COSI

Formerly NCT

COSI – the Compton Spectrometer and Imager

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for the COSI collaboration

The COSI Collaboration:

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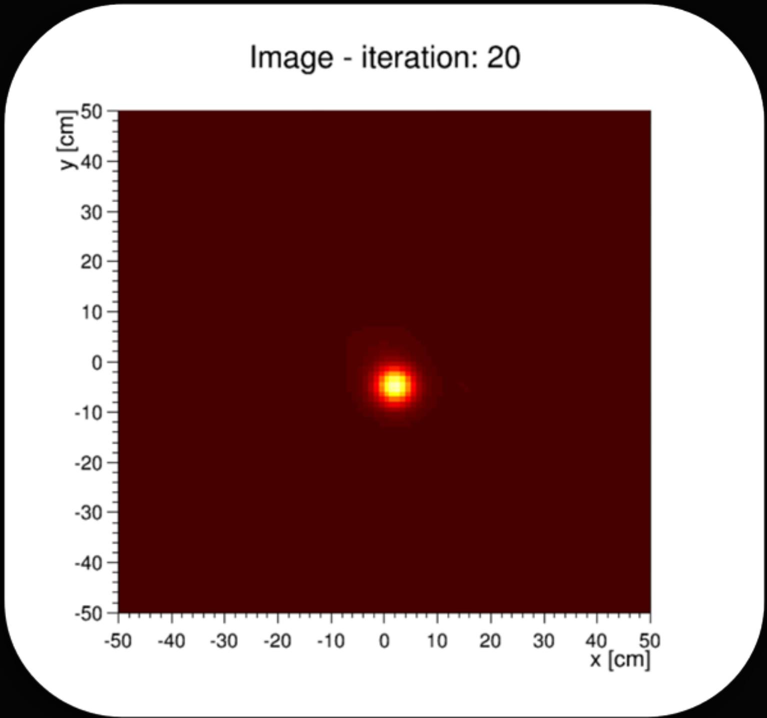
COSI in the US is supported through grants by NASA



"First Light" image of a ^{137}Cs calibration source ~56 cm above the instrument.

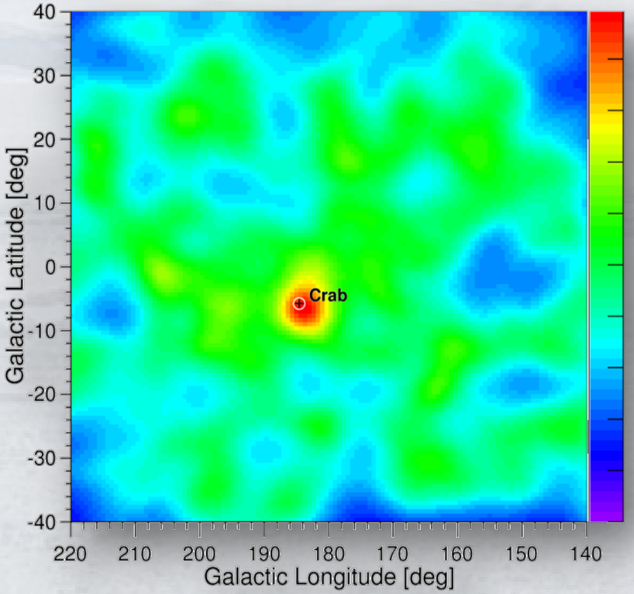
Overview: Instrument & Campaigns

Instrument

- Balloon-borne Compton telescope
- Energy range: 0.2 – several 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 sky

Balloon campaigns

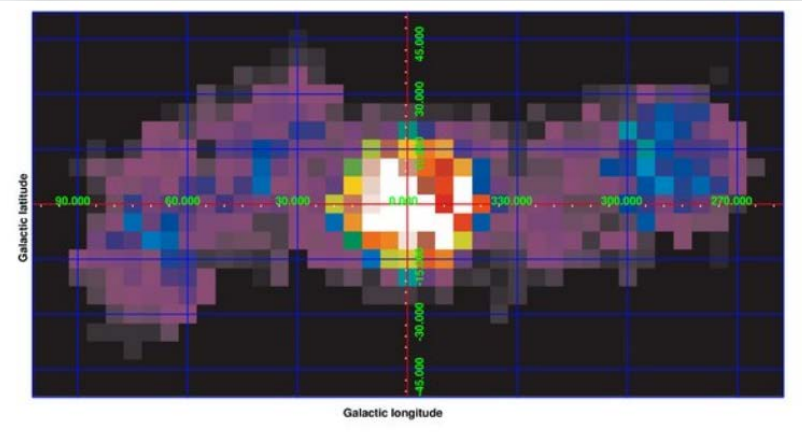
- NCT: 2 GeD prototype, Ft. Sumner, 2005
- NCT: Very successful 38-hour flight of 10 GeD instrument , Ft. Sumner, 2009
- NCT: Failed launch attempt from Alice Springs, Australia, 2010
- COSI: 1.5-day flight of 12 GeD instrument from McMurdo on Dec. 28th, 2014
- COSI: 2016, 2018 New Zealand campaigns



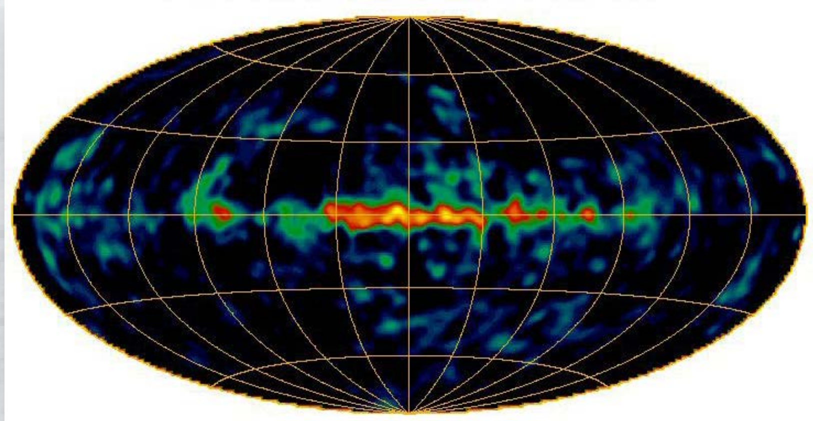
Overview: Science Goals

- Mapping 511 keV positron annihilation emission at the Galactic Center
- Studies of Galactic radioactivity: lines from stellar and supernova nucleosynthesis (^{26}Al, ^{60}Fe, ^{44}Ti)
- Polarimetry of Gamma-ray Bursts (GRBs), pulsars, X-ray binaries, and AGN

Characteristic	Performance
Energy Range	0.2-5 MeV
Spectral Resolution	0.2-1%
Field of View (FoV)	25% sky
Sky Coverage	50% sky
Angular Resolution	FWHM
0.511 MeV	5.1°
1.809 MeV	3.4°
Narrow Line Sensitivity (200 days, 3σ)	[γ cm^{-2} s^{-1}]
0.511 MeV (e^+e^-)	3.8×10^{-5}
1.157 MeV (^{44}Ti)	8.9×10^{-6}
1.173/1.333 MeV (^{60}Fe)	6.0×10^{-6}
1.809 MeV (^{26}Al)	8.5×10^{-6}
BH 100% Polarization (200 days, 3σ, threshold sensitivity)	23 mCrab
GRB 100% Polarization (3σ, threshold sensitivity)	1.2×10^{-5} erg cm^{-2}

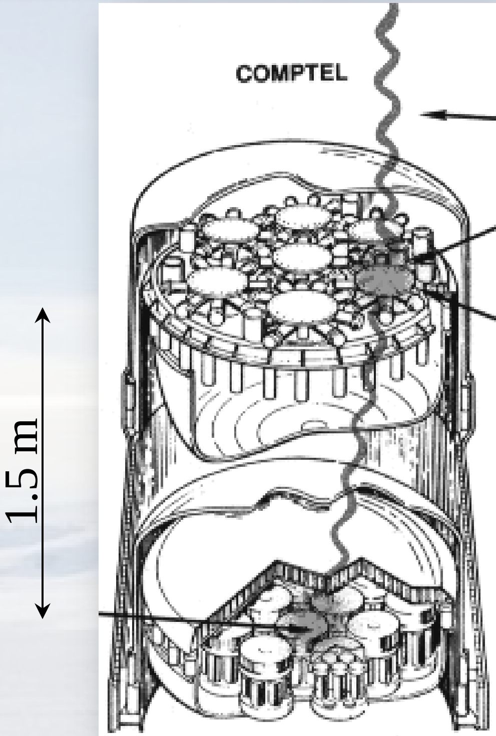


INTEGRAL/SPI Galactic center map of the positron annihilation radiation (0.511 MeV) *(Bouchet et al. 2010)*



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

Compton Telescopes: From COMPTEL to COSI



30+ years development

CGRO/COMPTEL:

- ~40 cm^3 resolution
- $\Delta E/E$ ~10%
- Up to 0.4% efficiency
- ToF background rejection

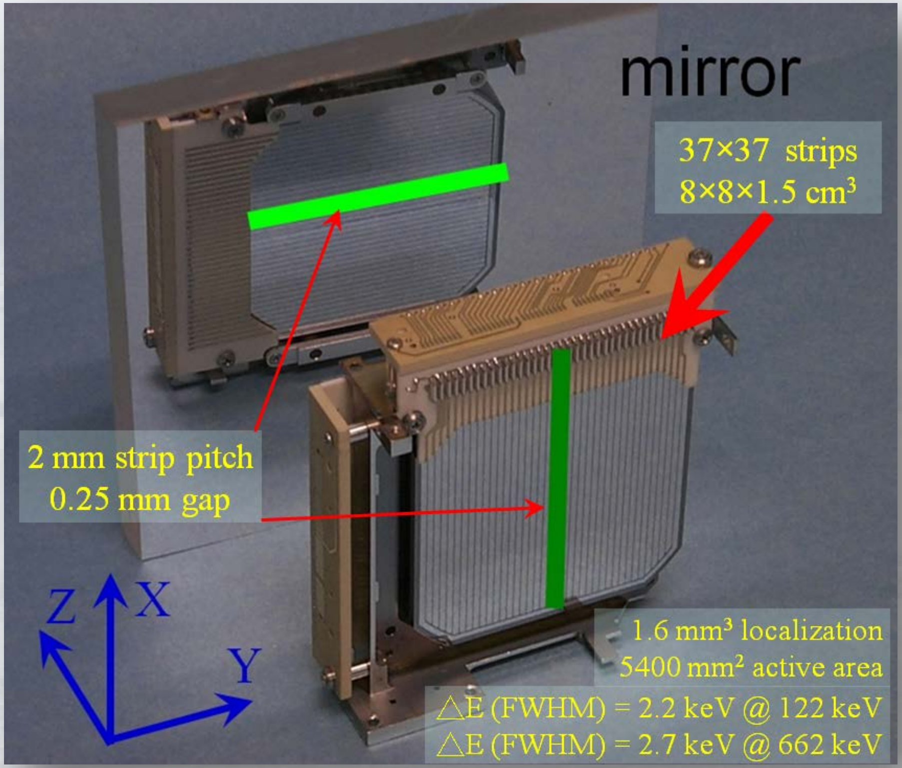
COSI:

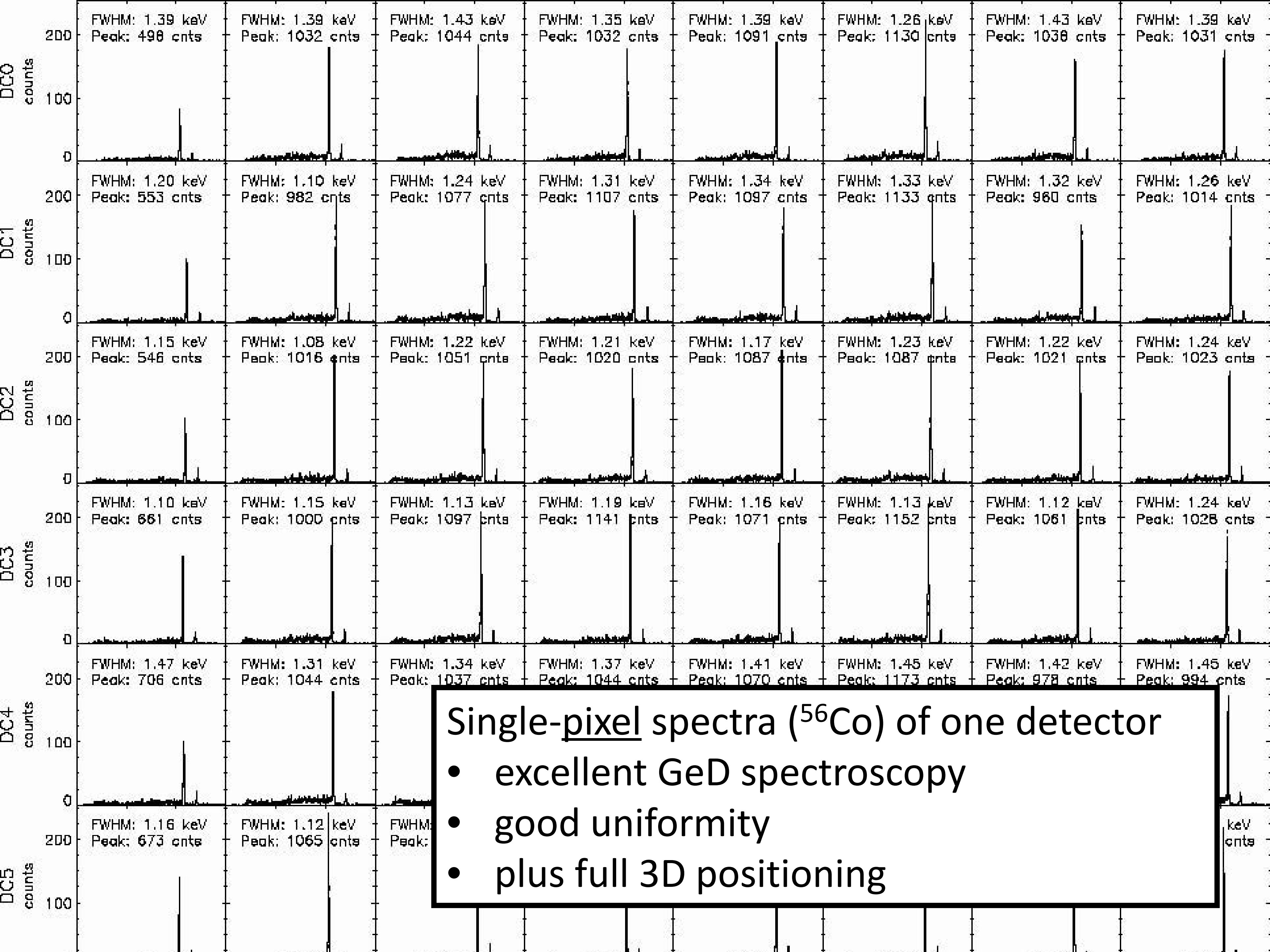
- 2 mm^3 resolution
- $\Delta E/E$ ~0.2-1%
- Up to 16% efficiency
- Multi-mode background suppression & rejection
- polarization

➢ Improved performance with a fraction of the mass and volume

The Germanium Detectors

- Size: 8 x 8 x 1.5 cm^3
- 37 orthogonal strips per side
- 2 mm strip pitch
- Operated as fully-depleted p-i-n junctions
- a-Ge and a-Si surface layers
- Excellent spectral resolution: 0.2-1% FWHM
- Excellent depth resolution: 0.5 mm FWHM
- 12 are integrated in the COSI cryostat





Single-pixel spectra (^{56}Co) of one detector

- excellent GeD spectroscopy
- good uniformity
- plus full 3D positioning

The Detector Head

2x2x3 detector geometry

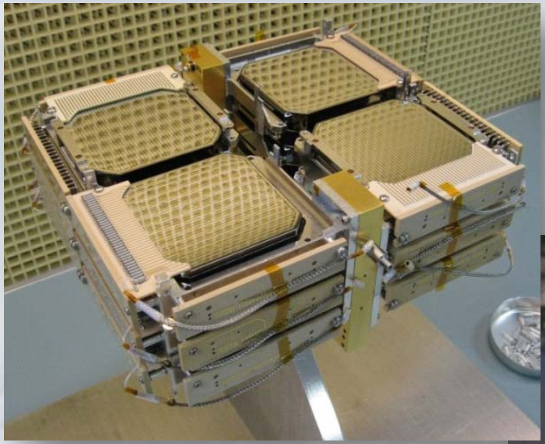
- Wide field-of-view,
- Good polarimetry

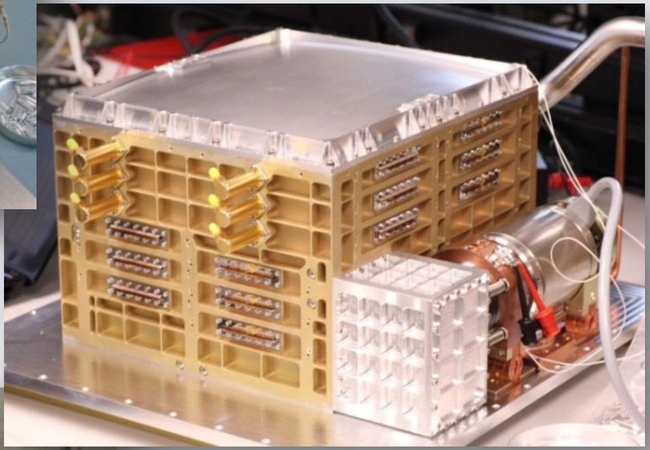
Mechanical cooler

- Constant temperatures
- Enables ULDB flights

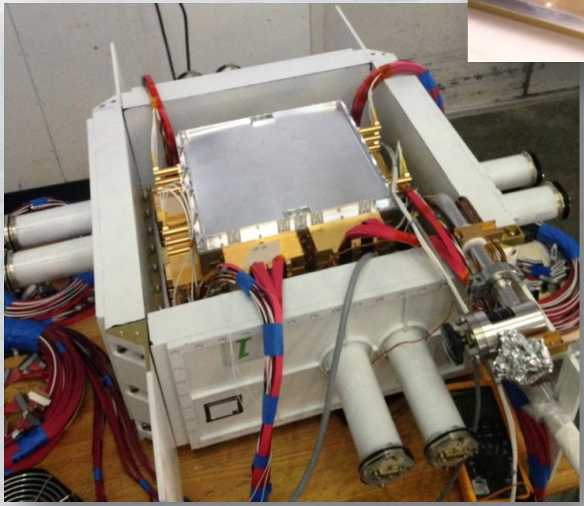
CsI shielding:

- Veto dominating atmospheric background component
- Material: CsI (NCT flights: BGO)
- Weight: ~21 kg each
- Veto threshold: ~80 keV





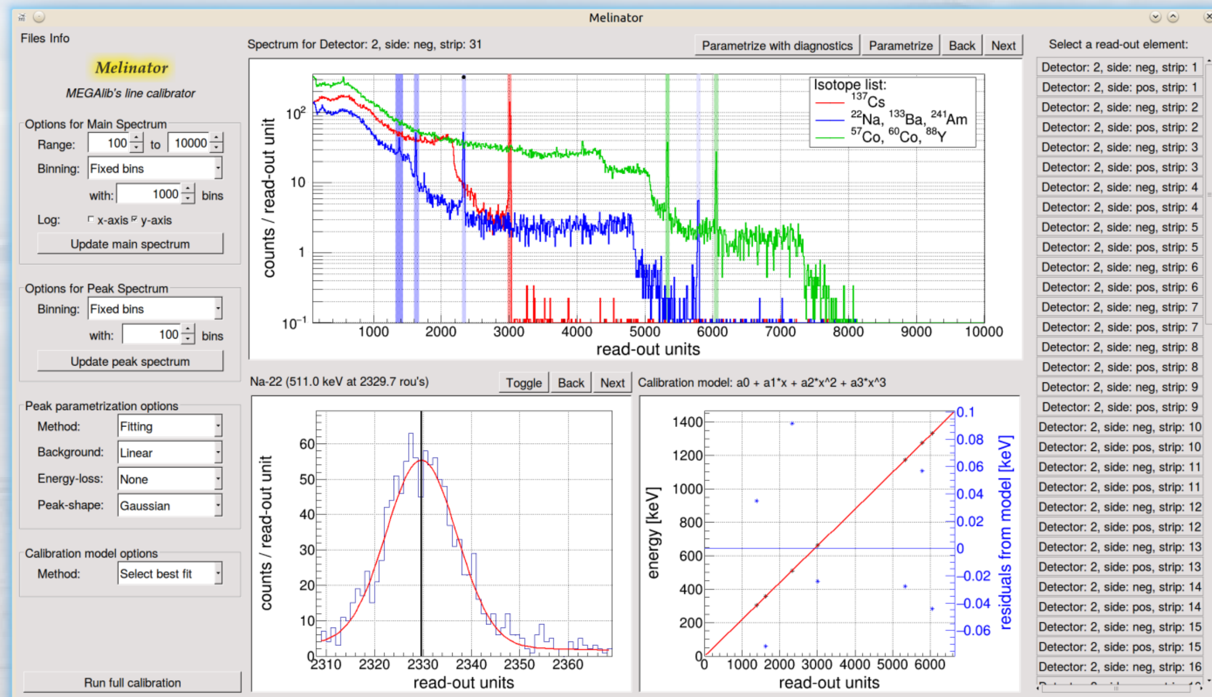
Sunpower CryoTel 10 W lift for 160 W input



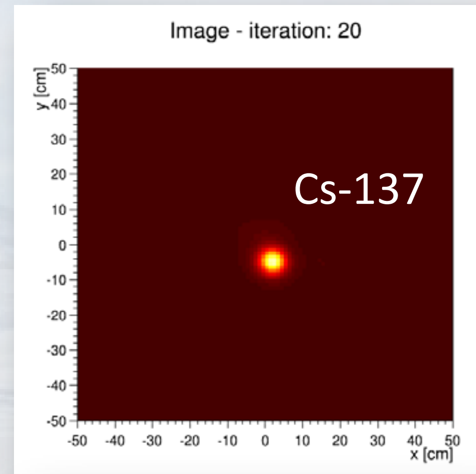
Detector surrounded by (white) CsI shield read out by conventional photo multipliers

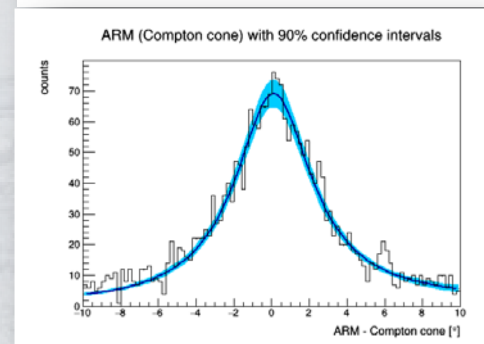
Overall Deteector Status Before 2014 Launch

- All 12 detectors worked: Only 6 bad channels out of 888
- Final calibration measurements were performed days before launch – still work in progress



Calibration of one detector channel with multiple sources using Melinator, MEGAlib's line calibration tool

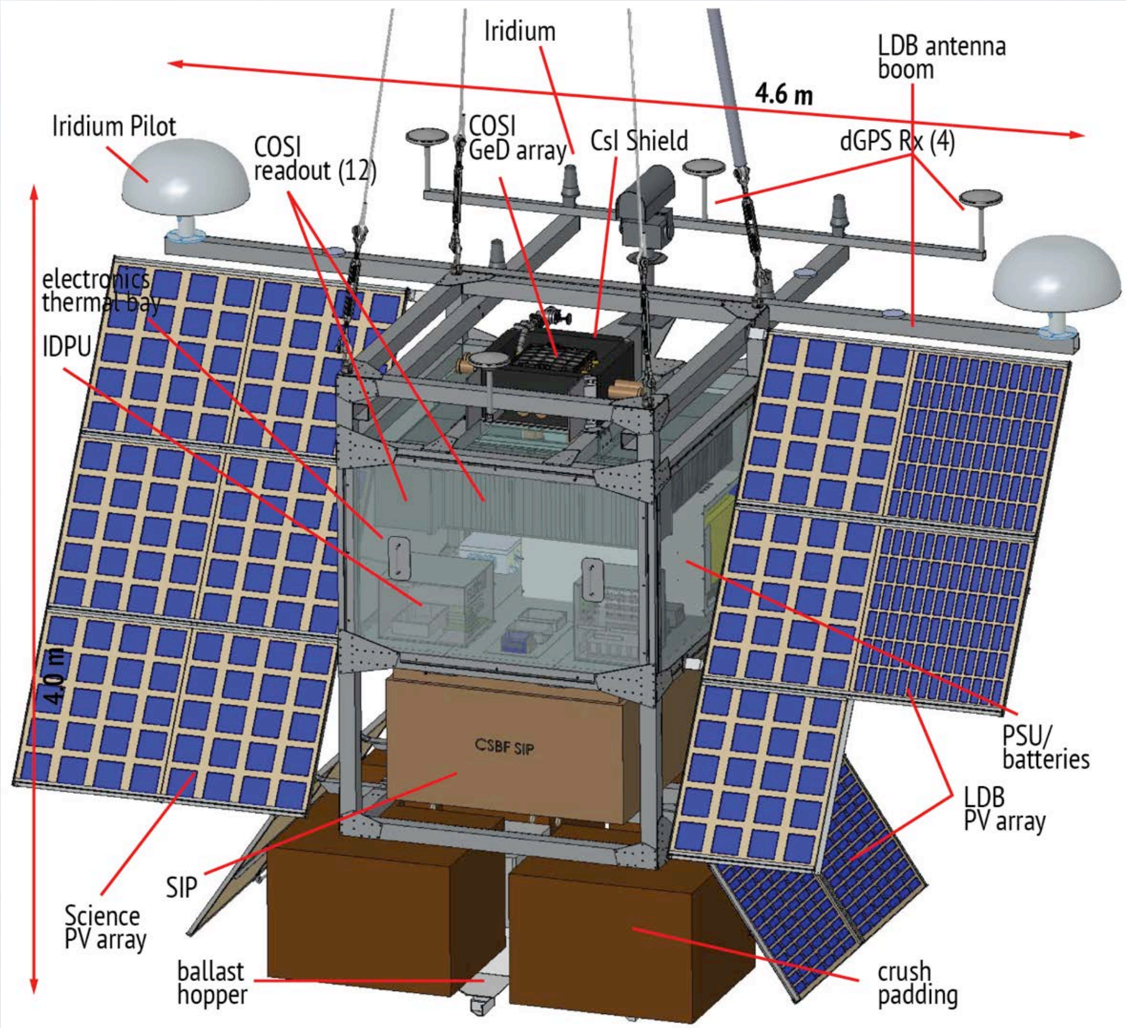




5 deg FWHM (depends on event selections)

The COSI 2014 Gondola System

- Significant upgrade from 2005-2010 NCT
- Simple, lightweight gondola
- Compatible with NASA's 18 MCF super-pressure balloon (~50 m radius)



The 2014 Antarctica Test Flight – The Plan

Flight type: ULDB with ~18.8 MCF SPB at >110 kft

Originally intended flight duration: up to 100 days!

Main technical goals:
- Long duration test of upgraded COSI system
- Real-time GRB analysis
- 1^{st} science test flight of a NASA 18 MCF SPB

Main science goals:
- GRB polarization
- Carina region for nuclear science
- Cen A (AGN)

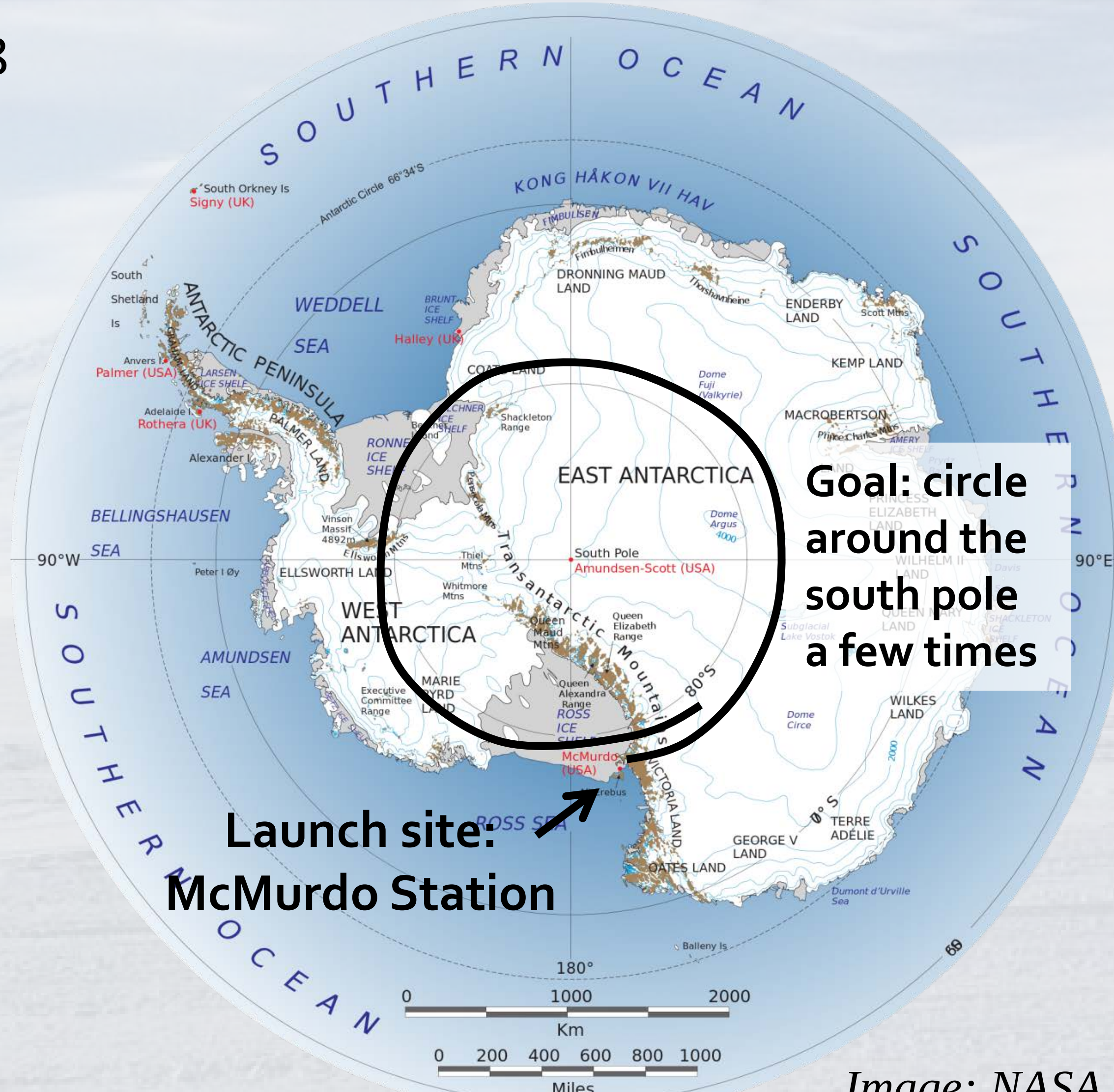
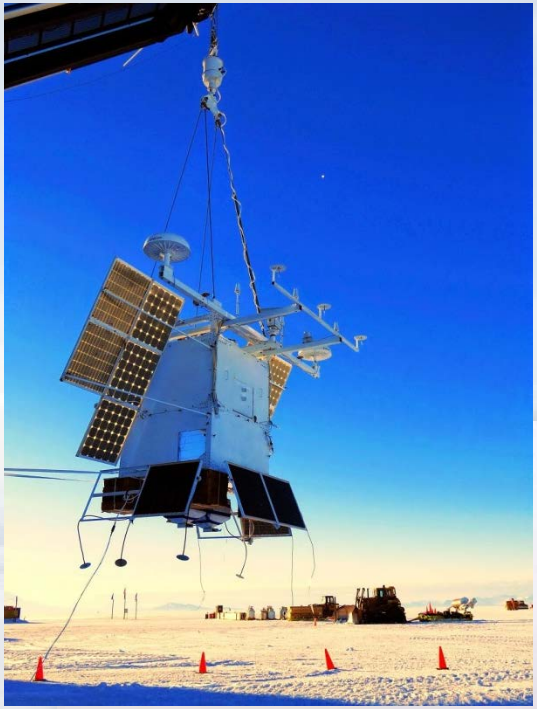


Image: NASA

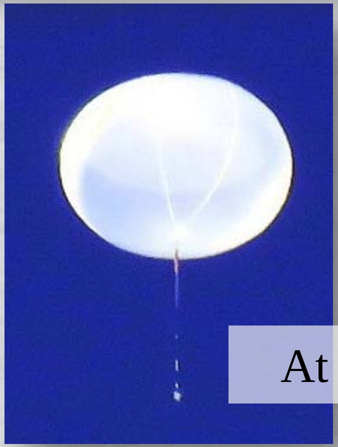
The Launch



Getting ready…

The moment of launch

Rising into the sky

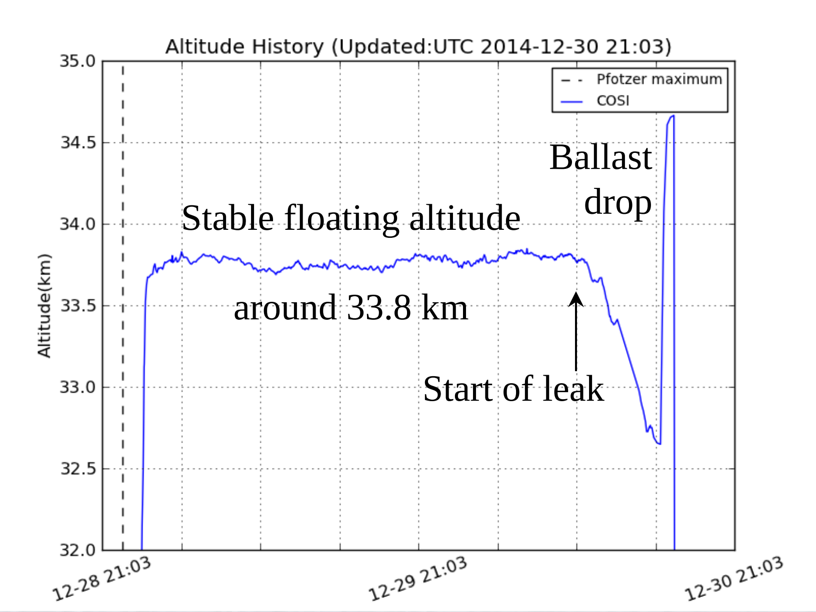


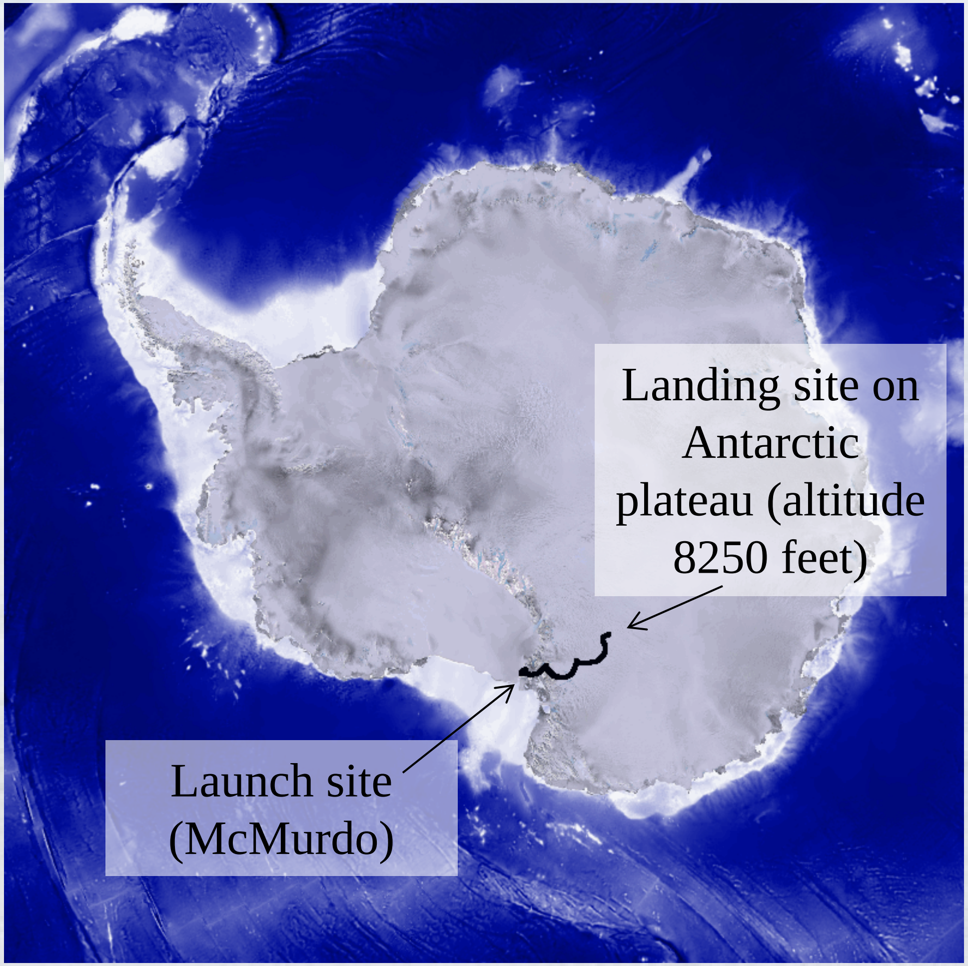
At float

The Test Flight – The Reality

Successful launch on December 28th, 2014

But… the balloon started to leak after only 1.5 days, and the decision was made to terminate the mission while the payload still could be "easily" reached for recovery…





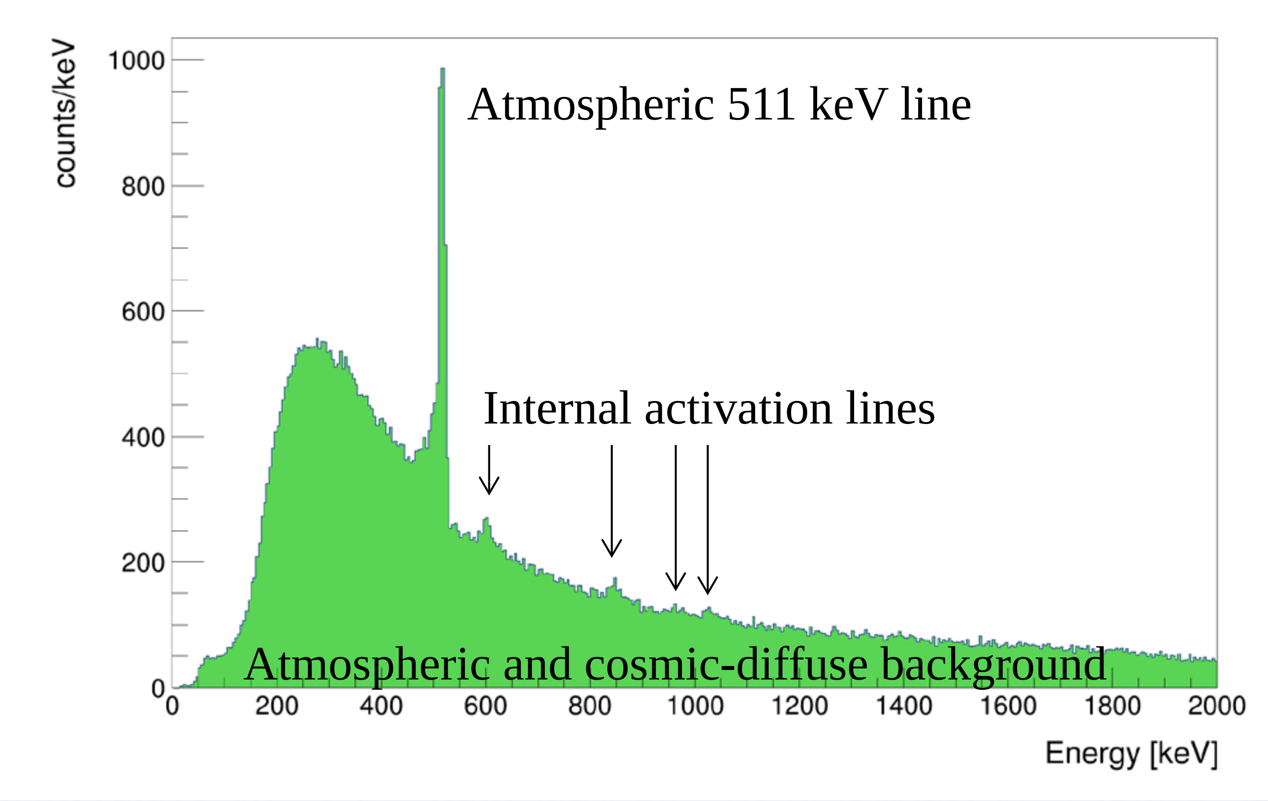
Recovery

COSI as found on the Antarctic Plateau

- Soft landing: COSI was still sending data after landing!
- Visually instrument looked OK (except some antennas and parts of solar array)
- Full evaluation will happen after instrument is back in Berkeley in ~March
- Prepare for next flight!

The PRELIMINARY Data

Raw, uncorrected COSI data



Unfortunately flight was too short for any significant science observations

But:

- Good background measurements
- Enough calibration and observation data for our graduate students to play with and graduate on ;-)

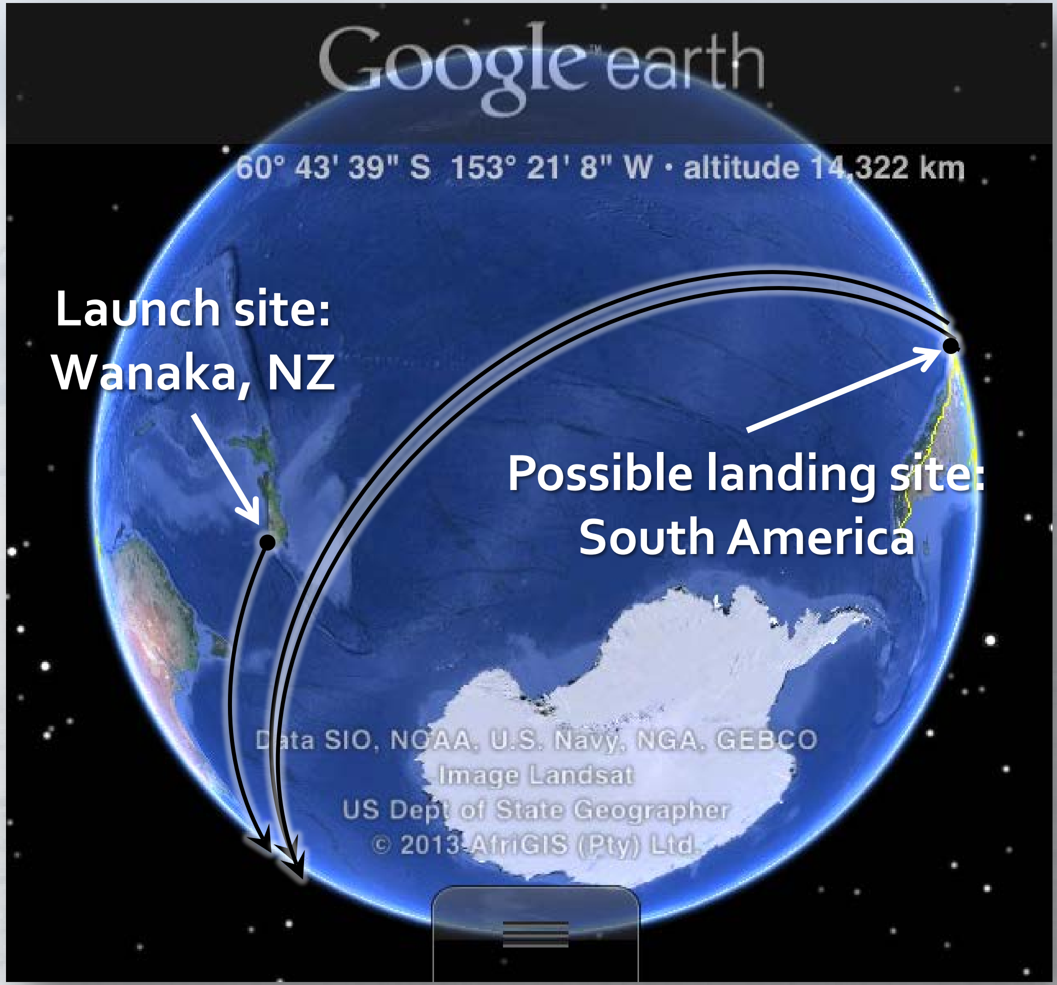
The 2016 & 2018 New Zealand Campaigns

Flight type: Super-pressure ULDB

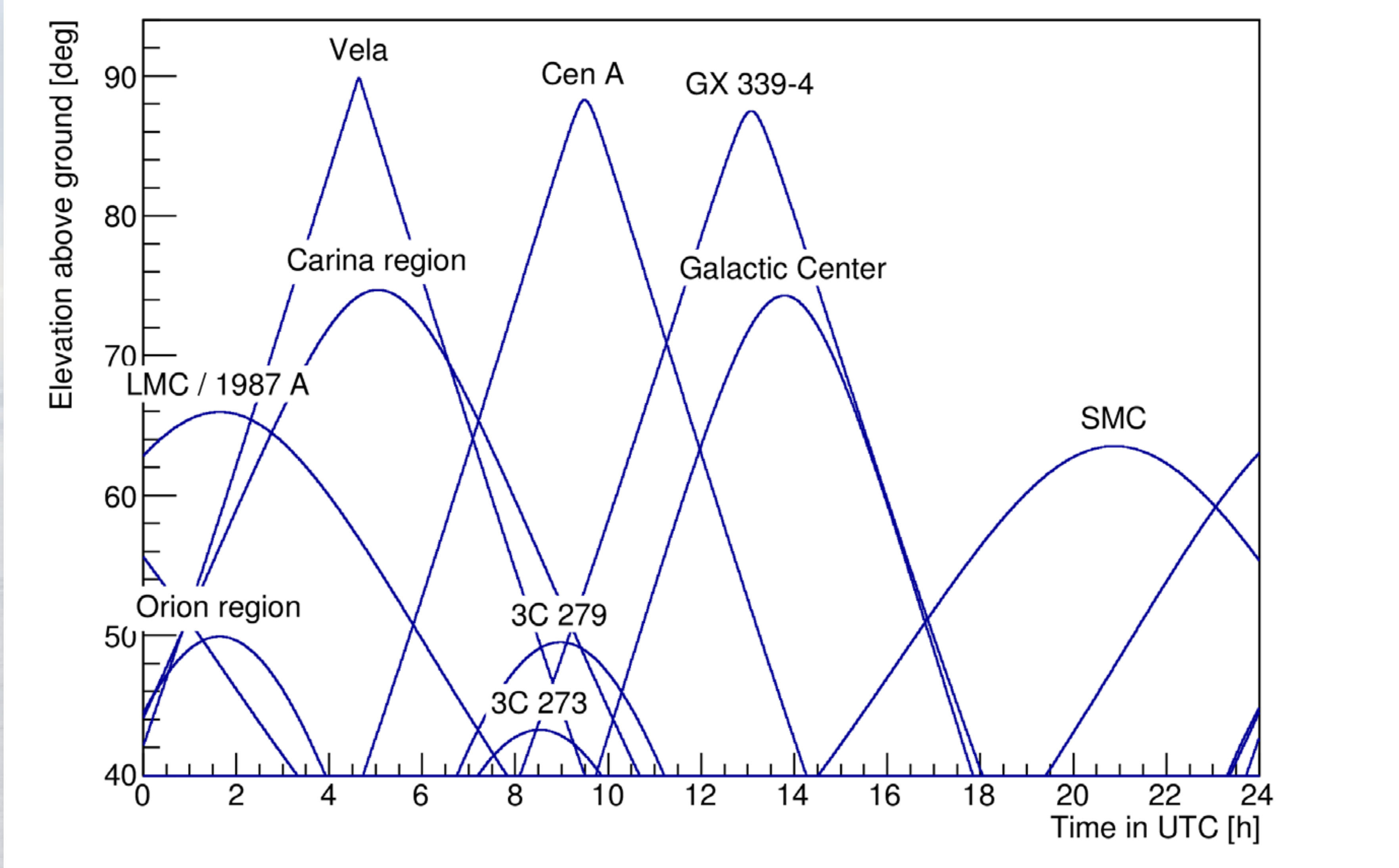
Duration: Up to 100 days – multiple times around the world

Main science goals:

- Gamma-ray burst polarization
- 511 keV imaging in Galactic Center region
- Nuclear line science
- Galactic black holes

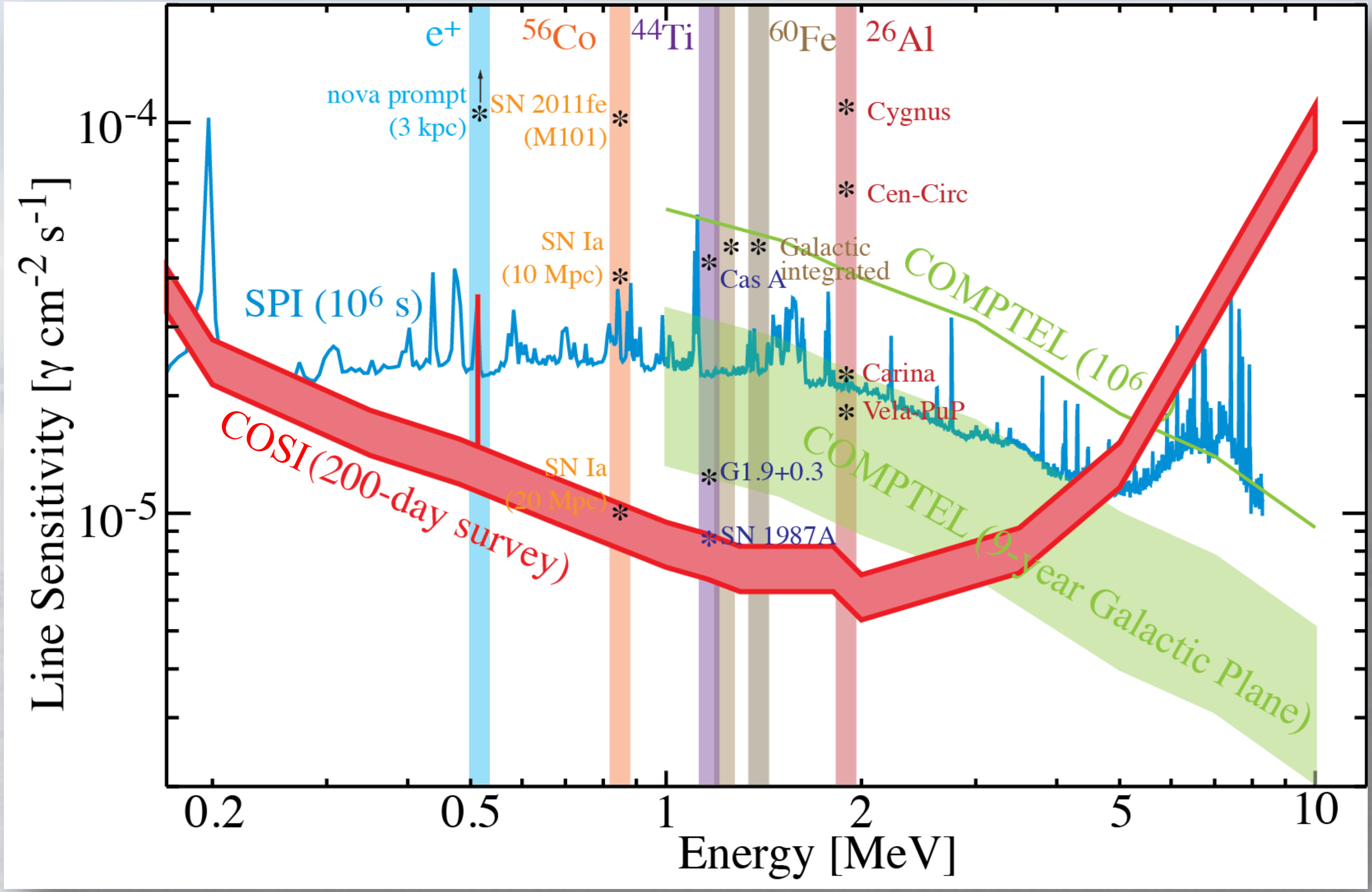


Observable Sources New Zealand Campaign



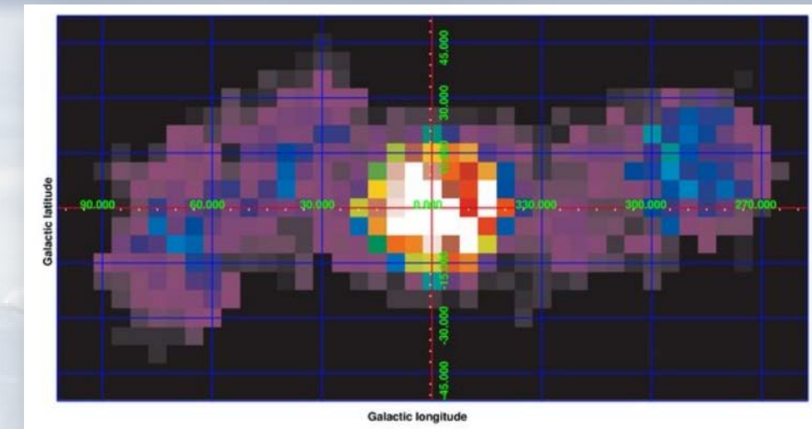
Nuclear Line Science

in the Galactic Center region

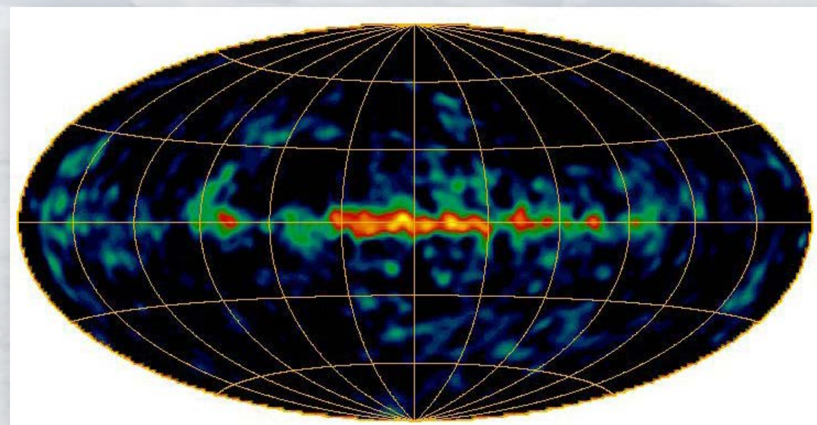


Goals for 511 keV and Nuclear Lines

- 511 keV – Is the "bulge" emission symmetric or asymmetric?
- ^{26}Al – Improved mapping
- ^{60}Fe – First mapping
- Comparison of 511 keV and ^{26}Al distributions to constrain positron propagation



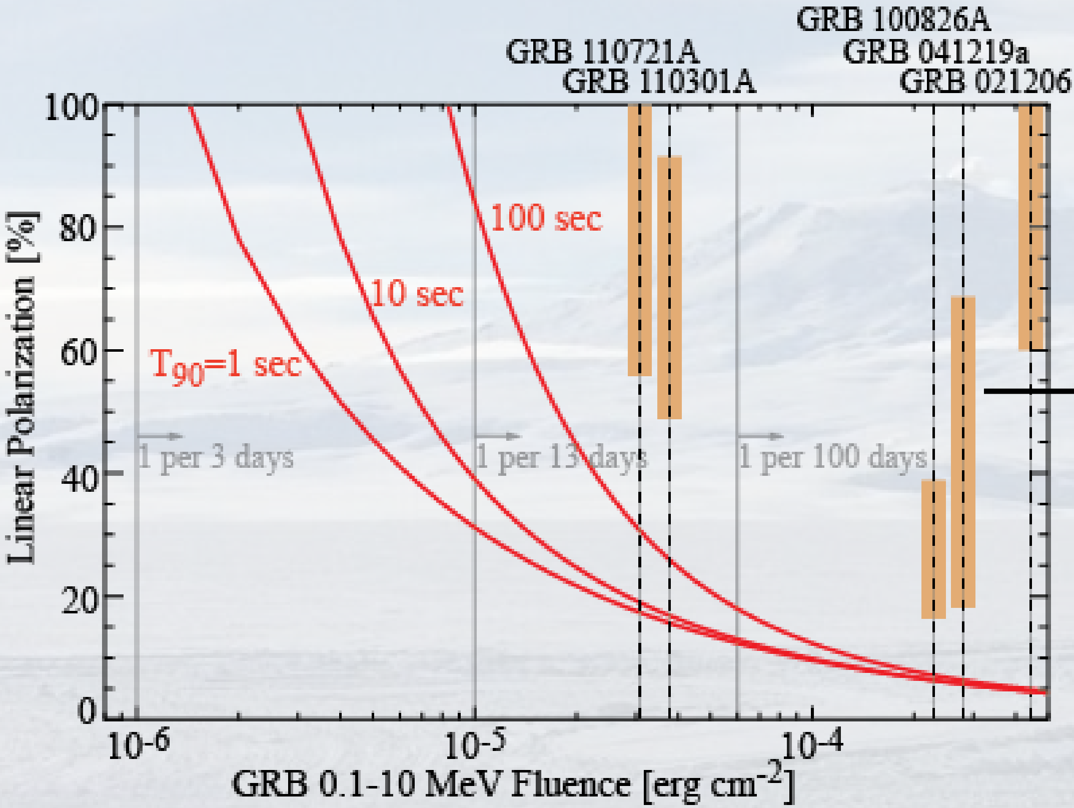
INTEGRAL/SPI Galactic center map of the positron annihilation radiation (0.511 MeV)
(Bouchet et al. 2010)



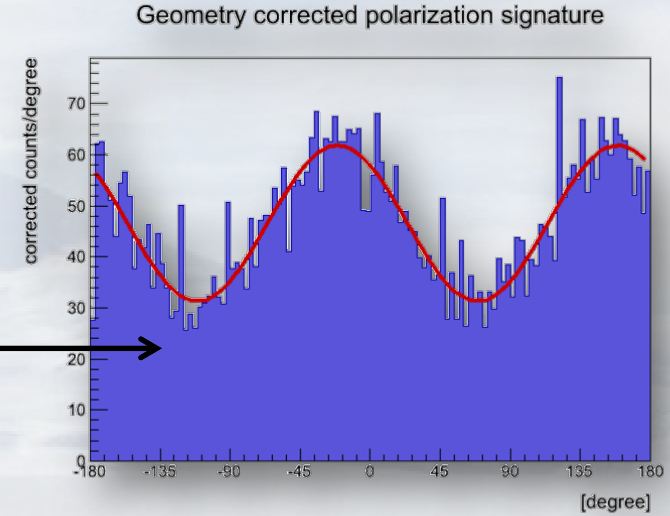
COMPTEL map of ^{26}Al emission (1.809 MeV)
(Oberlack et al. 1997)

Gamma-ray Burst Science

3-sigma minimal detectable polarization as a function of fluence and burst duration



Simulation of GRB 041219a: (60% linear polarization)



For bursts, we will downlink Compton and single-hit data, thus we will have spectra from ~30 keV to several MeV

For a 100-day flight, we estimate COSI will detect 30 GRBs, including 7-8 bright enough for polarization constraints!

Further detector developments

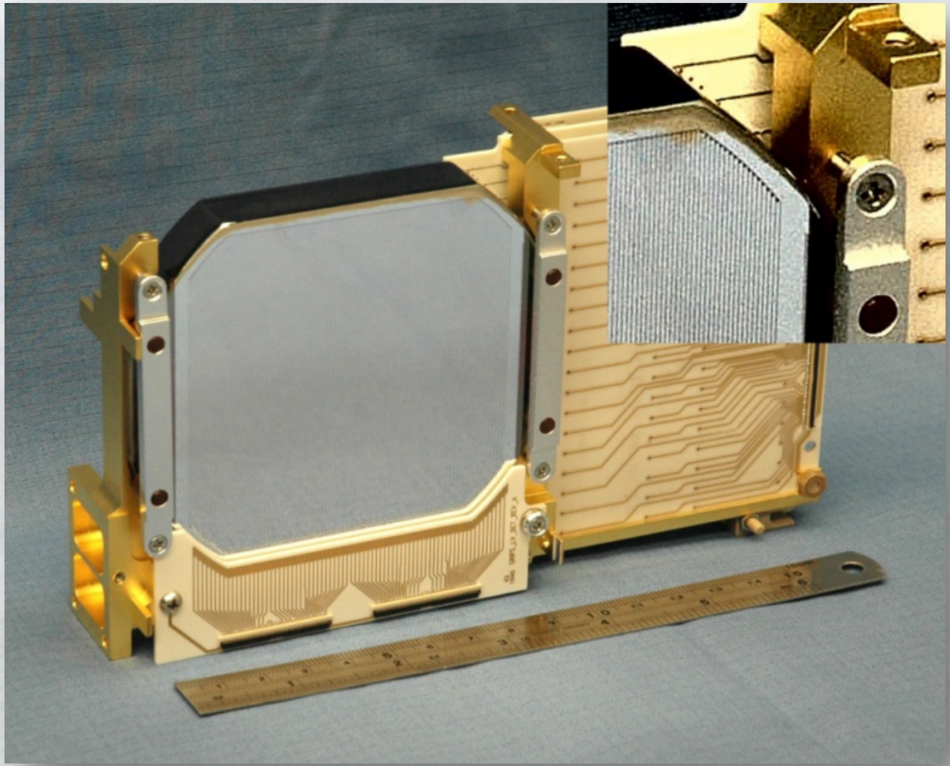
Angular resolution is limited by position resolution, i.e. strip pitch.

Improved Germanium detectors with 0.5 mm instead of 2.0 mm strip pitch:

- ✓ Better interaction resolution
  - ➢ Better event reconstruction performance
  - ➢ Better background suppression
  - ➢ Better angular resolution (up to 1.6 degree)
  - ➢ Better sensitivity

Switch to ASIC read-out instead of discrete read-out

- ✓ lower power consumption
- ✓ lower mass
- ✓ enables more channels and thus better resolution
- ✓ enables satellite mission



GRIPS Germanium detector

Ultimate Goal: Space Mission

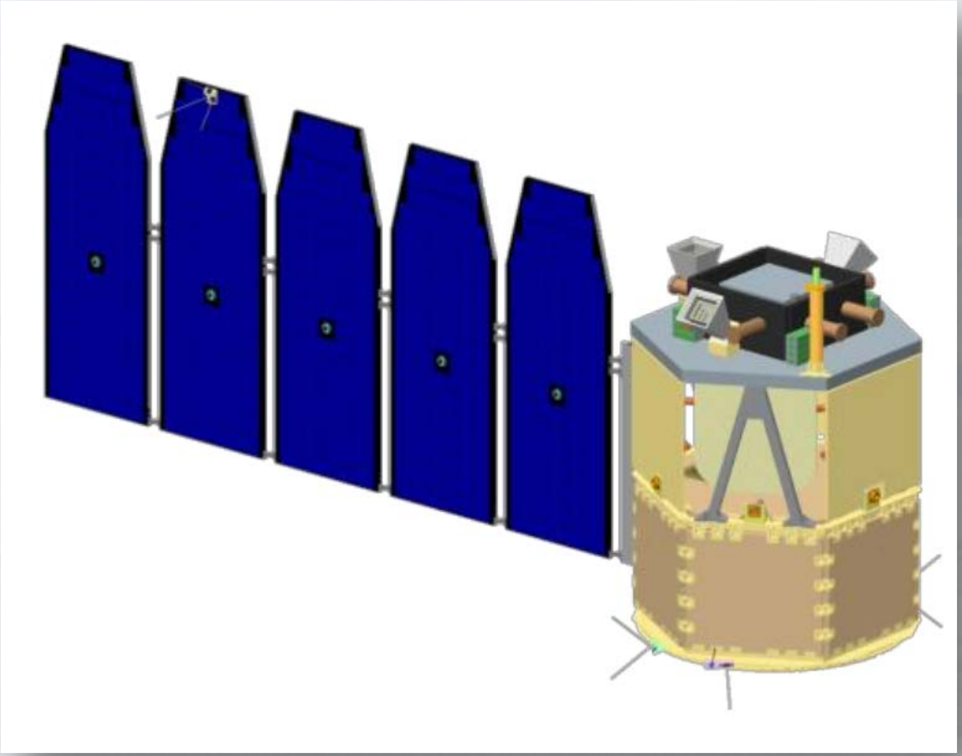
Advantages compared to balloon mission:

- No atmospheric absorption
- Less background
- Less event cuts needed
- Larger field-of-view
- Longer mission

→ Significantly improved sensitivity

The Gamma-Ray Explorer – GRX

A proposed SMEX mission based on COSI design



- 2x2x4 detector geometry
- 128 channels per detector side
- ASIC readout
- Low-Earth equatorial orbit for stable background conditions (similar to NuSTAR)

Advancements over COMPTEL / INTEGRAL

- Wide field-of-view enables uniform exposure and all-sky monitoring for transient sources
- Multi-mode background rejection
- Up to an order of magnitude improvement in grasp [cm^2 sr]
- Up to an order of magnitude improvement in nuclear line science:
  - Greatly improved sensitivity to annihilation emission
  - Significantly improved sensitivity and angular resolution for ^{26}Al
  - First ^{60}Fe all-sky map
- Unprecedented polarization survey for gamma-ray bursts, black holes, etc.

How to Simulate the Next Gamma-ray Telescope?

MEGAlib

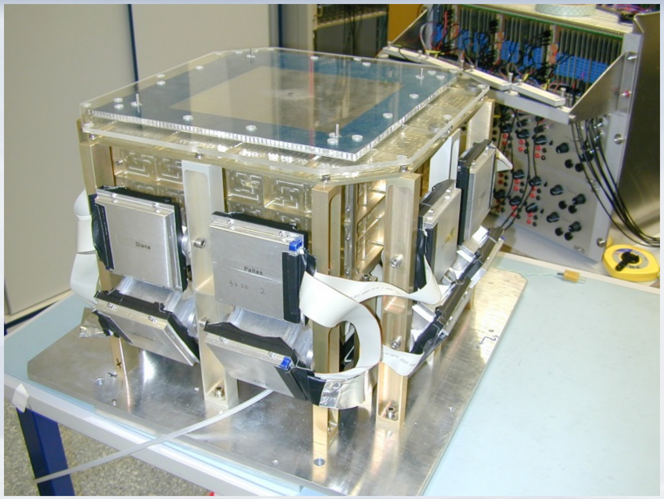
„Medium-Energy Gamma-ray Astronomy library“

Provides calibration, simulation & data analysis tools for hard X-ray and soft-to-medium-energy gamma-ray detectors/cameras/telescopes

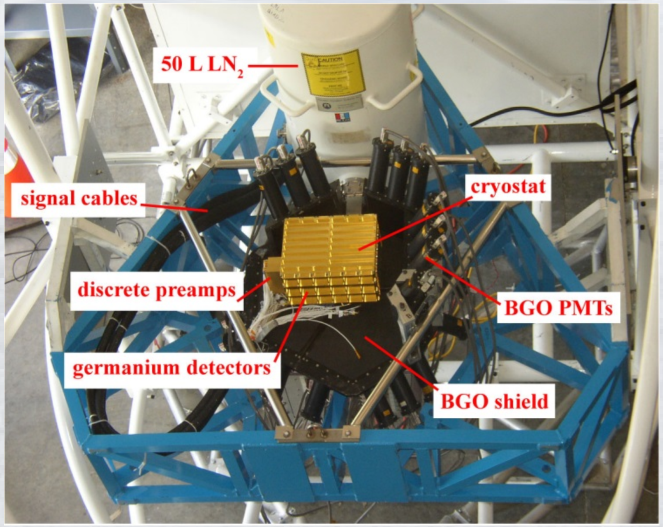
Its flexible design allows it to be easily applied to different projects and missions, such as MEGA, ACT, NCT/COSI, COMPTEL, GRI, GRIPS, NuSTAR, ASTRO-H, AstroGAM, hadron therapy monitoring, X-FEL detectors, HEMI, and many more!

MEGAlib is completely object-oriented, written in C++, and utilizes ROOT and Geant4

For more information see:
http://megalibtoolkit.com

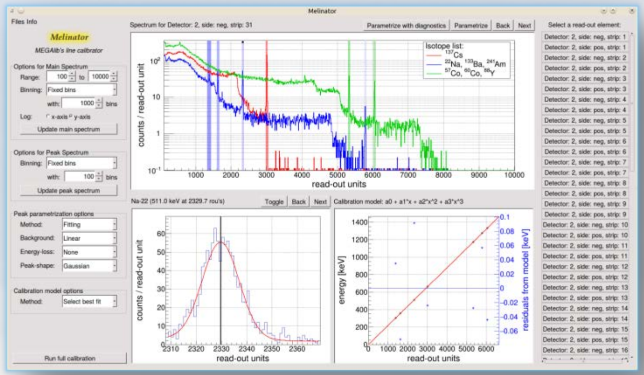


MEGA prototype

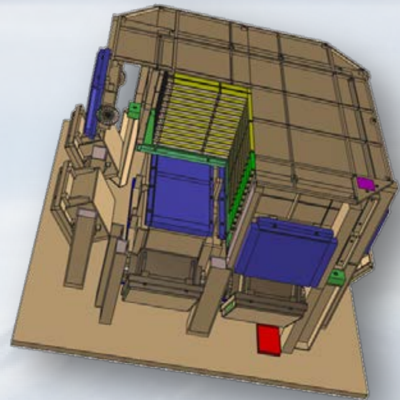


NCT balloon prototype

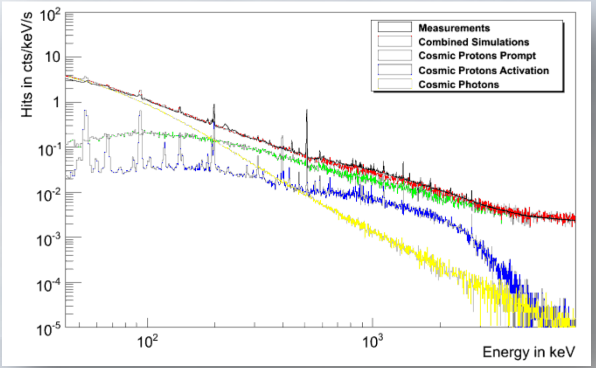
MEGAlib provides…



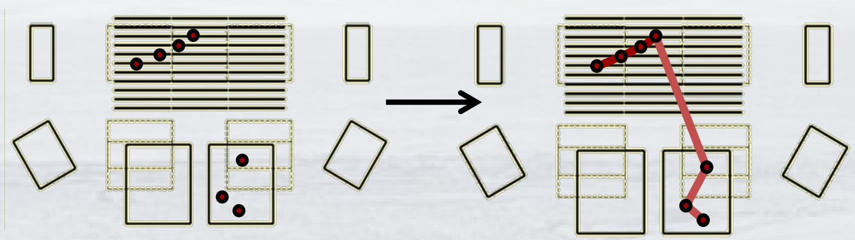
Calibration tools (Melinator, Fretalon)



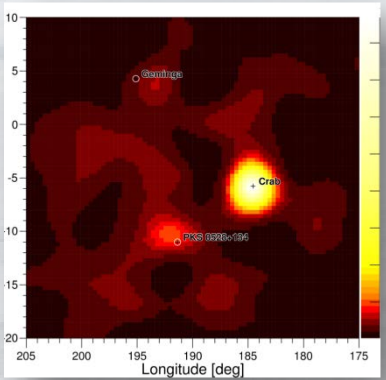
Geometry and detector description tool (Geomega)

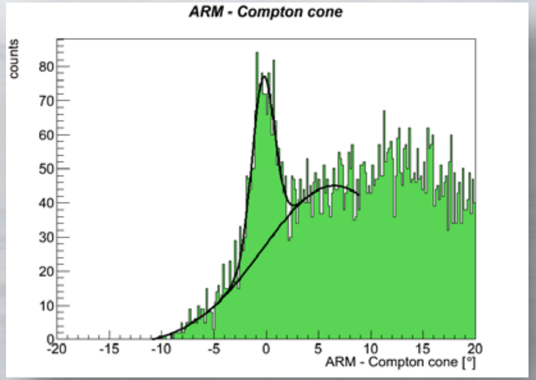


Geant4-based simulation tool (Cosima)



Event reconstruction tools (Revan, sivan)





Imaging and analysis tools (Mimrec)

Plus tools for response generation, event viewing, detector analysis, sensitivity estimation, general detector performance estimation, and many more!

Thank You!

The COSI super-pressure balloon passing by the sun – Copyright by Alan Chiu