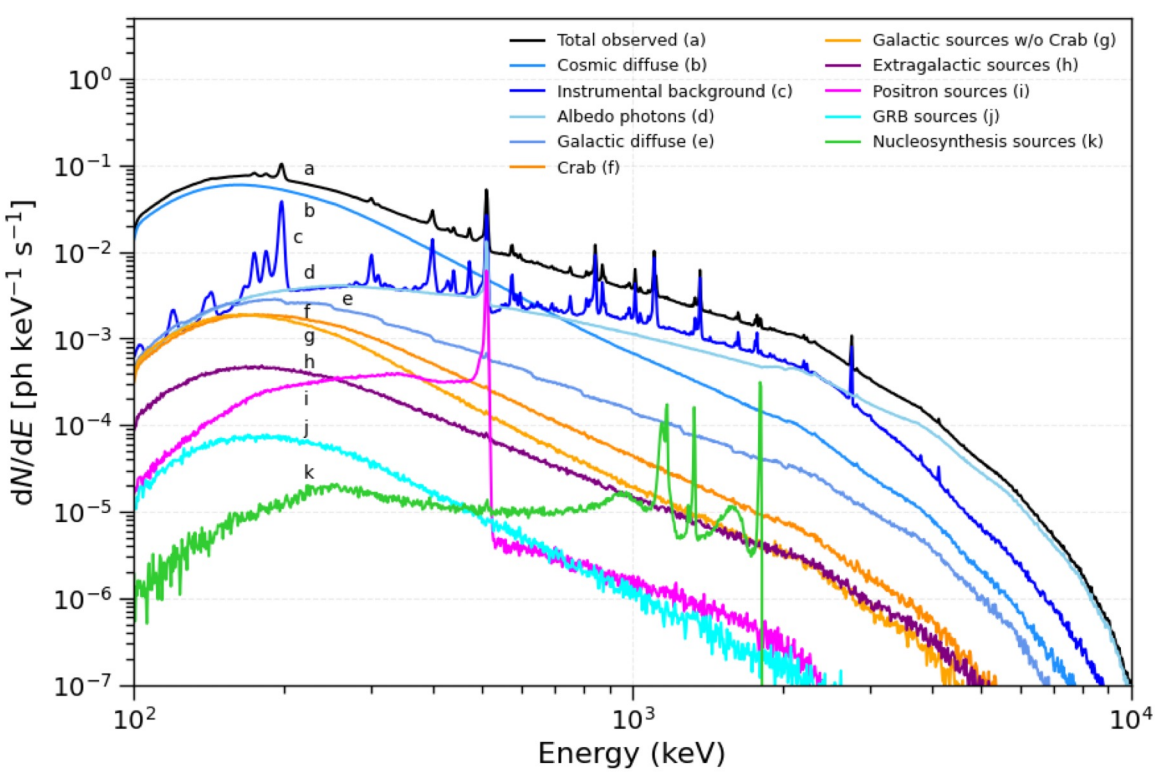
COSI
A Gamma-ray
Space Explorer

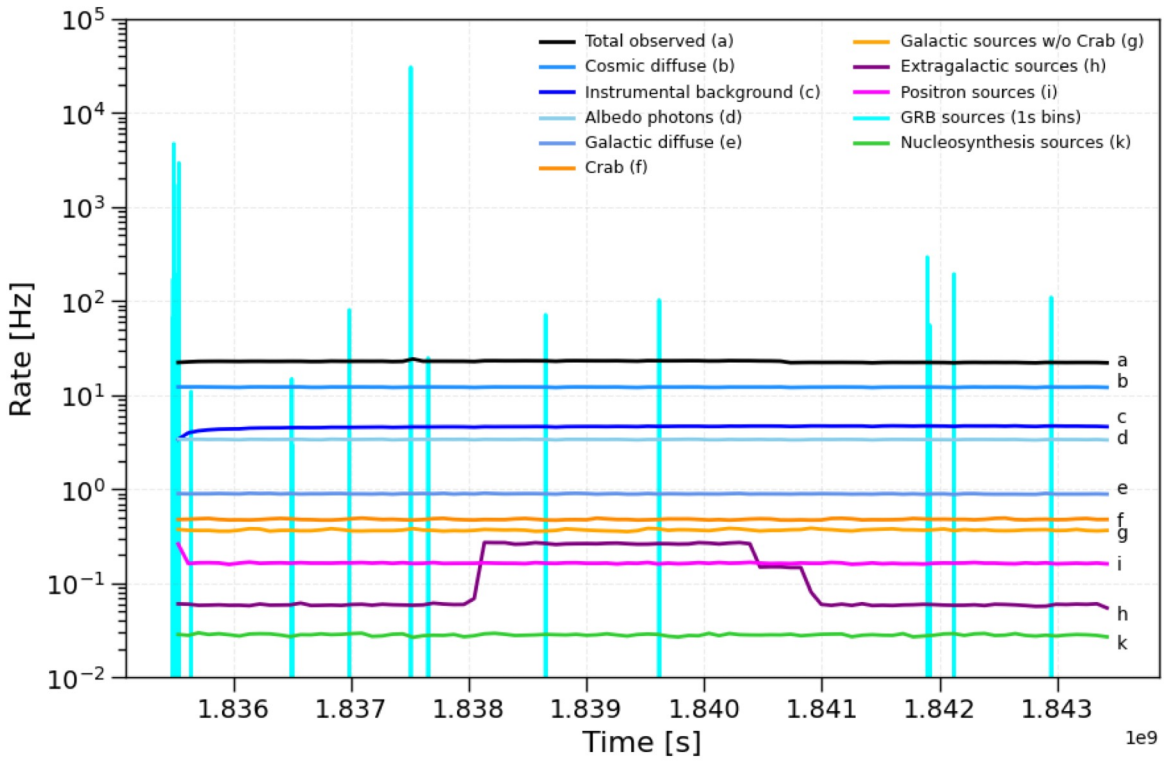


- We have been developing detailed BG predictions, as described in Gallego+26
- Total BG includes instrumental (including SAA), albedo, cosmic diffuse (i.e., EGB), and Galactic diffuse continuum

DC4 Mock Dataset

COSI
A Gamma-ray
Space Explorer

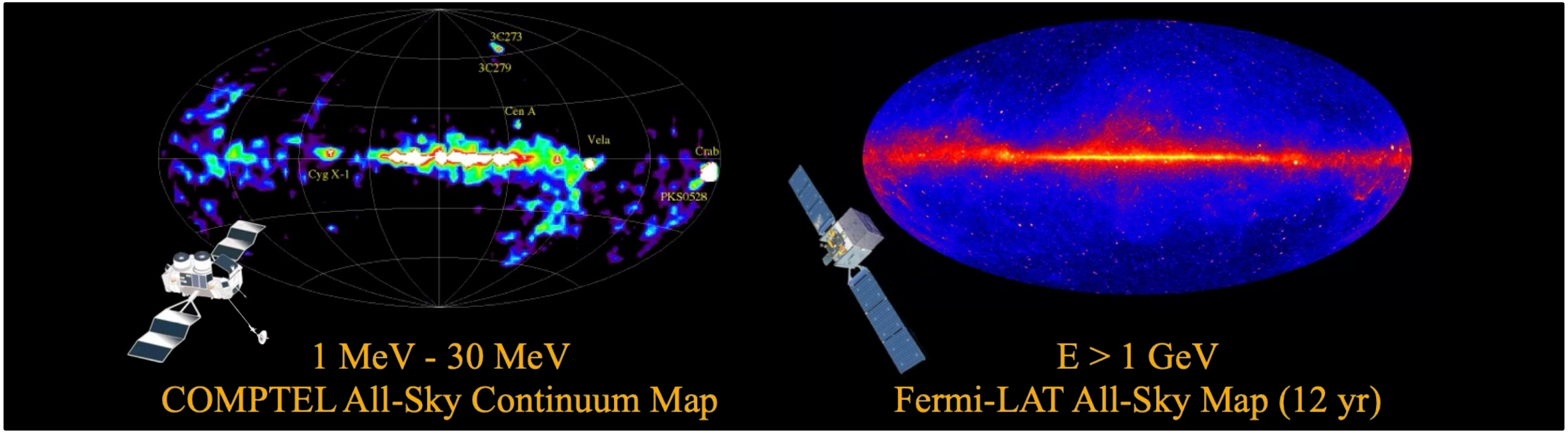




- Consist of 64 astrophysical sources (from COSI science team) plus total background (See Gallego+26 for detailed background predictions)
- Counts spectra (left) and light curves (right) from the DC4 mock dataset.

Galactic Diffuse Continuum Emission (GDCE)

COSI
A Gamma-ray
Space Explorer

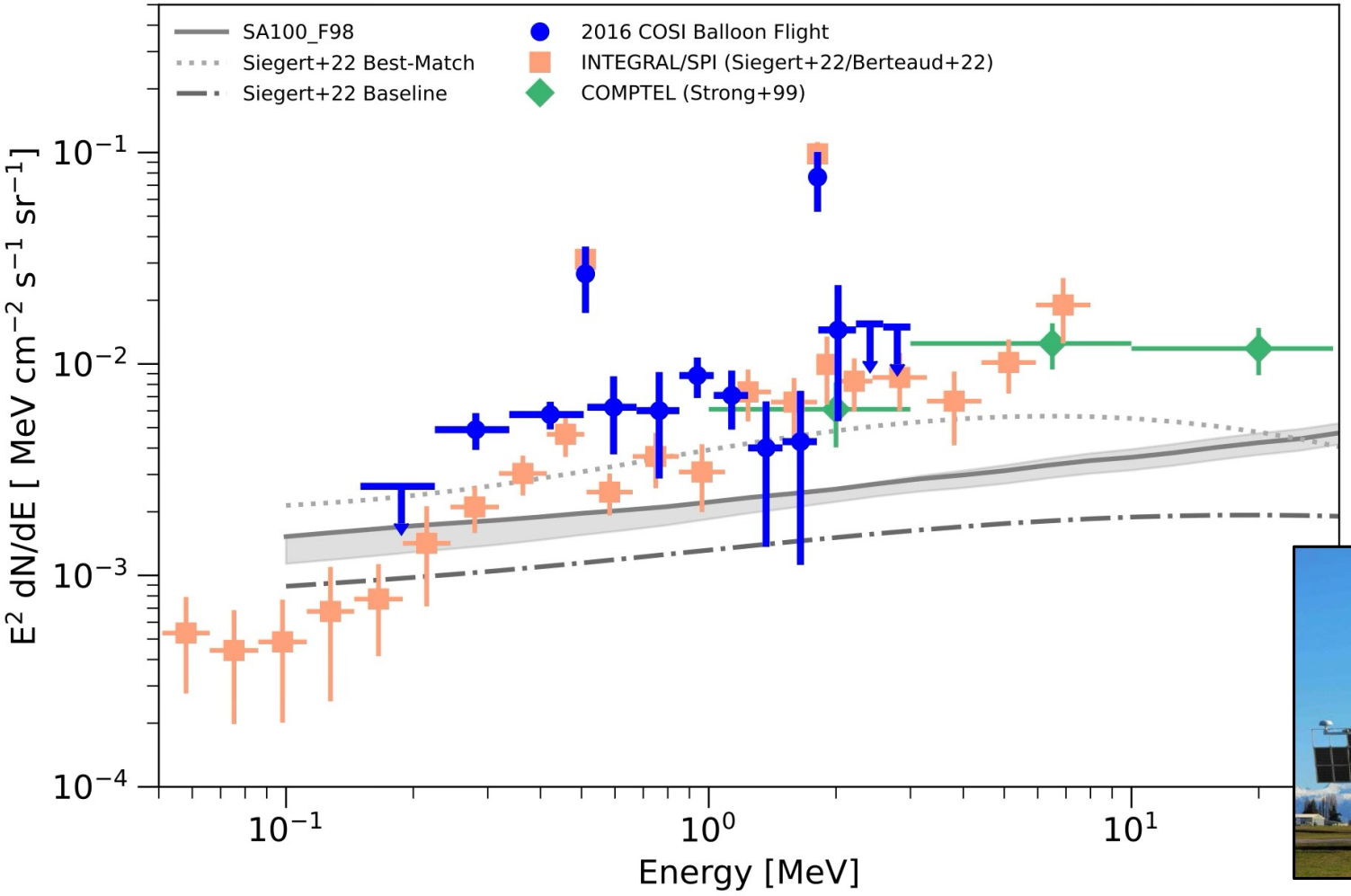


- The Galaxy is filled with high-energy cosmic rays, which interact with gas, dust, and light to produce gamma rays

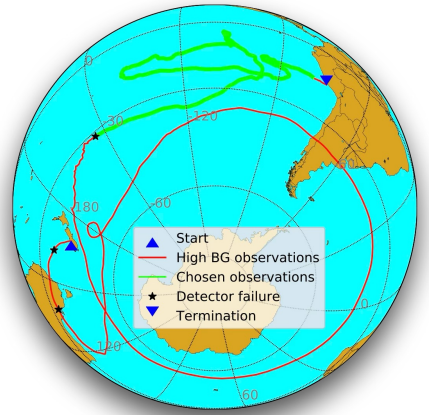
2016 COSI ULDB Flight

COSI
A Gamma-ray
Space Explorer

Karwin+23, ApJ, 959, 90



A unique probe into the nature of cosmic ray electrons in the Galaxy!

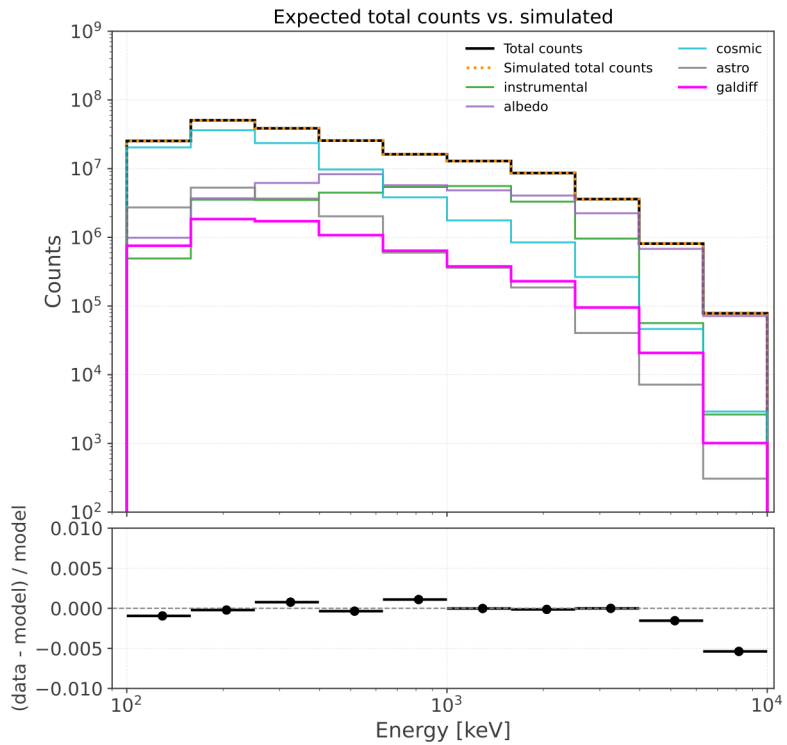


- 46 days of COSI balloon observations compared to 20+ years of INTEGRAL/SPI data

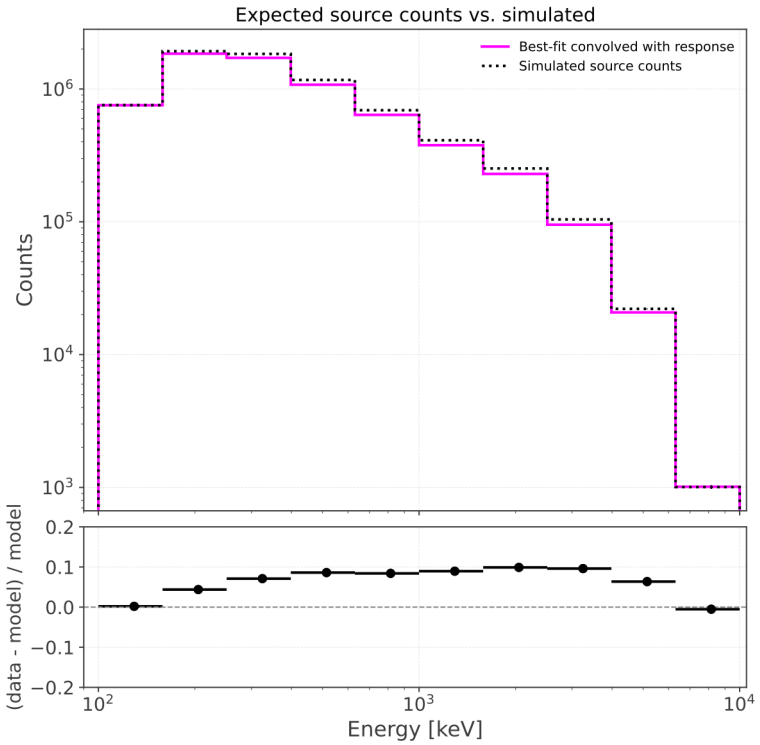
Spectral Fit with COSI Data Challenge 4

COSI
A Gamma-ray
Space Explorer

Total Photons



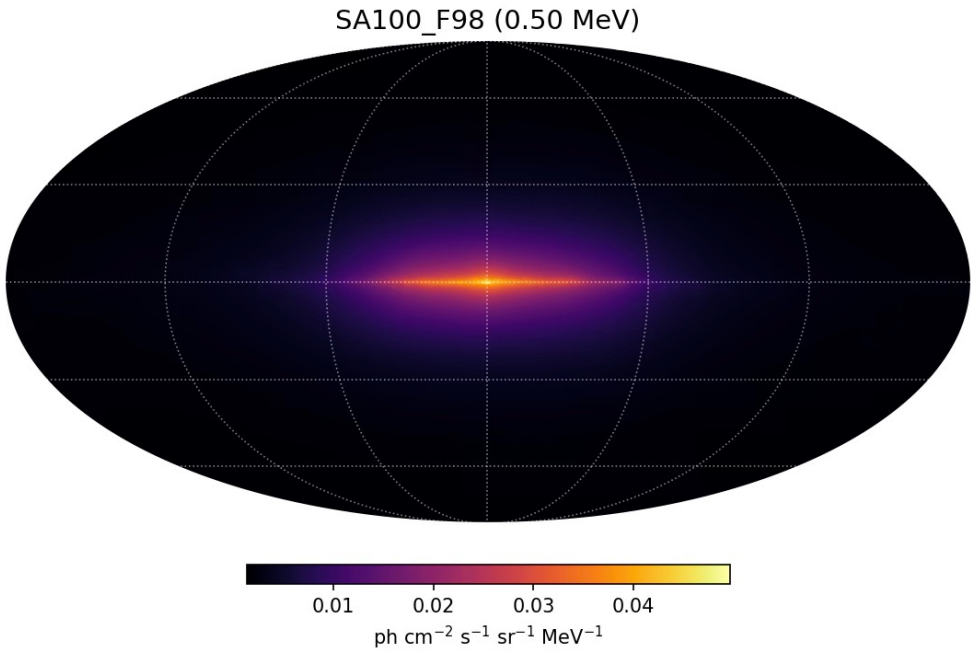
Galdiff Photons



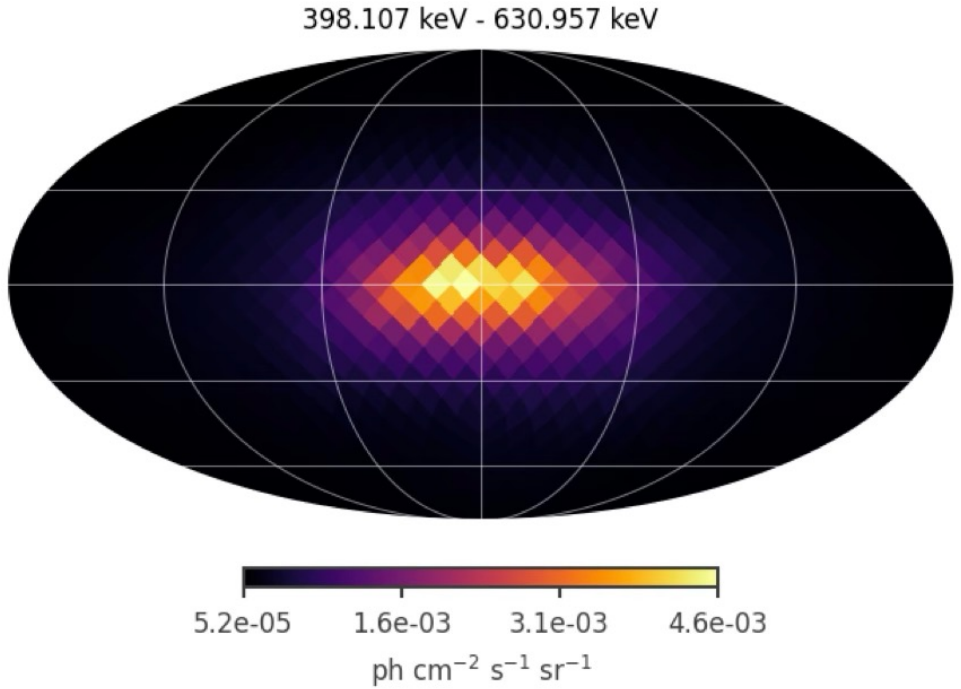
- Total counts agree within 1%
- Current fit systematic in galdiff spectrum ~10-15% (includes software limitations, statistical fluctuations, and background smoothing)
- Initial estimates of systematics including galdiff modeling uncertainties ~25%

Imaging with COSI Data Challenge 4

COSI
A Gamma-ray
Space Explorer



Input Galdiff Model



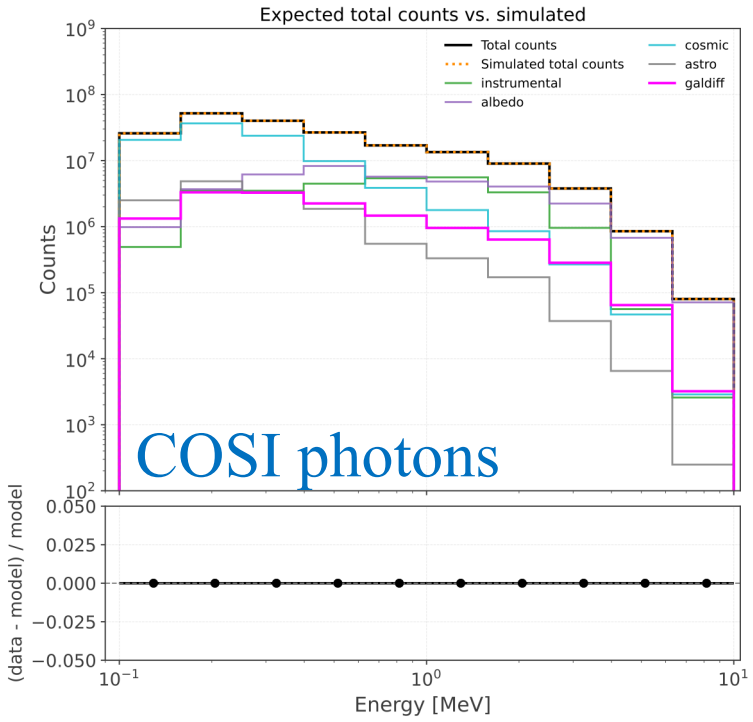
RL Image

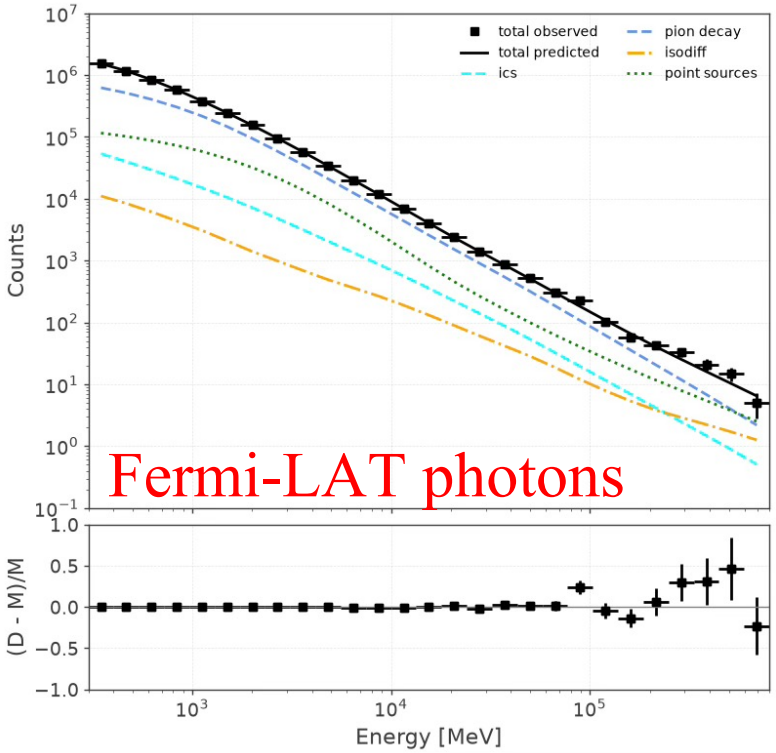
- Galdiff image (linear color scale) at 0.5 MeV from Richardson-Lucy (RL) deconvolution algorithm
- Current response resolution is nside=8 (~7.3° pixel size), compared to COSI's required resolution of 4.1° deg (FWHM) at 0.511 MeV
- RL imaging provides a qualitative model-independent assessment of the source morphology, although relies on a background assumption

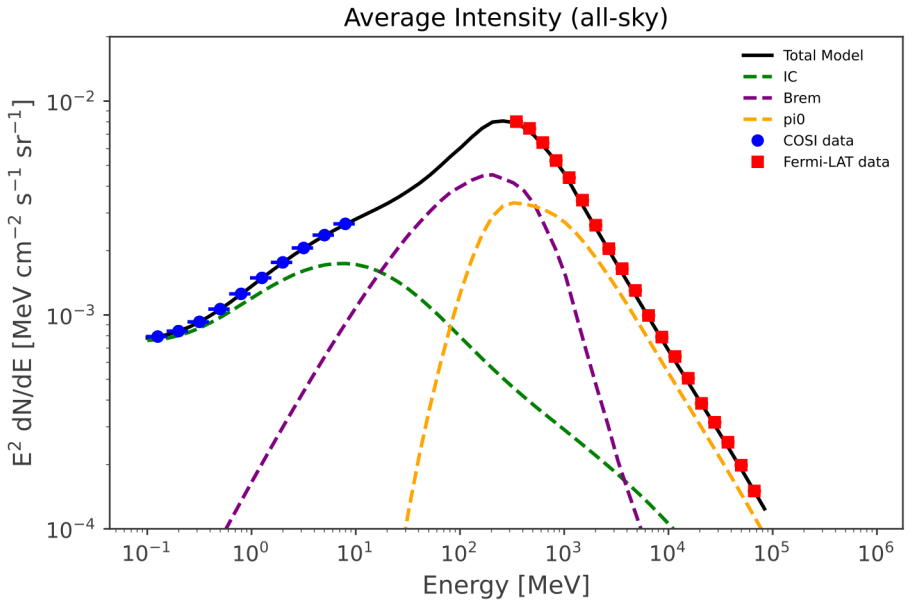
Karwin+26 in prep

Joint Fit with COSI and Fermi-LAT

COSI
A Gamma-ray
Space Explorer







Broad-band spectrum
(100 keV – 100 GeV)

pion_decay.GalpropMap.K	(9.982 +/- 0.022) x 10^-1	
ic.GalpropMap.K	1.000 +/- 0.004	
brem.GalpropMap.K	(9.988 +/- 0.026) x 10^-1	
LAT_isodiff_Normalization	1.059 +/- 0.030	
instrumental	4.1440 +/- 0.0031	Hz
albedo	5.572 +/- 0.004	Hz
cosmic	(1.4827 +/- 0.0005) x 10	Hz
astro	2.079 +/- 0.004	Hz

Joint parameters

LAT Nuisance parameters

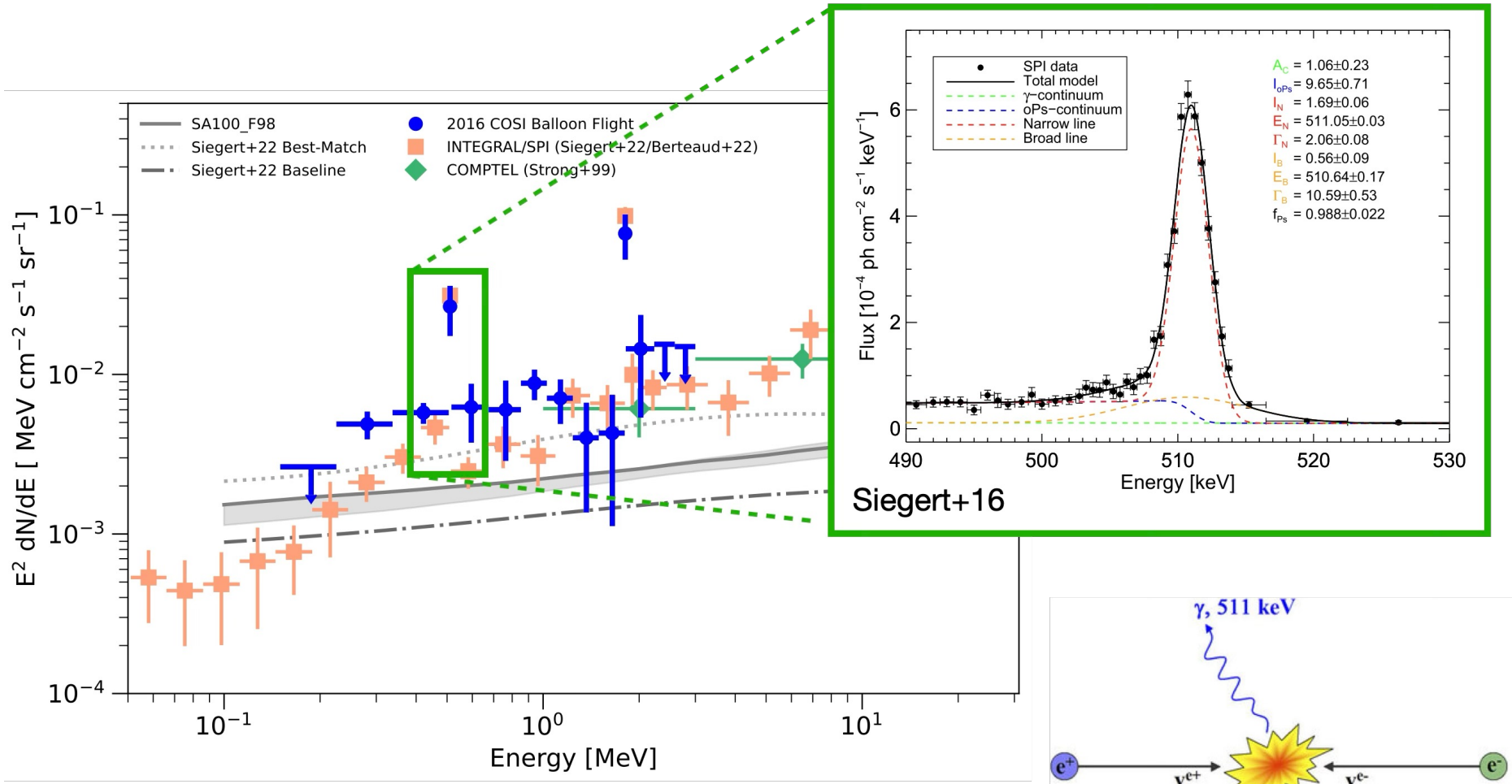
COSI Nuisance parameters

- We now have a working pipeline to perform joint fits of diffuse sources with COSI and LAT, utilizing the 3ML framework
- Shown here is an example proof-of-principle fit, which uses injected data for both COSI and Fermi-LAT (thus the very good agreement)

Karwin+ in prep

Positron Puzzle

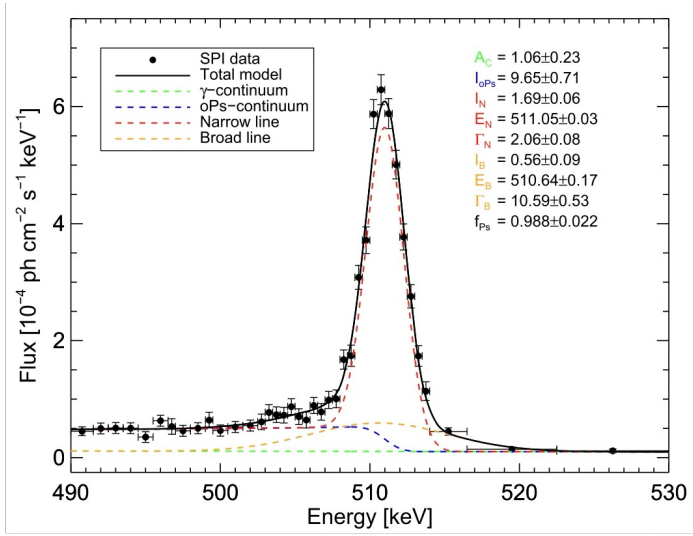
COSI
A Gamma-ray
Space Explorer

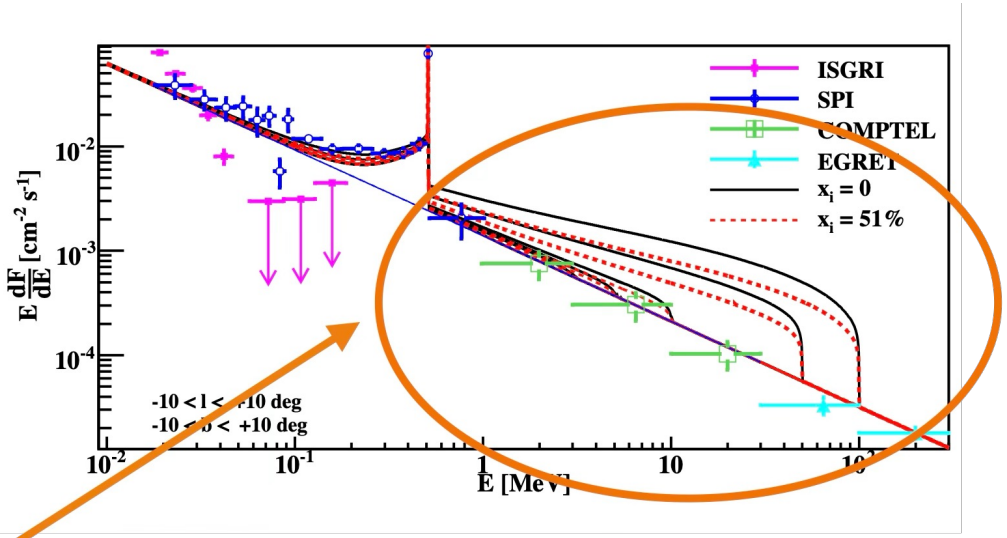


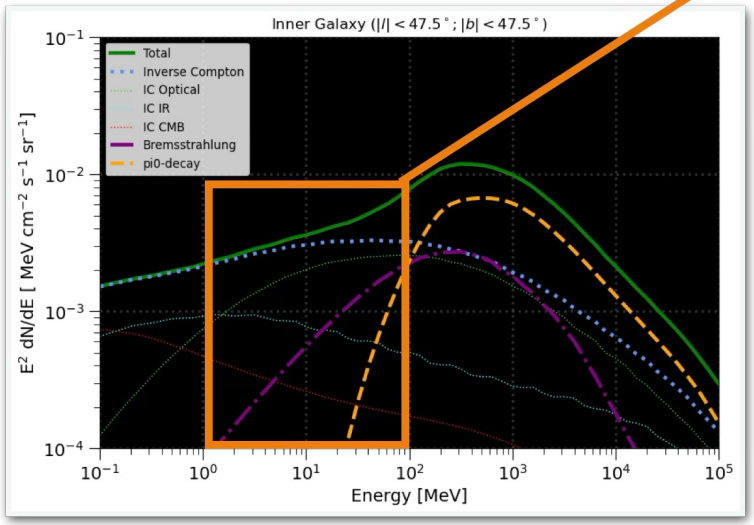
- Comes from annihilation of electrons and positrons
- Brightest steady gamma-ray line emission in the Galaxy

In-Flight Annihilation

COSI
A Gamma-ray
Space Explorer







Galactic diffuse continuum dominates emission

Relaxation of Energy Constraints for Positrons Generating the Galactic Annihilation Signal

Souradeep Das [1,2,*] Mark R. Krumholz [1,†]
Roland M. Crocker [1,‡] Thomas Siegert [3,§] and Laura Eisenberger[3,¶]

[1] *Research School of Astronomy and Astrophysics, Australian National University, 233 Mt Stromlo Road, Stromlo ACT 2611, Australia*
[2] *Center for High Energy Physics, Indian Institute of Science, C. V. Raman Avenue, Bengaluru 560012, India*
[3] *Julius-Maximilians-Universität Würzburg, Institut für Theoretische Physik und Astrophysik, Lehrstuhl für Astronomie, Emil-Fischer-Str. 31, D-97074 Würzburg, Germany*

(Dated: June 12, 2025)

Detection of positron in-flight annihilation from the Galaxy

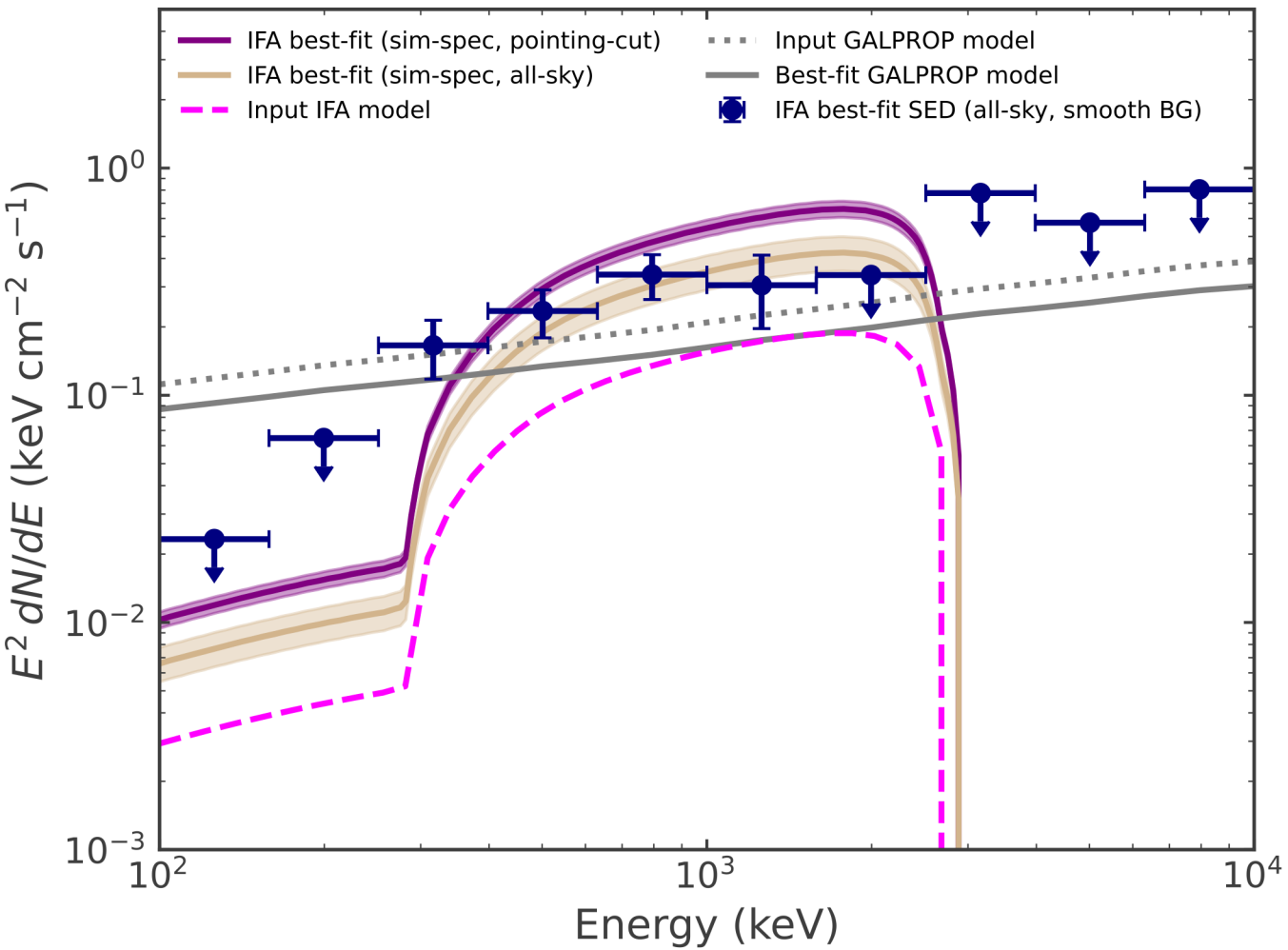
J. Knödlseder[1], K. Sabri[1,2], P. Jean[1], P. von Ballmoos[1], G. Skinner[3], and W. Collmar[4]

[1] Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse, CNRS, CNES, UPS, 9 avenue Colonel Roche, 31028 Toulouse, Cedex 4, France
e-mail: jknodlseder@irap.omp.eu
[2] Laboratoire Univers et Particules de Montpellier, Université de Montpellier, CNRS/IN2P3, Place Eugène Bataillon, 34095 Montpellier Cedex 5, France
[3] Honorary Senior Research Fellow, School of Physics and Astronomy, University of Birmingham, UK
[4] Max-Planck-Institut für extraterrestrische Physik, Postfach 1603, 85740 Garching, Germany

Received 23 June 2025 / Accepted 9 July 2025

- Two recent analyses of in-flight annihilation reach notably different conclusions: one reports evidence for a signal, while the other derives substantially higher limits on the positron injection energy.
- Constraining in-flight annihilation is one of COSI's key science goals, and it will have strong dependence on the Galactic diffuse
- In prep: constraining in-flight annihilation with joint fit of LAT, SPI, and COSI (DC4), part of Fermi GI program (cycle 18)

In-Flight Annihilation



- DC4 input model based on recent analysis of COMPTEL data in Knödlseder+25
- DC4 signal is detected at the ~4σ confidence level (using an empirical model), but our power to constrain the cutoff energy above 1 MeV is limited
- This is based on the DC4 mock dataset (3 months of observations), which is by no means complete in terms of the included sources

Summary

COSI
A Gamma-ray
Space Explorer

- The COSI Data Challenges support the development of the COSI data analysis pipeline while providing the astrophysics community with resources to learn how to analyze COSI data
- The Data Challenges are being used to prepare for flight observations across COSI's different science cases (e.g., Galactic diffuse continuum and in-flight annihilation)
- COSI will map the Galactic diffuse continuum emission across the entire sky with unprecedented sensitivity, providing a unique probe into the nature of CR electrons in the Galaxy
- COSI will play a key role in constraining the positron injection energy, which in turn will have important implications for the plausible positron sources

Thank you!