The Path From COSI to COSI-X

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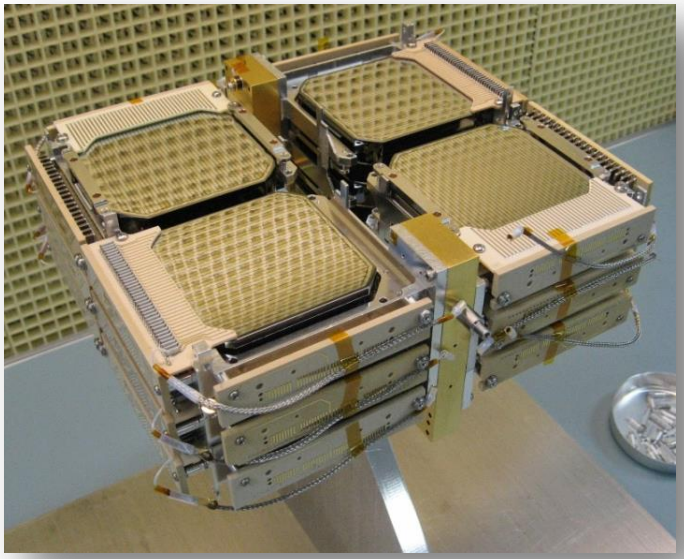
for the COSI / COSI-X collaboration

Instruments & Campaigns

COSI

- Balloon-borne Compton telescope
- Energy range: 0.2 – 5.0 MeV
- 12 high-purity Ge double-sided strip detectors, 2 mm strip pitch
- Energy resolution: 1.5-3.0 keV FWHM
- Depth resolution: ~0.5 mm FWHM
- Angular resolution: up to ~4° FWHM
- Large field-of-view: almost 1/4 of full sky

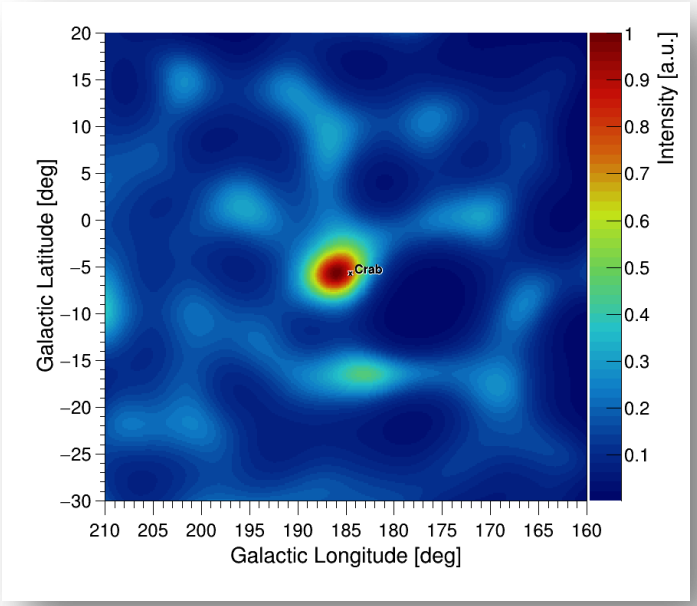


Successful Balloon Campaigns

- NCT: 2 GeD prototype, Ft. Sumner, 2005
- NCT: 38-hour flight of 10 GeD instrument , Ft. Sumner, 2009
- COSI: 46-day flight from Wanaka, New Zealand on super-pressure balloon, 2016

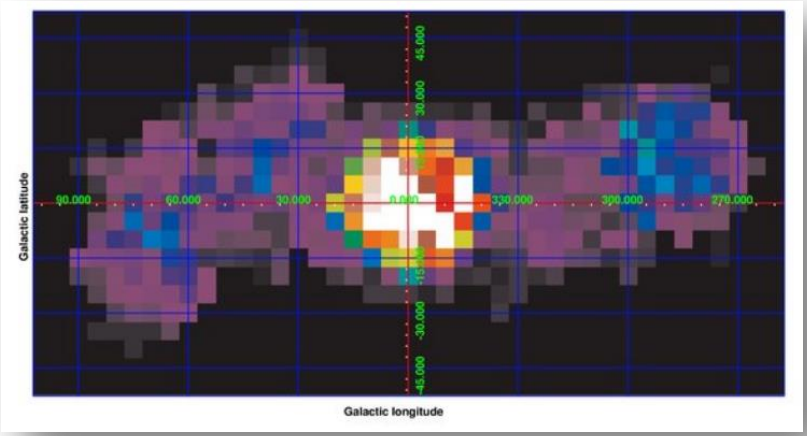
Future

- COSI-X: 3 flights from Wanaka, New Zealand, starting 2023

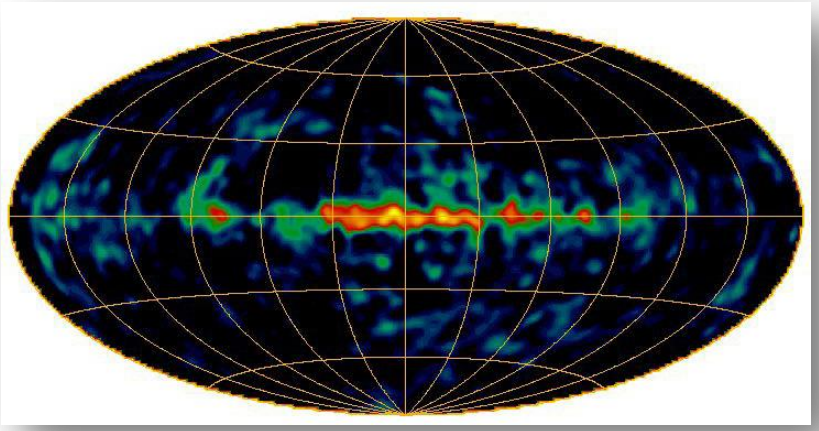


Science Goals

- Uncover the mysterious origin of the 511-keV positron annihilation emission near the Galactic Center
- Study Galactic nucleosynthesis by mapping newly generated elements such as ^{26}Al, ^{60}Fe, ^{44}Ti
- Use polarimetry to study source geometries and emission processes of Gamma-ray Bursts (GRBs), pulsars, X-ray binaries, and Active Galactic Nuclei (AGN)

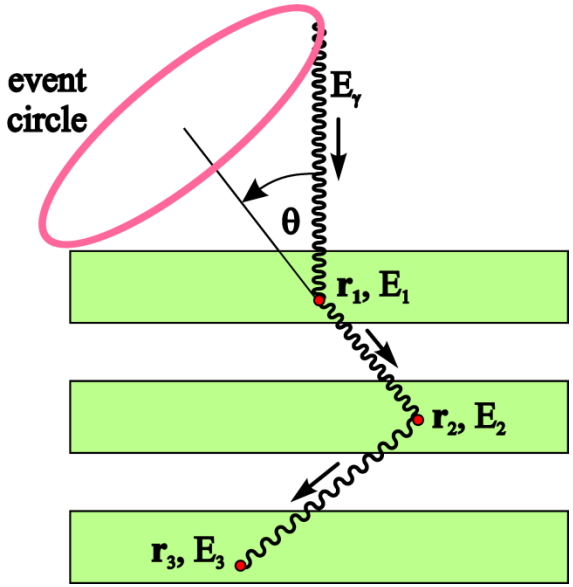


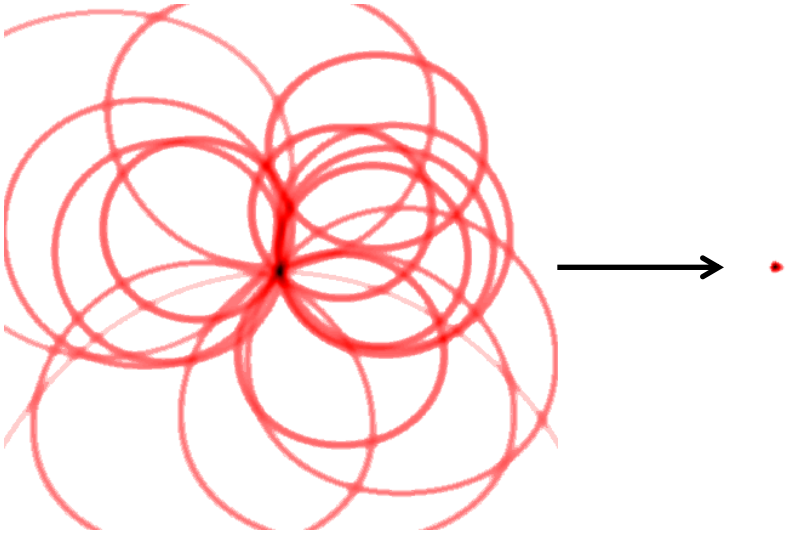
INTEGRAL/SPI Galactic center map of the positron annihilation radiation (0.511 MeV) *(Bouchet et al. 2010)*



COMPTEL map of ^{26}Al emission (1.809 MeV) *(Oberlack et al. 1997)*

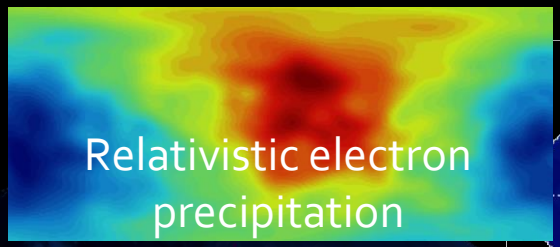
Operating Principle

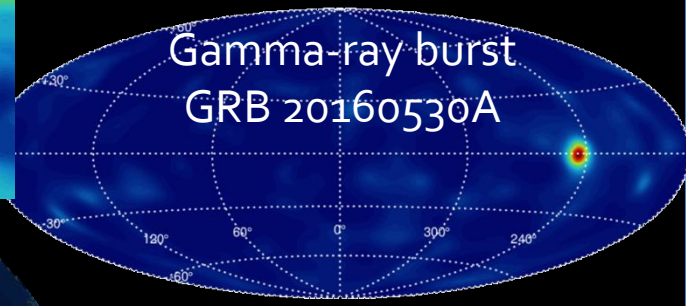


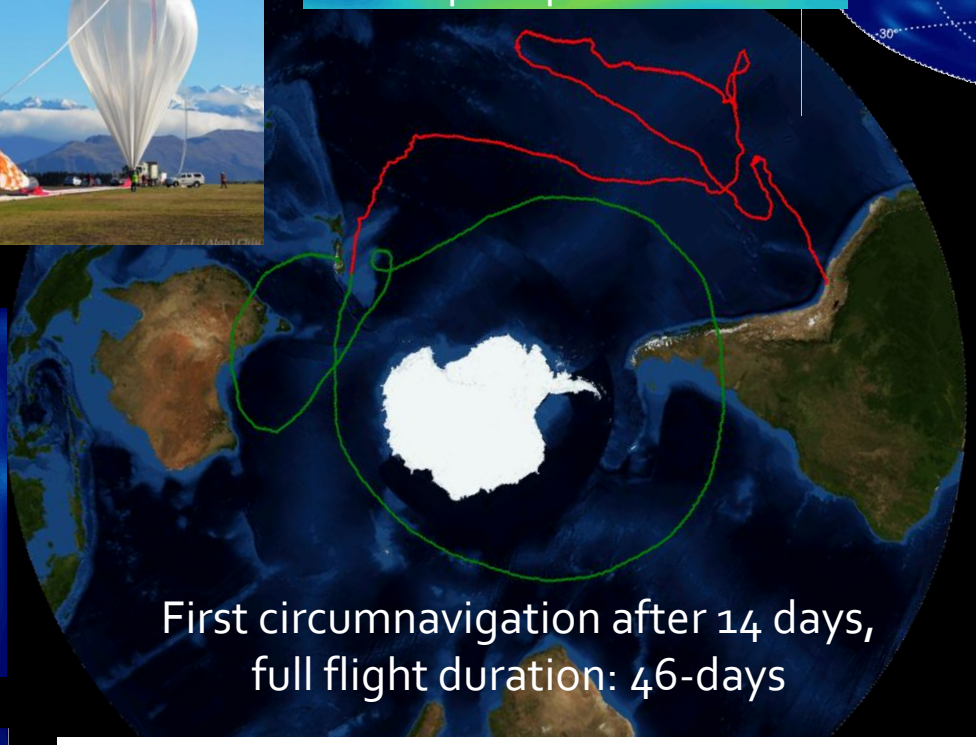


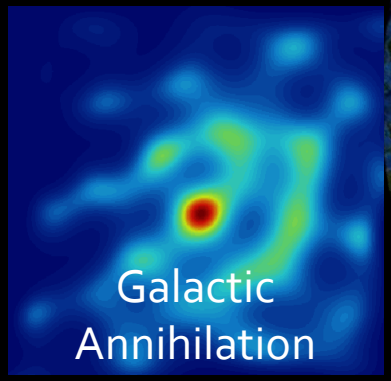
- Photons interact multiple times in active detector (here: Ge).
- The interaction sequence can be determined from information such as scatter angles, absorption probabilities, scatter probabilities.
- The origin of a single not-tracked event can be restricted to the so called “event circle”.
- The photon originated at the point of all overlap.
- Deconvolve to obtain sky maps.

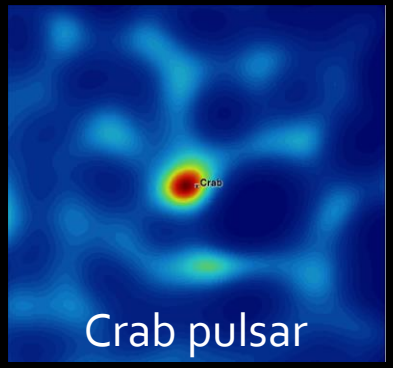
Highlights of COSI's 2016 Balloon Flight

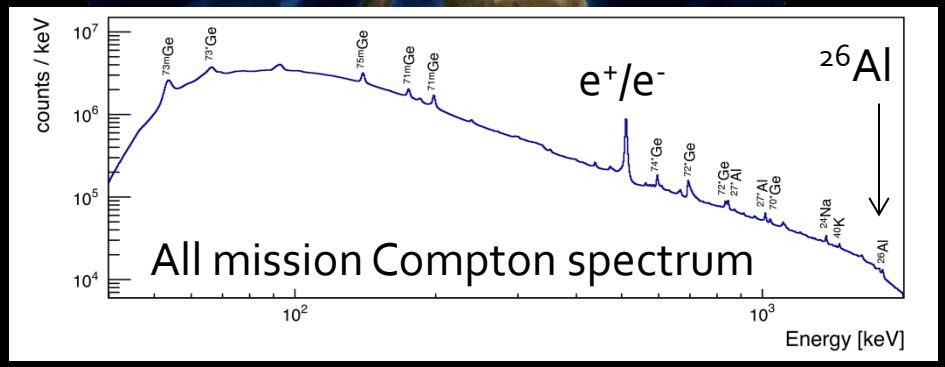


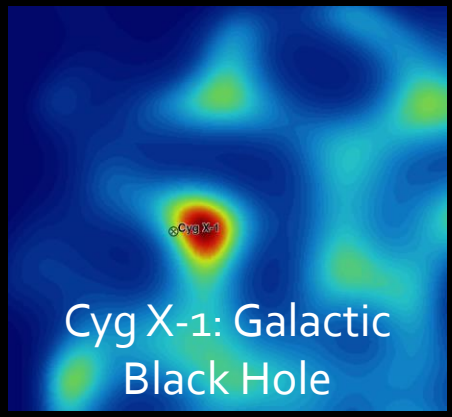




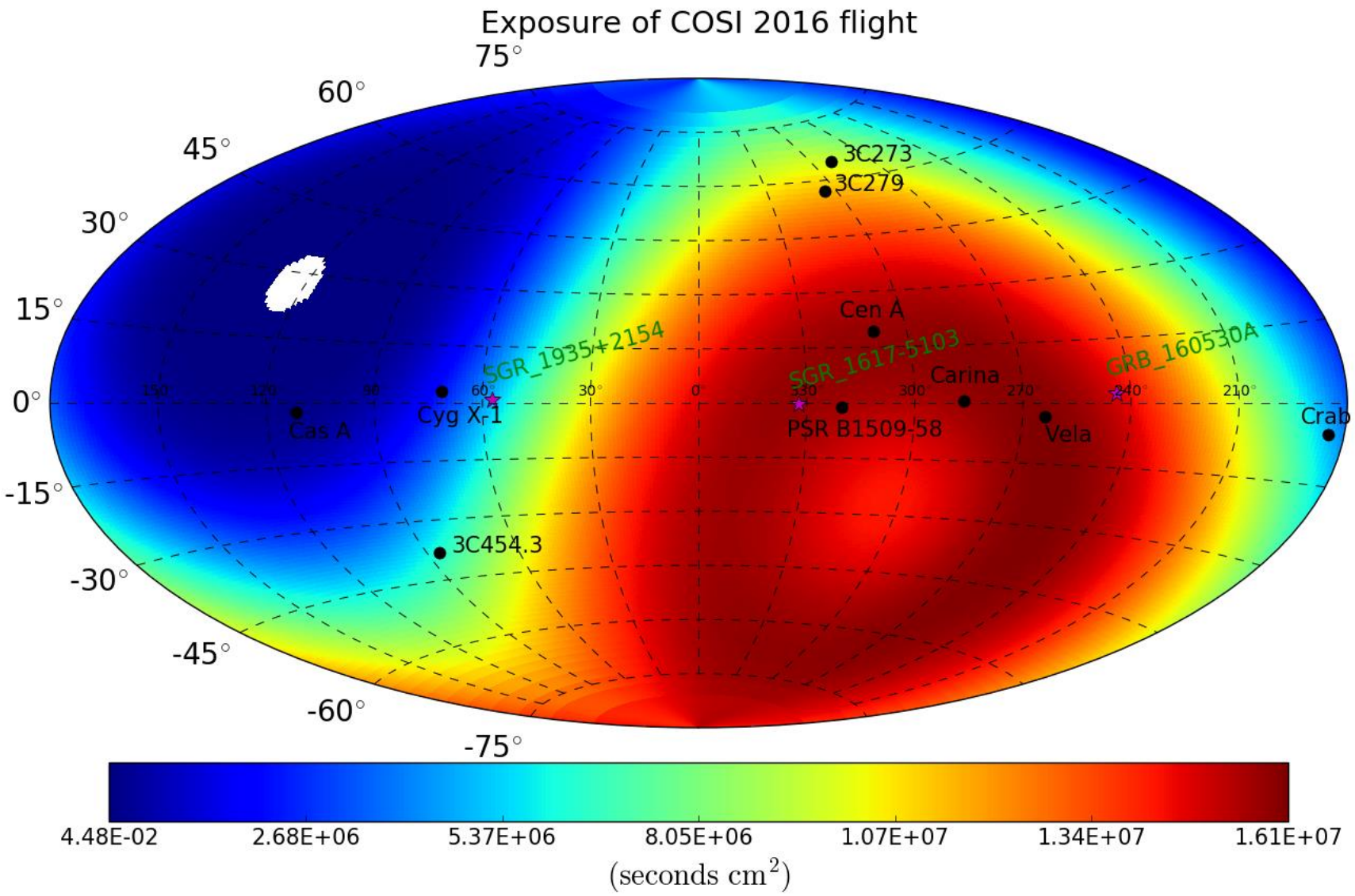






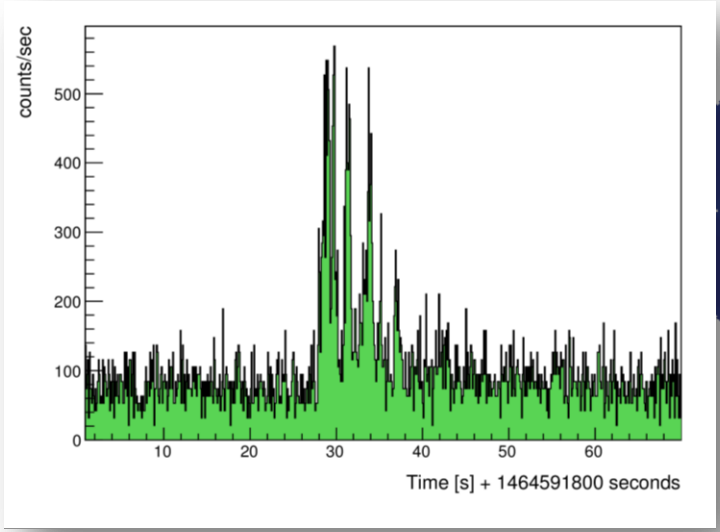


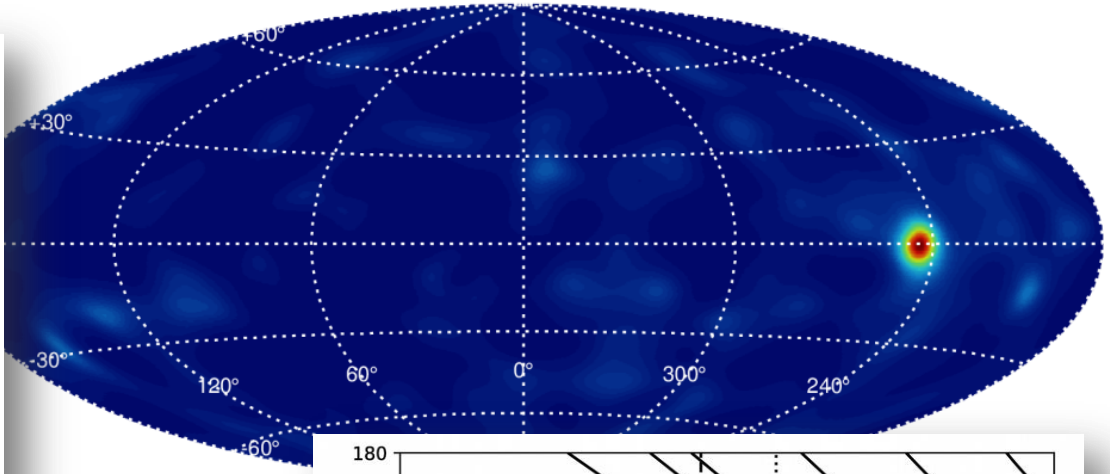
Sky Exposure

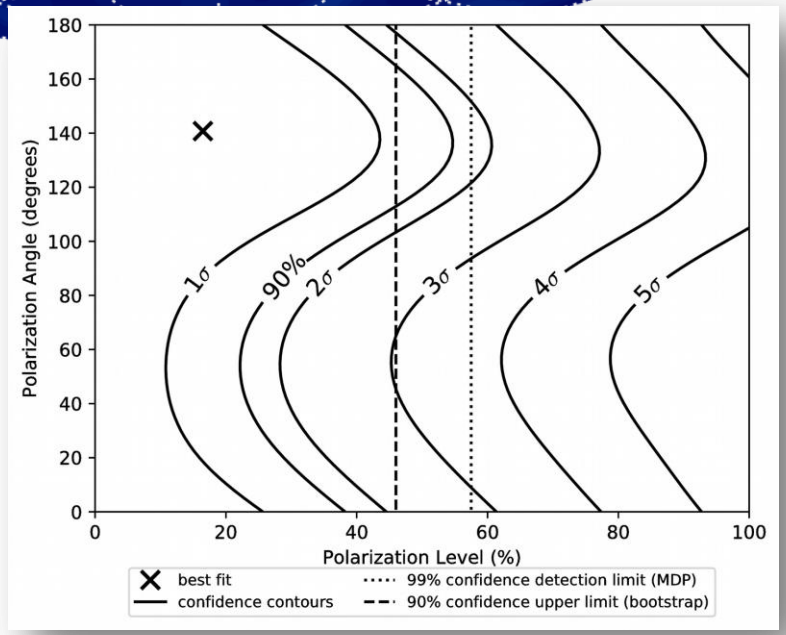


GRB 160530A – Polarization Analysis

PhD thesis Alex Lowell







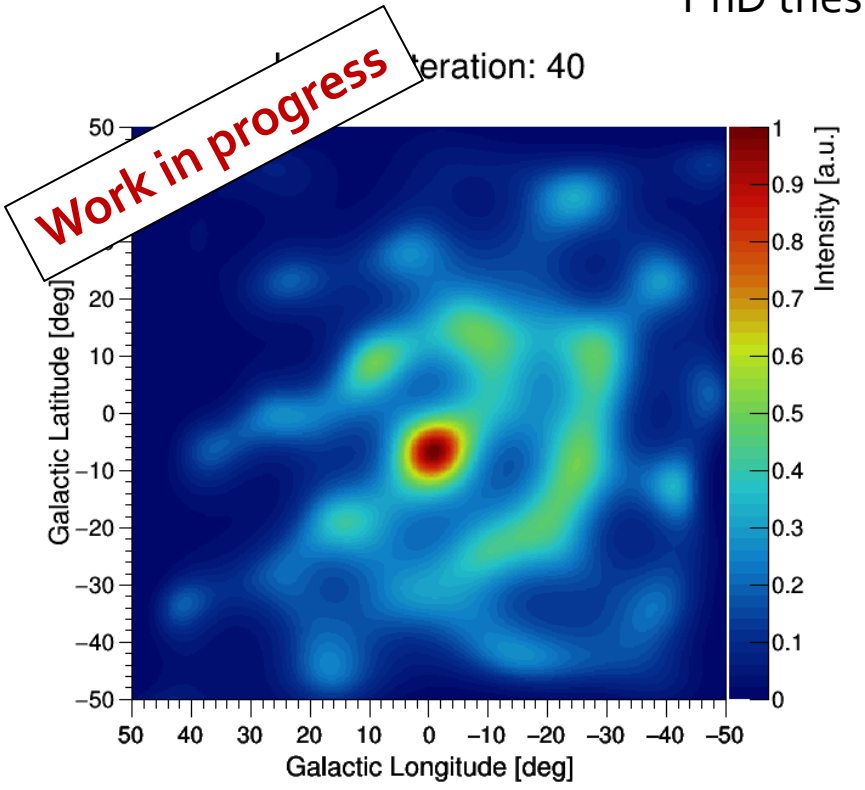
- 90% confidence upper limit: 46%
- 99% MDP: 58%
- Best fit: 16% (+27%, -16%)

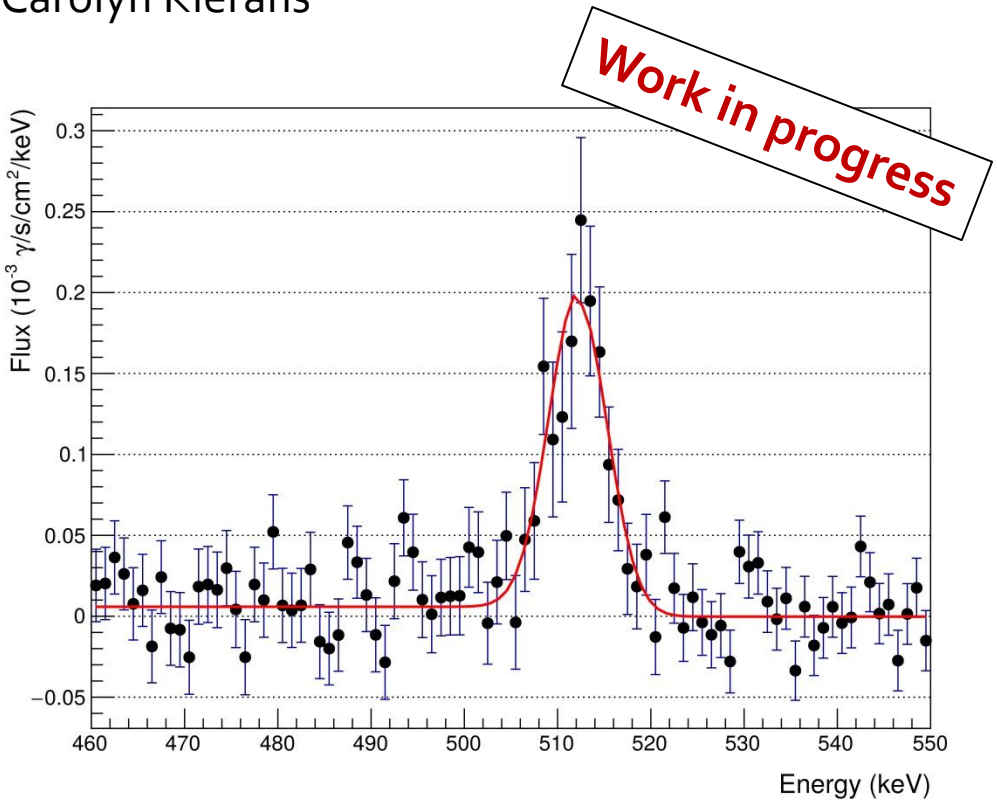
Lowell+ 2017:

arXiv:1709.05352, arXiv:1709.05349

511-keV Emission from Galactic Center

PhD thesis Carolyn Kierans





Key challenge: Background!

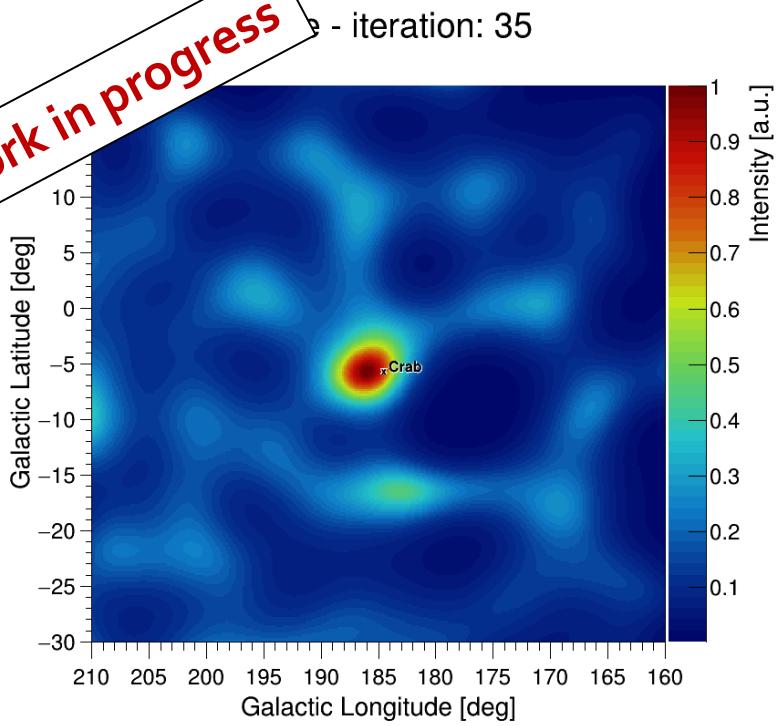
Working on:

- Improved background identification, rejection, modelling
- Background estimation directly during image reconstruction

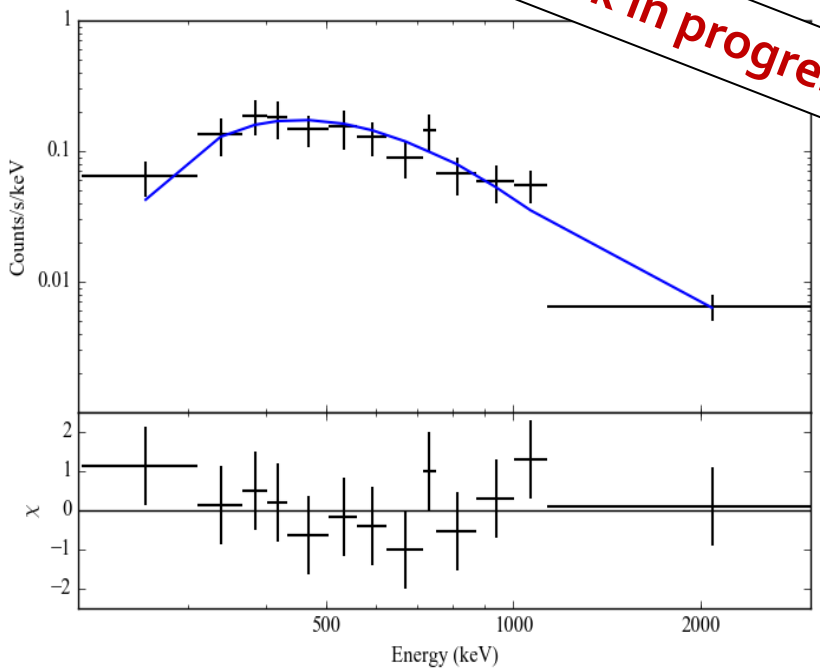
Crab and other point sources (Cyg X-1, Cen A)

PhD thesis Clio Sleator

Work in progress



Work in progress

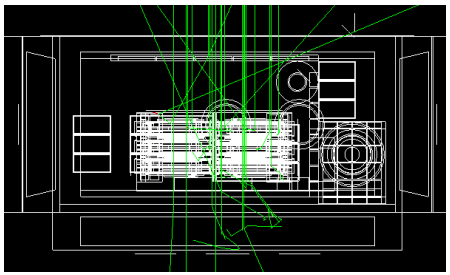


Goals:

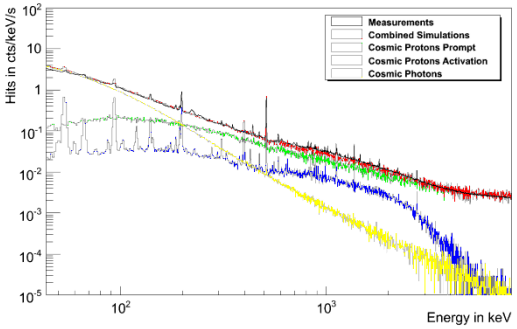
- Develop spectral fitting pipeline using xspec
- Testing calibration, simulations, detector effects engine & analysis tools by reproducing Crab results
- Analyze detected point sources

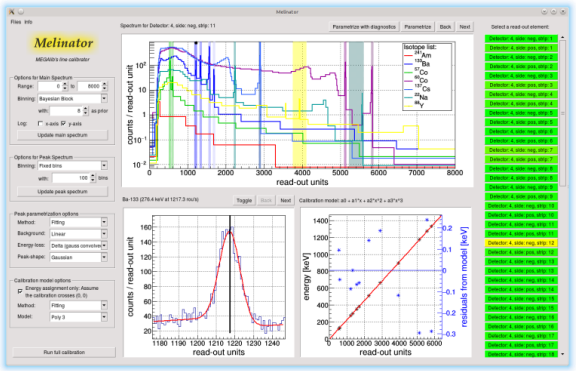
MEGAlib – Medium-Energy Gamma-ray Astronomy library

- Full data analysis chain for γ-ray instruments in space & on ground
- Generalized to be applied to arbitrary detector systems not only COSI
- Free, open-source & on GitHub

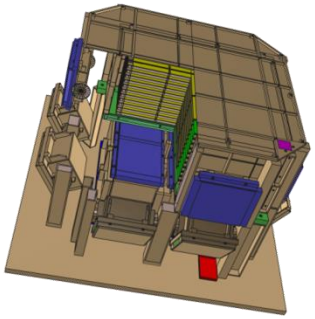


Monte-Carlo simulations

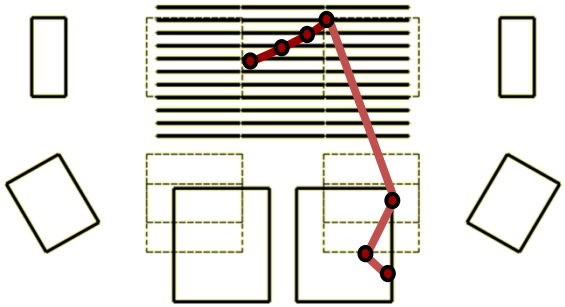




Calibrations



Geometry



Event pattern classification

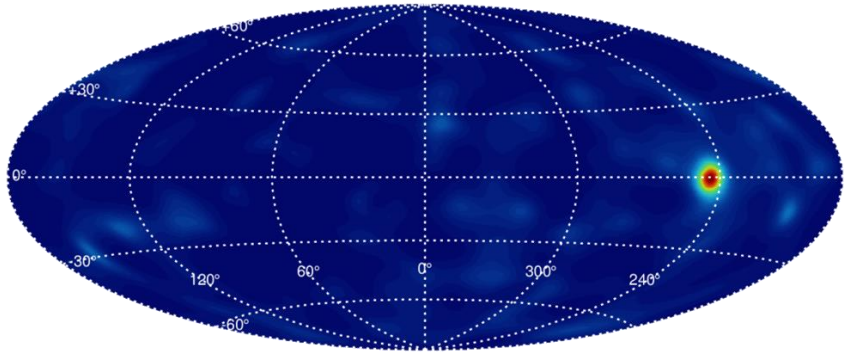
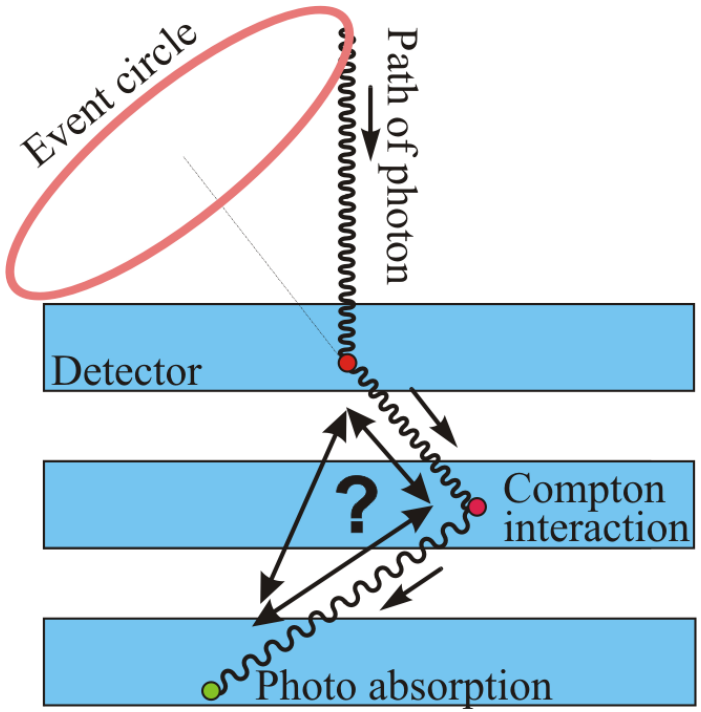


Image deconvolution

Event Reconstruction Advancements: Task

Find unknown path of photon in detector utilizing:

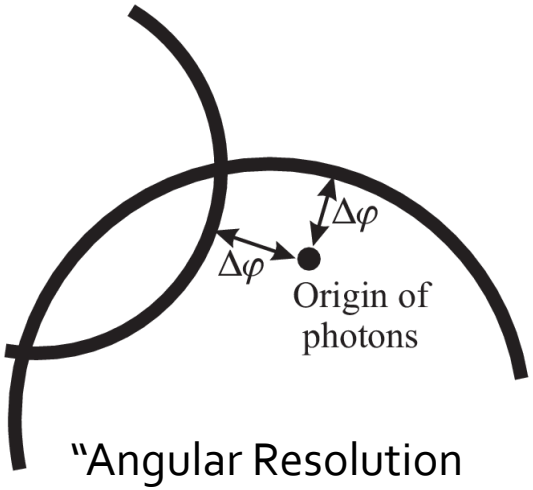
- Positions
- Energies
- Compton scatter angles
- Redundant Compton scatter angle difference between geometry & kinetics
- Klein-Nishina scatter probabilities
- Compton interaction probabilities
  - Arriving to first interaction
  - Along the path between interactions
- Final photo absorption probabilities
- (For electron tracking Compton telescopes: Redundant total scatter angle)



2-site event: 16 parameters
5-site event: 44 parameters

Event Reconstruction Advancements: Results

Metric: ARM



"Angular Resolution Measure"

All results seen so far have been done with the Classic CSR – complete reanalysis with Neural Network coming soon

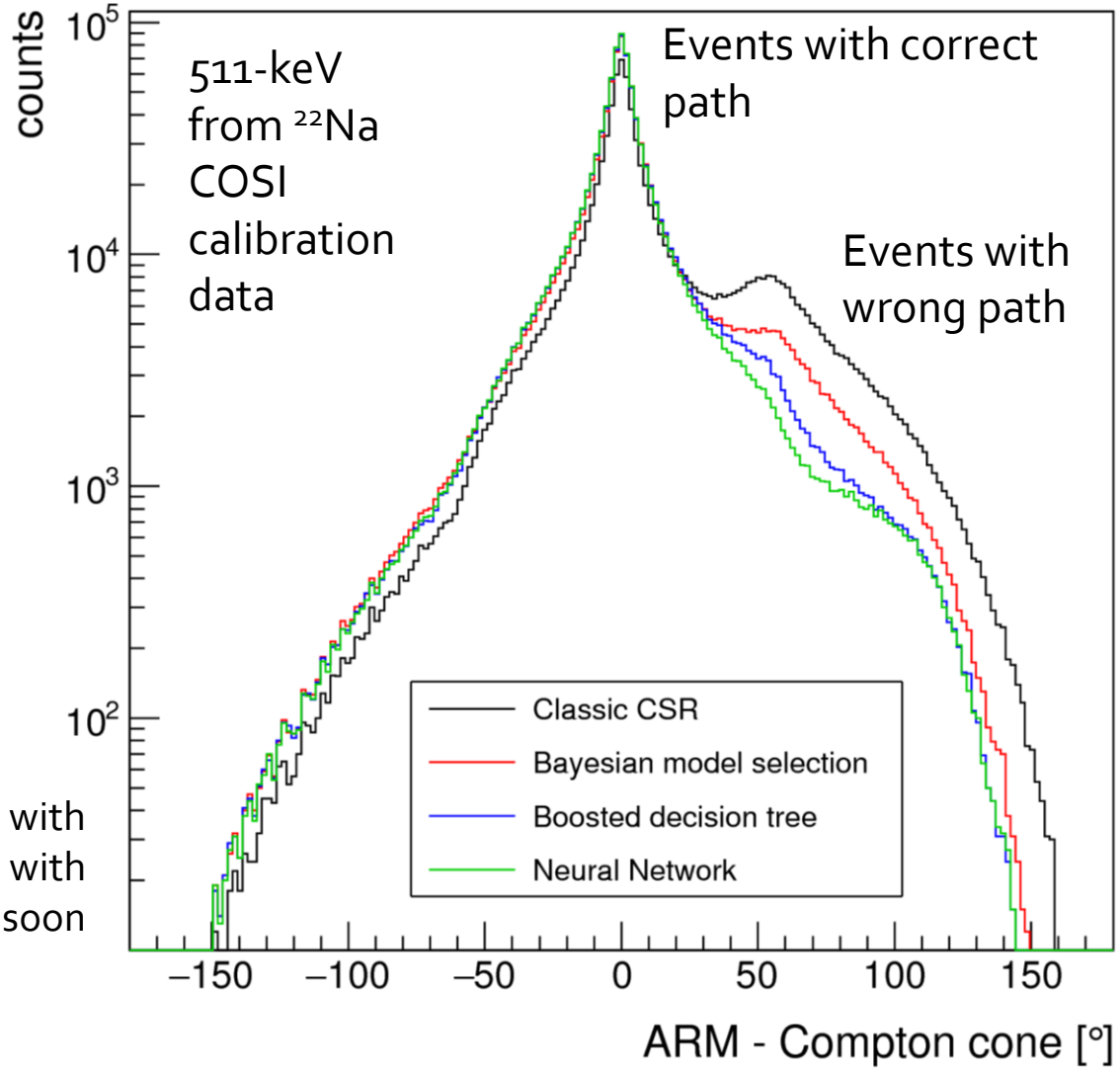
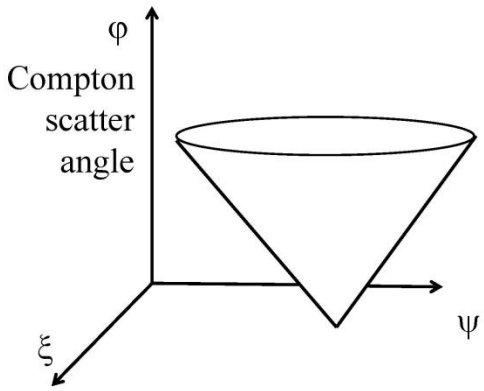


Image Reconstruction Advancements

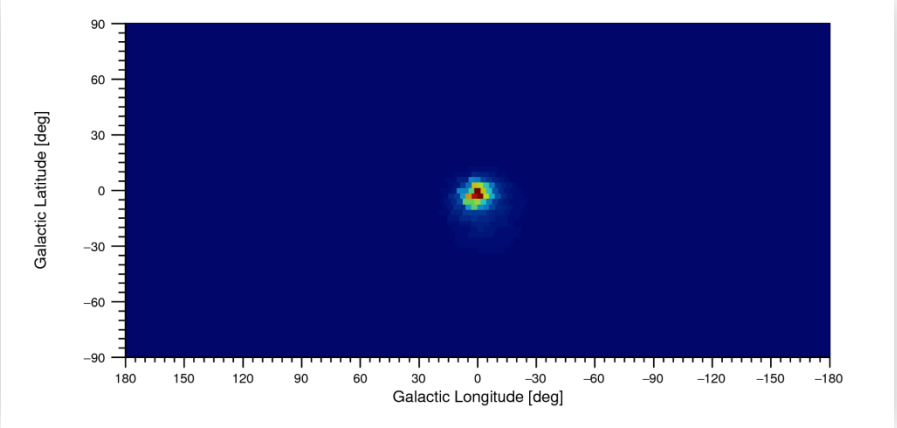
Goal:
Improve upon list-mode imaging by using hybrid list-mode binned-mode approach

Challenges:
- 5 - 11+ dimensional response
- Need supercomputer for response simulations…
- Absolute need to estimate background during image deconvolution accurately



ξ, ψ: Scattered gamma-ray direction

Status of upgraded imaging approach:
- ✓ 7D response generation
- ✓ Maximum-Entropy deconvolution
- ✓ Background model generation and estimation during deconvolutions
- ✓ Flux retrieval
- ✓ Works nicely with simulations
- • COSI data: Working on more detailed background model…



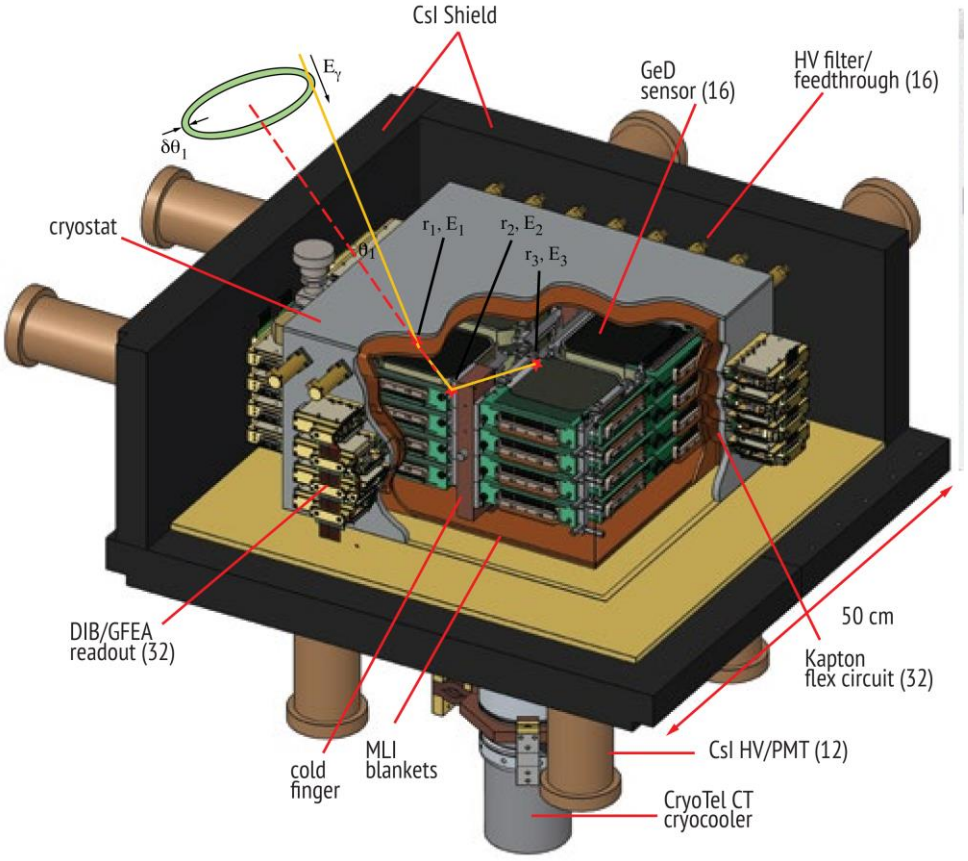
Reconstructed simulation of 511-keV emission from GC sitting on dominating background

The Future: COSI-X

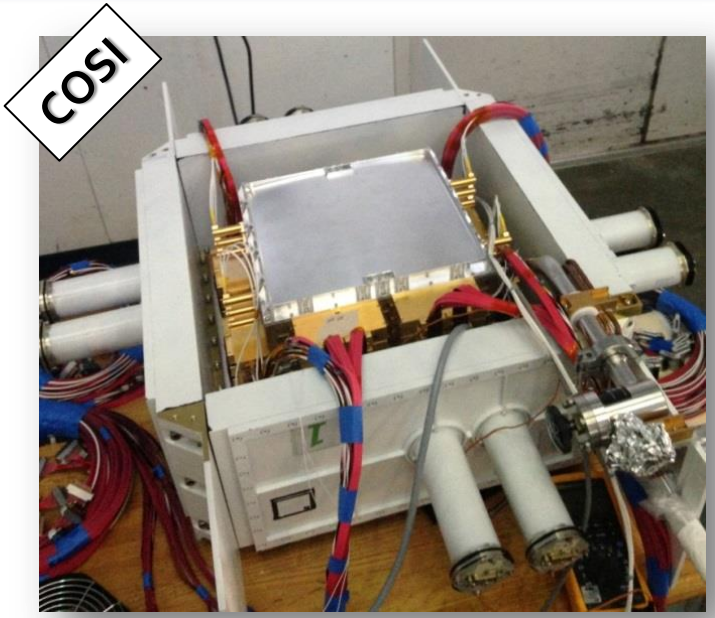
X = eXplorer

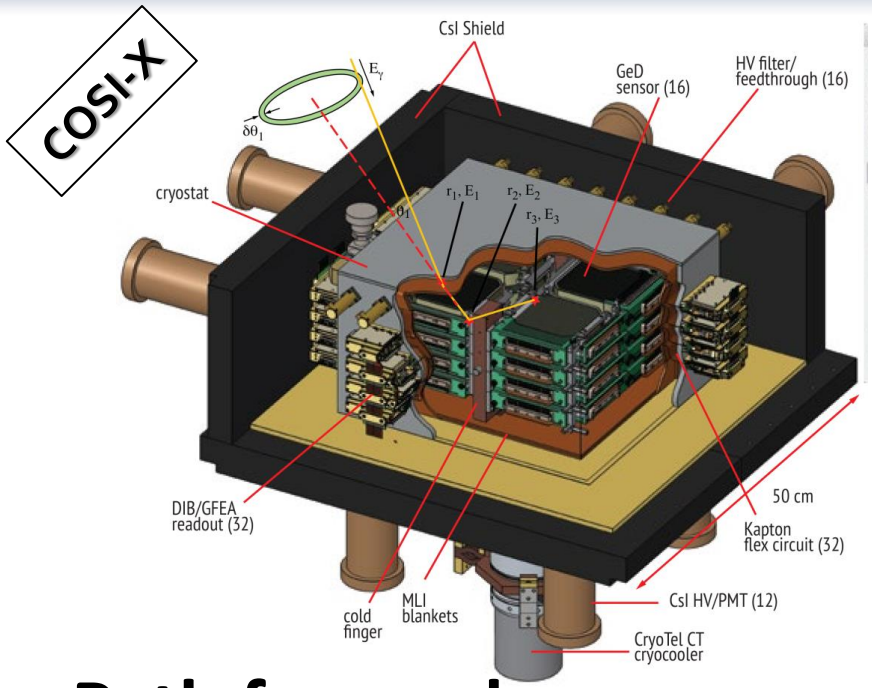
Goals:

- Build 2 upgraded COSI-like instruments with improved performance
- Perform 3 100-day flights from Wanaka, NZ, starting 2022/23
- Currently in NASA-sponsored phase A study



Upgrades from COSI to COSI-X





Goals:

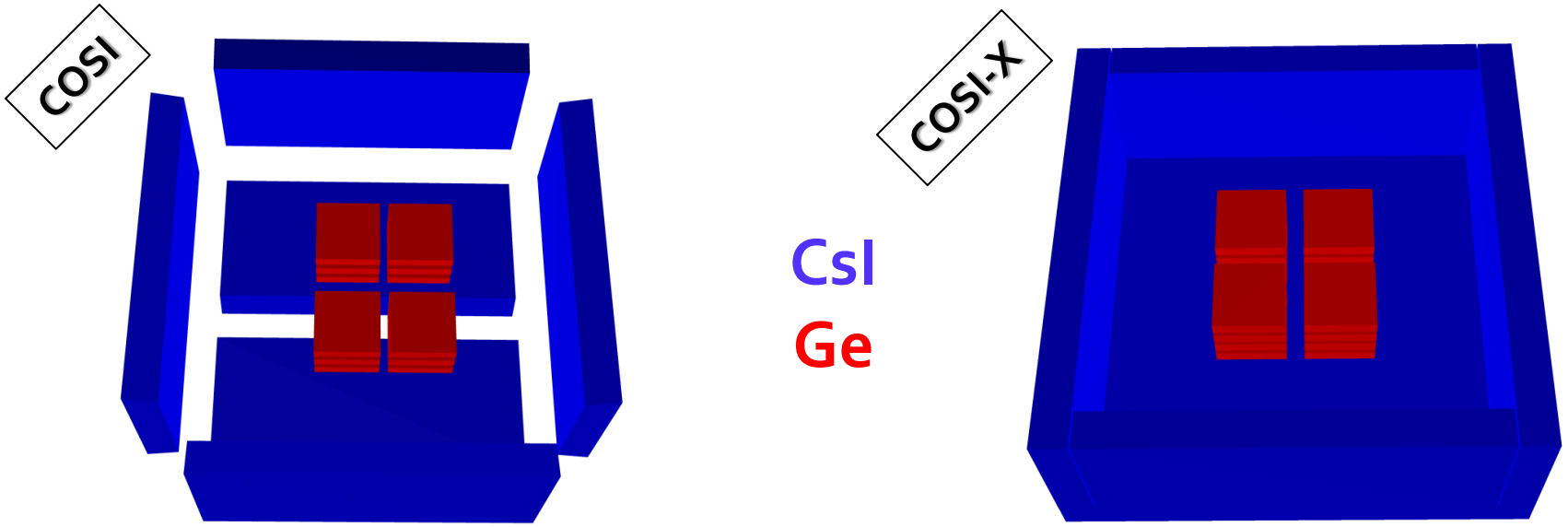
- Improved angular resolution
- Enhanced effective area
- Stronger background rejection

Path forward:

- 3.4x smaller strip pitch
- ASICS
- More detectors
- Better shielding

Improvements: Shielding

Goal: Block / veto dominating atmospheric photon background from below



COSI / COSI-X simulation model showing only active materials (Ge edge & connector/coldfinger cut outs not shown)

COSI

- Shielding has large gaps letting too much atmospheric background through

COSI-X

- No gaps on side and bottom
- Just some (not shown) holes for cold finger & connectors
- Optimized side walls height

Improvements: Detectors

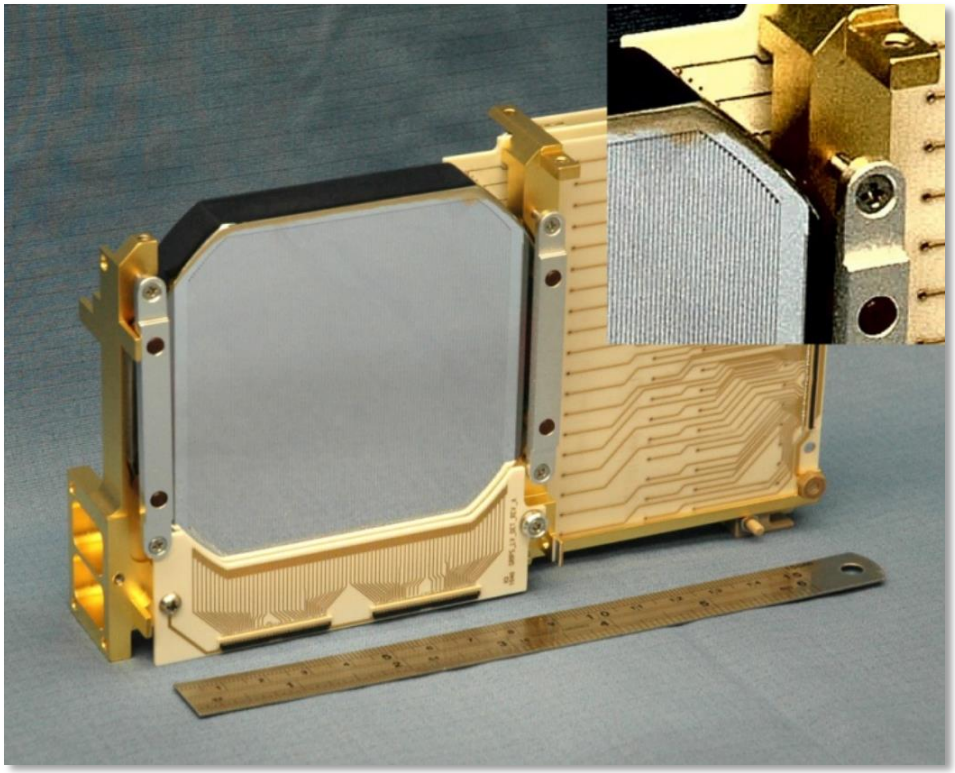
Finer strip pitch (0.58 mm)

Improves:

- Position resolution
- Angular resolution
- Event reconstruction efficiency
- Effective area
- Background identification / rejection

Additional upgrades:

- ASIC read-out: handle large number of channels
  - Batch #1 testing has started
- Cryo-cooler: active damping to lower noise



GRIPS Germanium detector with 128 read-out channels

Summary

- COSI had very successful 46-day balloon flight
- COSI observed GRBs, pulsars, black holes, Galactic 511-keV annihilation, Galactic nucleosythesis, relativistic electron preciptitation, etc.
- First results published, but analysis of data still ongoing and improving
- Upgrades for COSI-X have started

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Compton Spectrometer and Imager (COSI) @ Wanaka, New Zealand