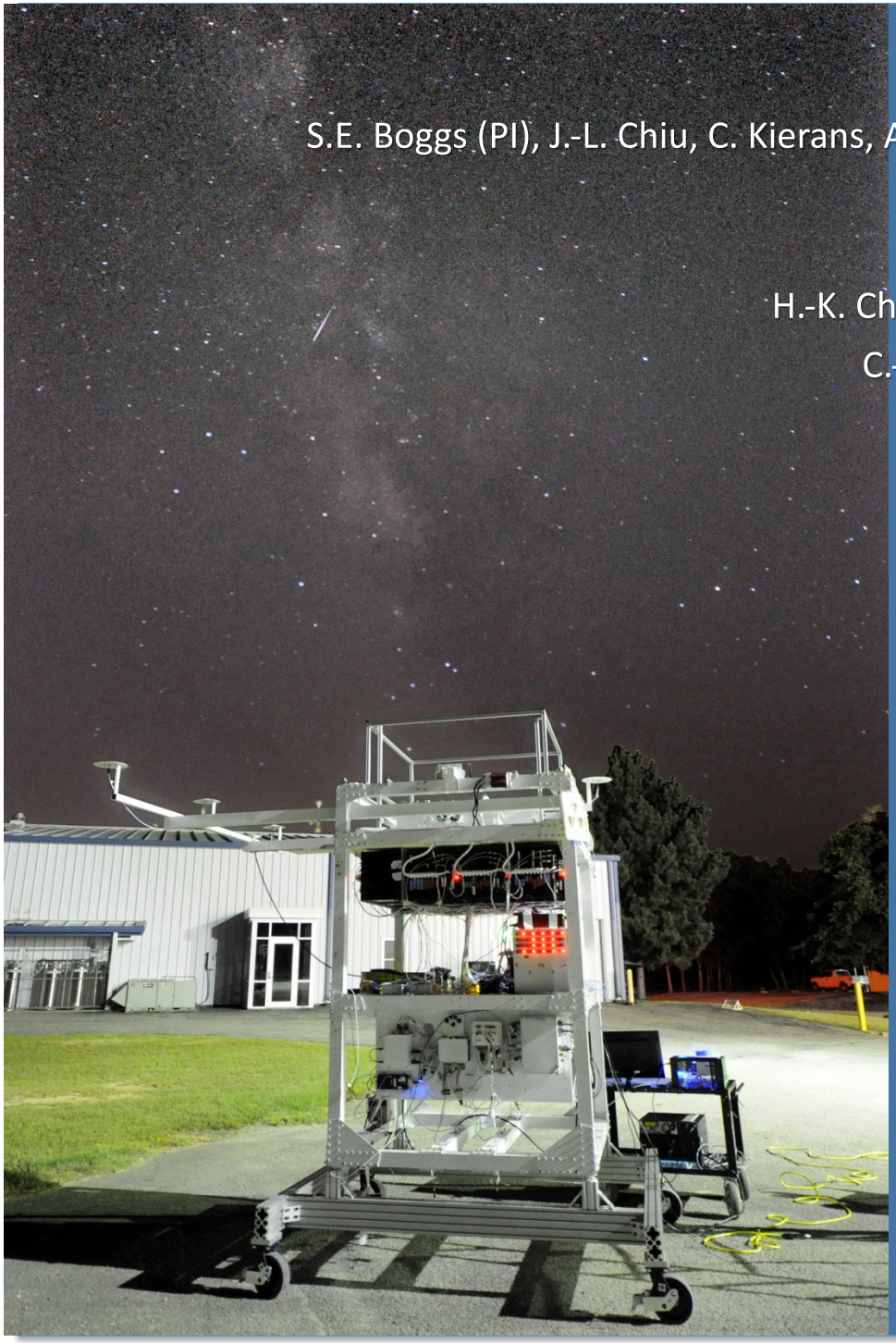
The Compton Spectrometer and Imager

A balloon-borne gamma-ray spectrometer, polarimeter, and imager

John Tomsick, UC Berkeley

for the COSI collaboration



The COSI Collaboration:

S.E. Boggs (PI), J.-L. Chiu, C. Kierans, A. Lowell, C. Sleator, J.A. Tomsick, A. Zoglauer *(UCB/SSL)*

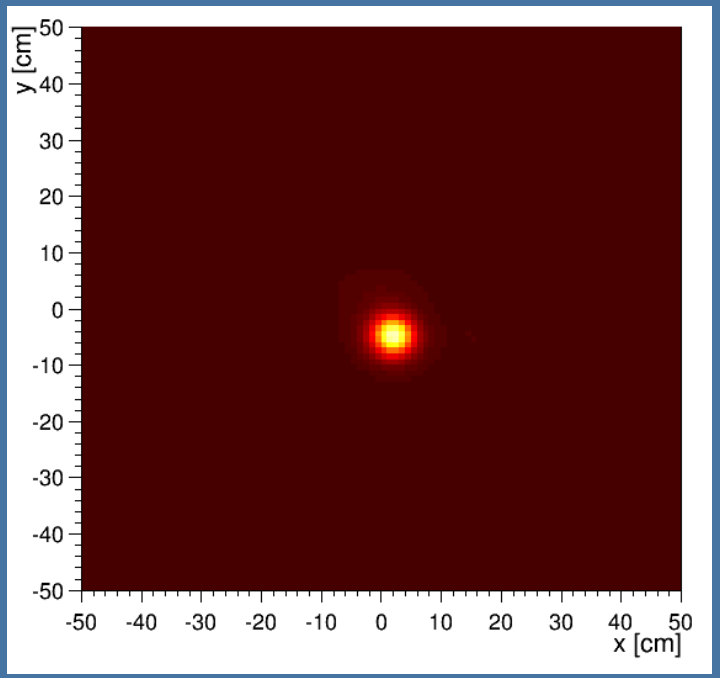
M. Amman *(LBNL)*

P. Jean, P. von Ballmoos *(IRAP, France)*

H.-K. Chang, C.-Y. Yang, J.-R. Shang, C.-H. Tseng *(NTHU, Taiwan),*

C.-H. Lin (AS, Taiwan), Y.-H. Chang , Y. Chou *(NCU, Taiwan)*

COSI US is supported through grants by NASA



Calibration image of a 662 keV ^{137}Cs source ~56 cm above the instrument.

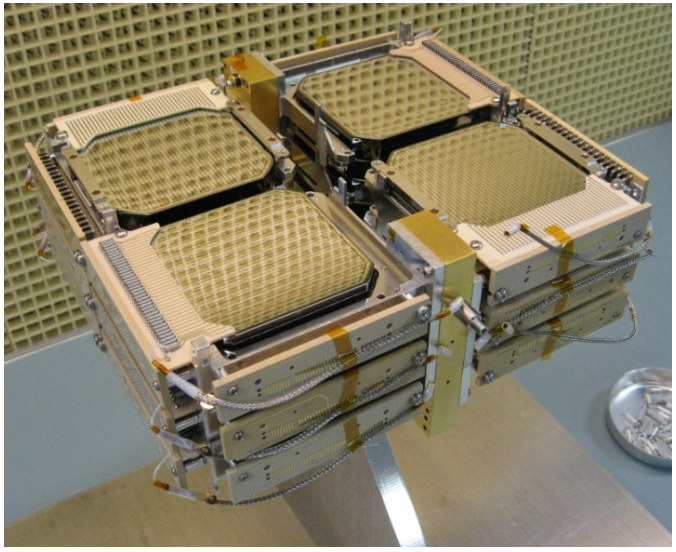
Overview: Instrument & Campaigns

Instrument:

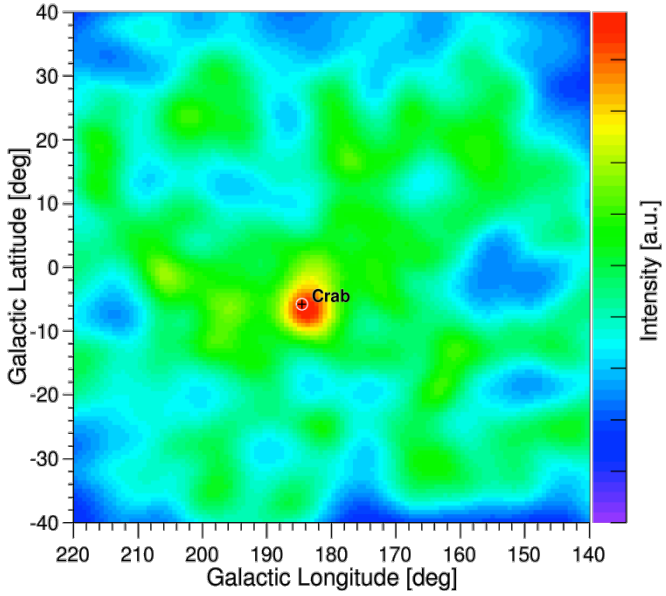
- Energy range: 0.2 – several MeV
- 12 high-purity Ge double-sided strip detectors
- Energy resolution: 1.5-3.0 keV FWHM
- Large field-of-view: almost 1/4 of sky
- Angular resolution: up to ~4° FWHM

Balloon campaigns:

- Nuclear Compton Telescope (NCT): 2 GeD prototype from Ft. Sumner, NM in 2005
- NCT: 10 GeD instrument from Ft. Sumner in 2009
- NCT: Failed launch from Australia in 2010
- COSI: Antarctica in 2014 (superpressure)
- *COSI: New Zealand in 2016 (superpressure)*



Detectors are 8x8 cm²

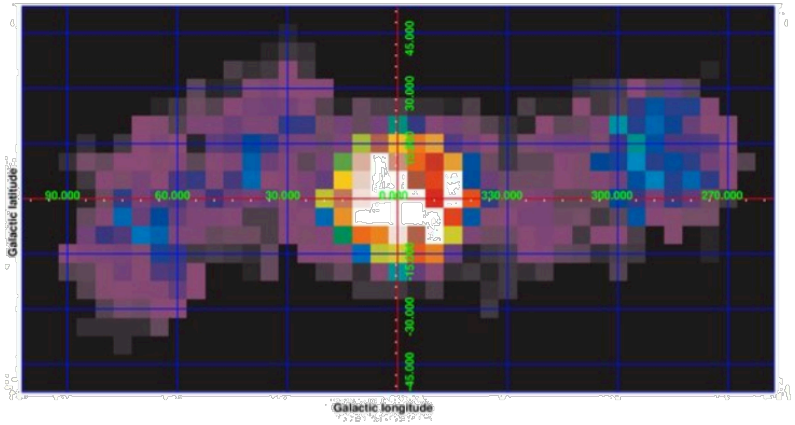


From 2009 flight (Bandstra et al. 2011)

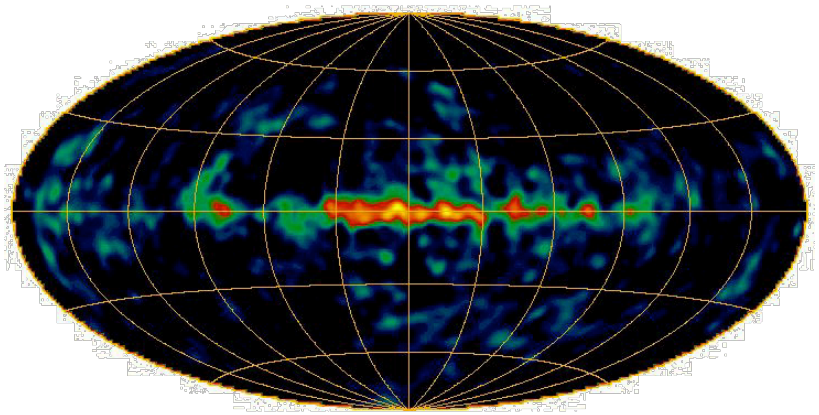
COSI Science Goals

- Mapping 511 keV positron annihilation emission at the Galactic Center
- Studies of Galactic radioactivity: lines from 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}

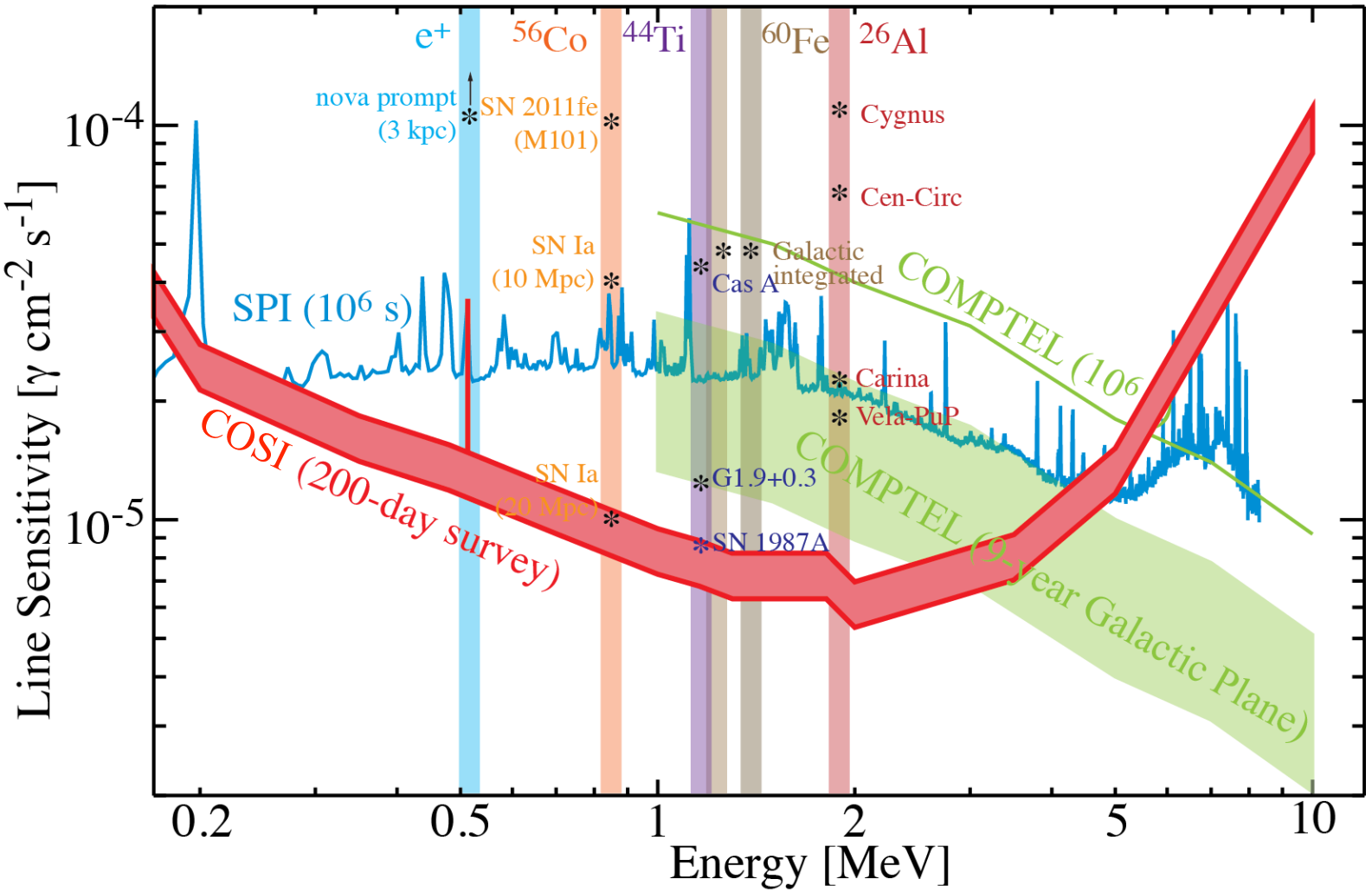


INTEGRAL/SPI Galactic center map of the positron annihilation radiation (0.511 MeV) *(Bouchet et al. 2010)*



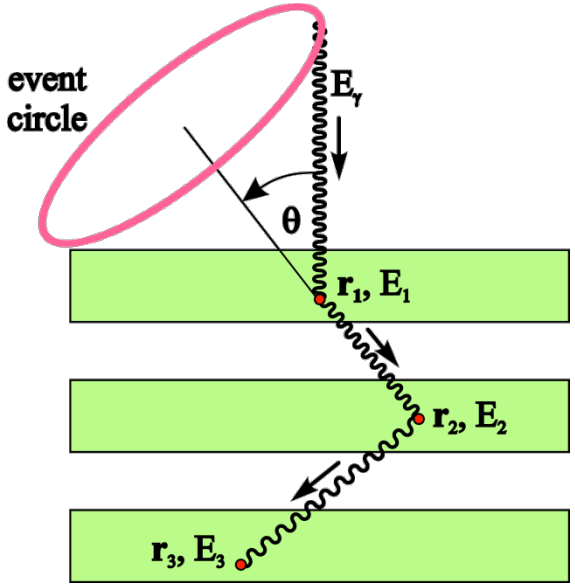
COMPTEL map of ^{26}Al emission (1.809 MeV) *(Oberlack et al. 1997)*

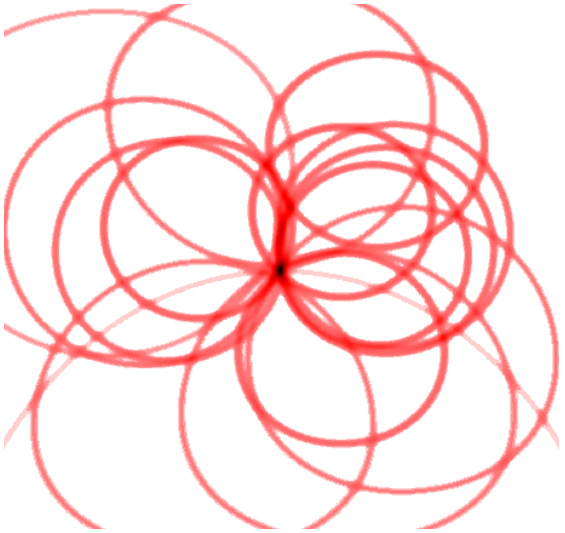
Nuclear Line Science



Operating Principle

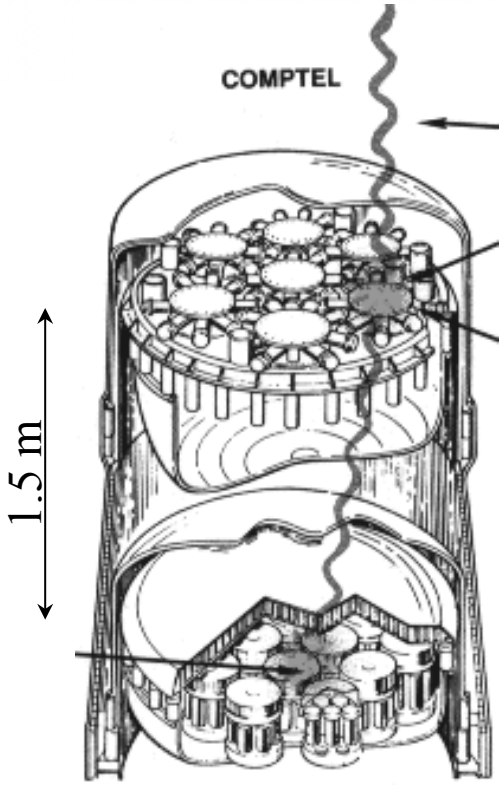
of COSI-style Compton telescopes



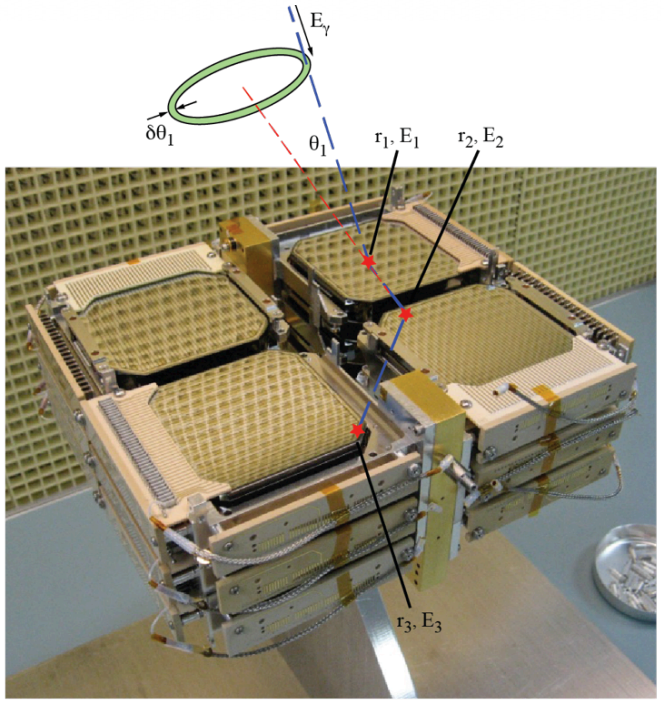


- Photons interact multiple times in active detector (here: Ge).
- The interaction sequence can be determined from information such as scatter angles, absorption probabilities, scatter probabilities
- The origin of a single not-tracked event can be restricted to the so called “event circle”.
- The photon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

Compton Telescopes: From COMPTEL to COSI



30+ years development



CGRO/COMPTEL:

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

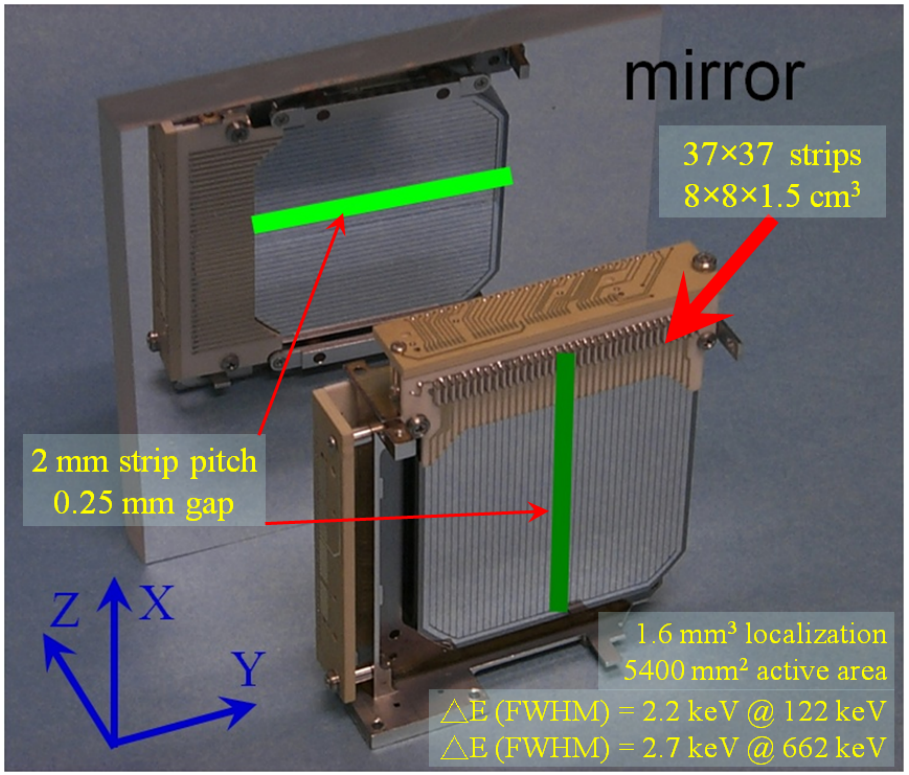
COSI:

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

➢ Improved performance with a fraction of the mass and volume

The Germanium Detectors

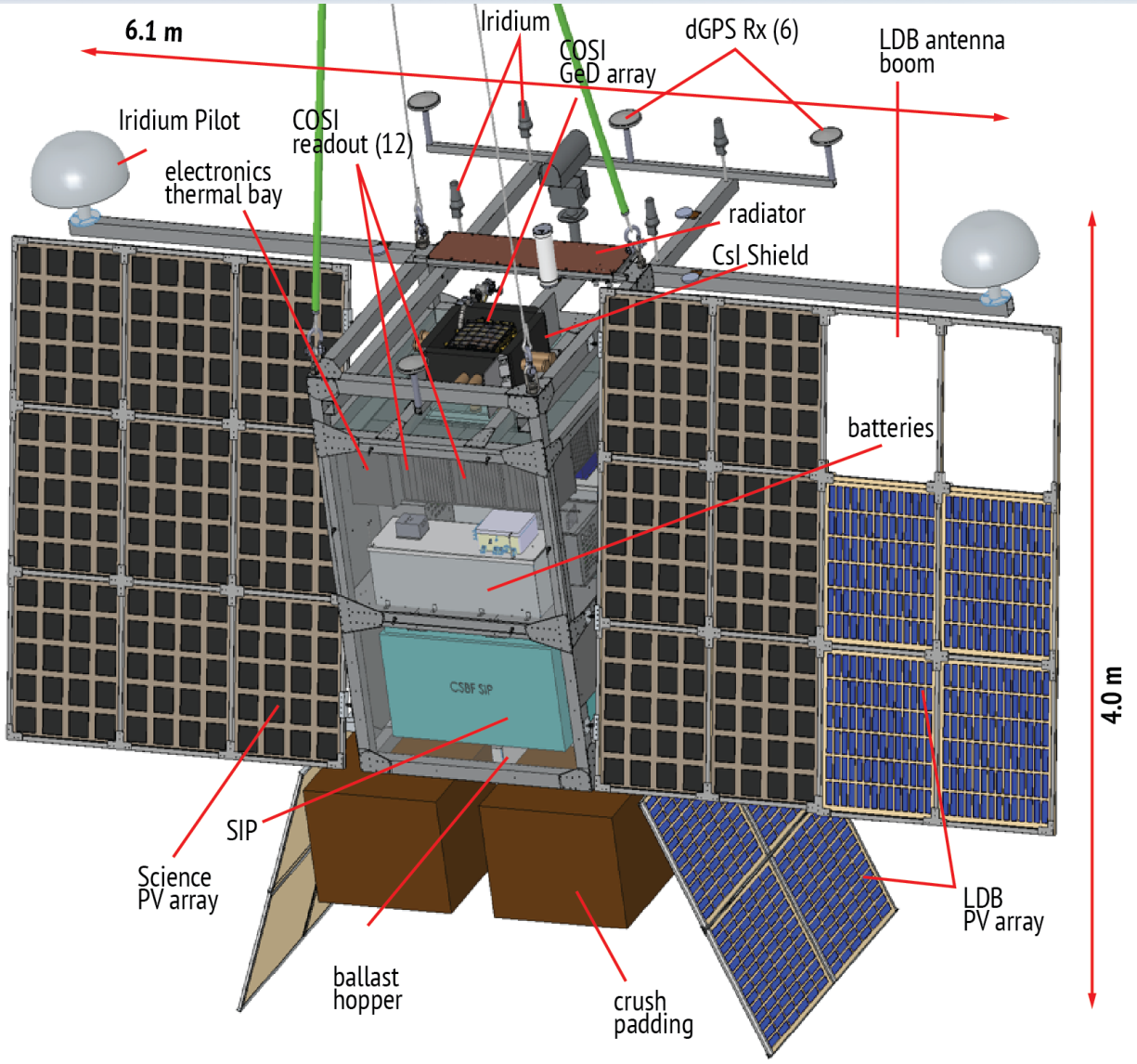
- Size: 8 x 8 x 1.5 cm^3
- 37 orthogonal strips per side
- 2 mm strip pitch
- Operated as fully-depleted p-i-n junctions
- a-Ge and a-Si surface layers
- Excellent spectral resolution: 0.2-1% FWHM
- Excellent depth resolution: 0.5 mm FWHM
- 12 are integrated in the COSI cryostat



COSI Upgrades from NCT

Key changes enabling long flights with the superpressure balloon:

- Simple, lightweight gondola
- Fits NASA's 18 MCF SPB
- No consumables
- Full science data download

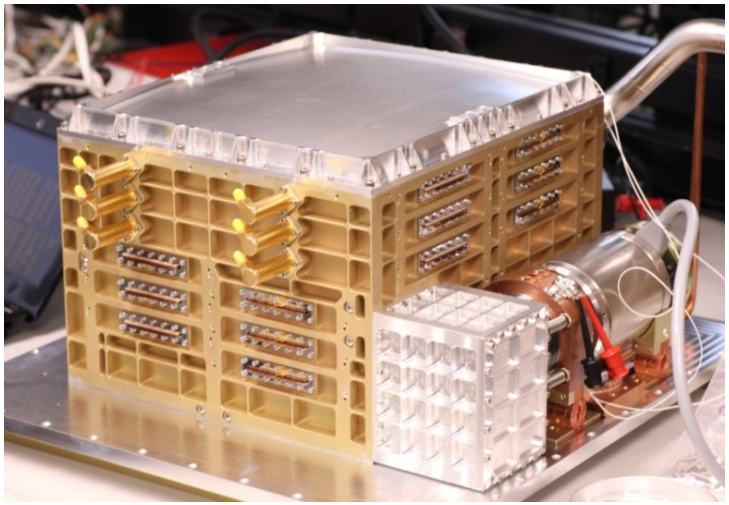


More COSI Upgrades from NCT

Mechanical cooler

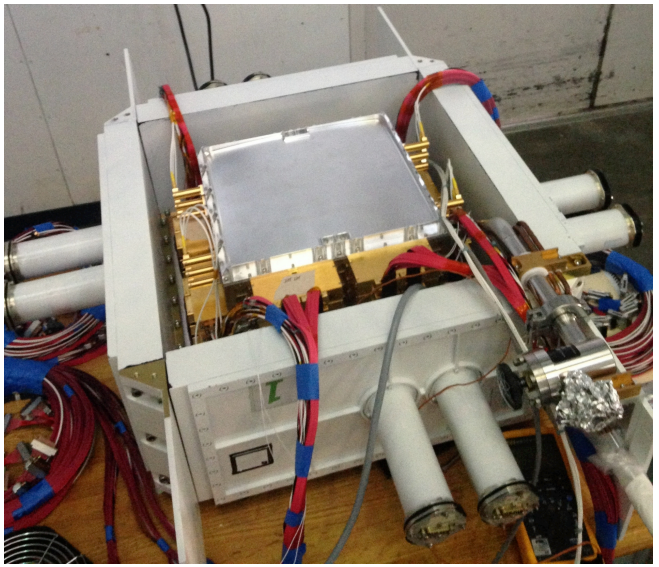
-Sunpower CryoTel 10 W lift for 160 W input

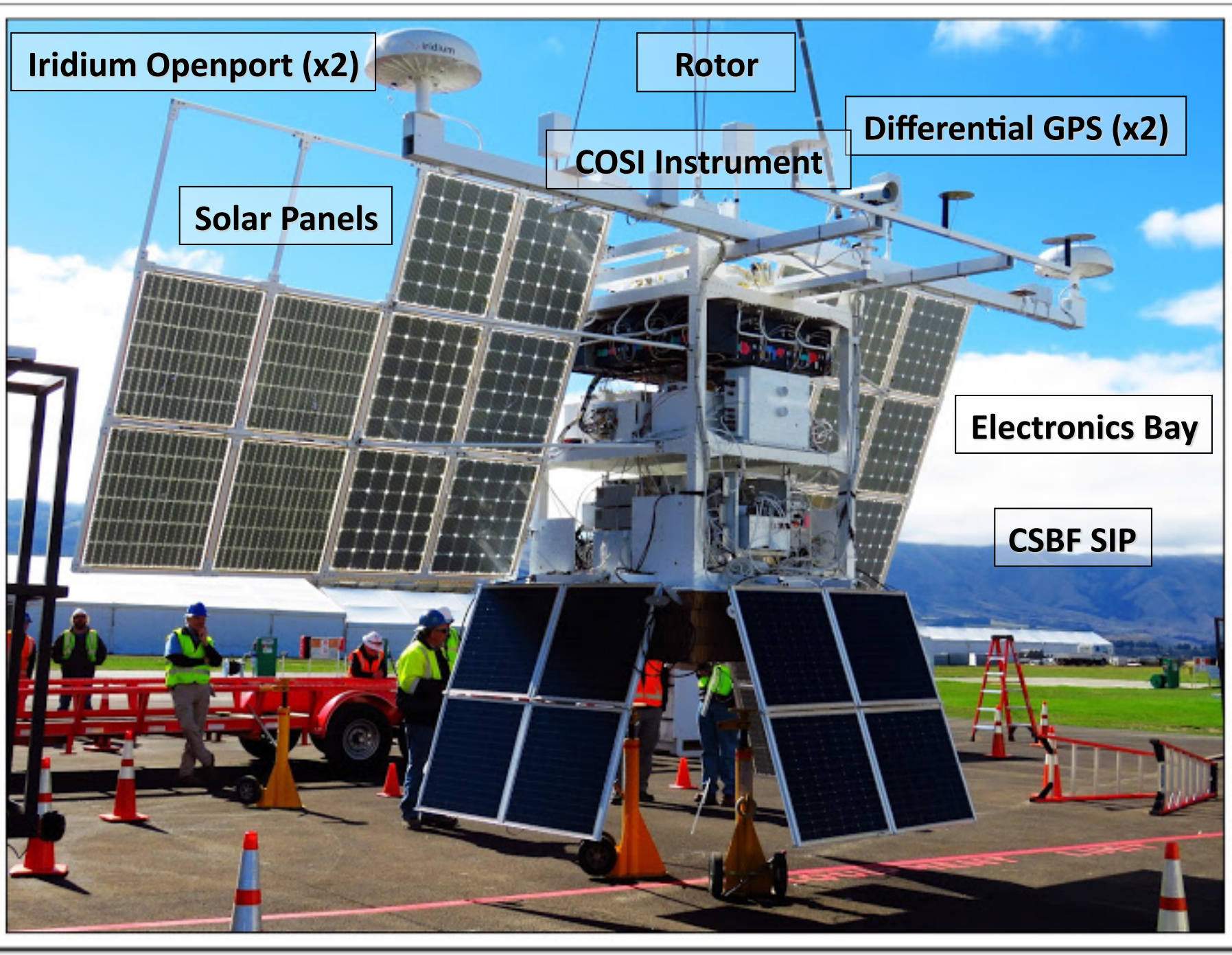
-Enables long flights



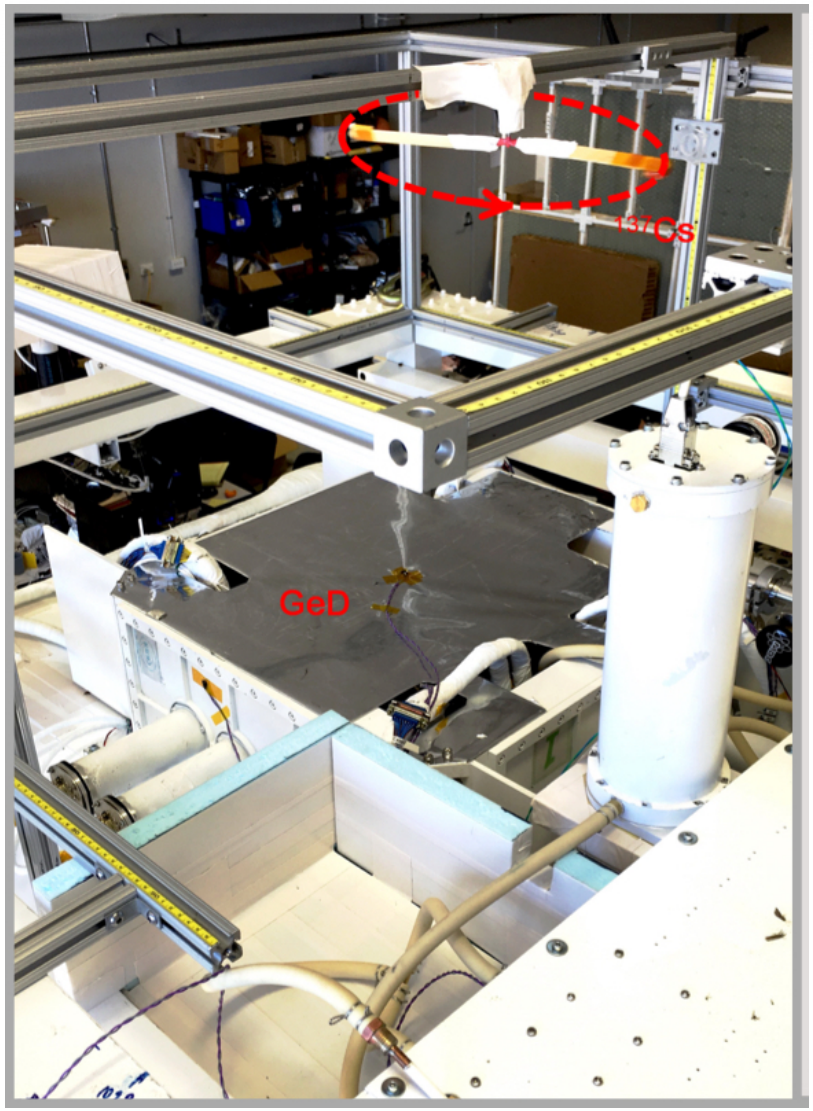
New CsI shielding

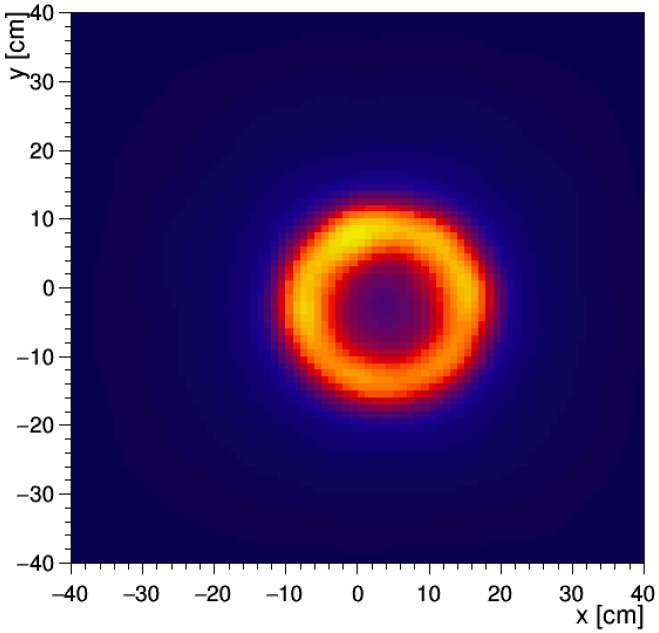
-More space available for detectors




Iridium Openport (x2)
Rotor
Differential GPS (x2)
COSI Instrument
Solar Panels
Electronics Bay
CSBF SIP

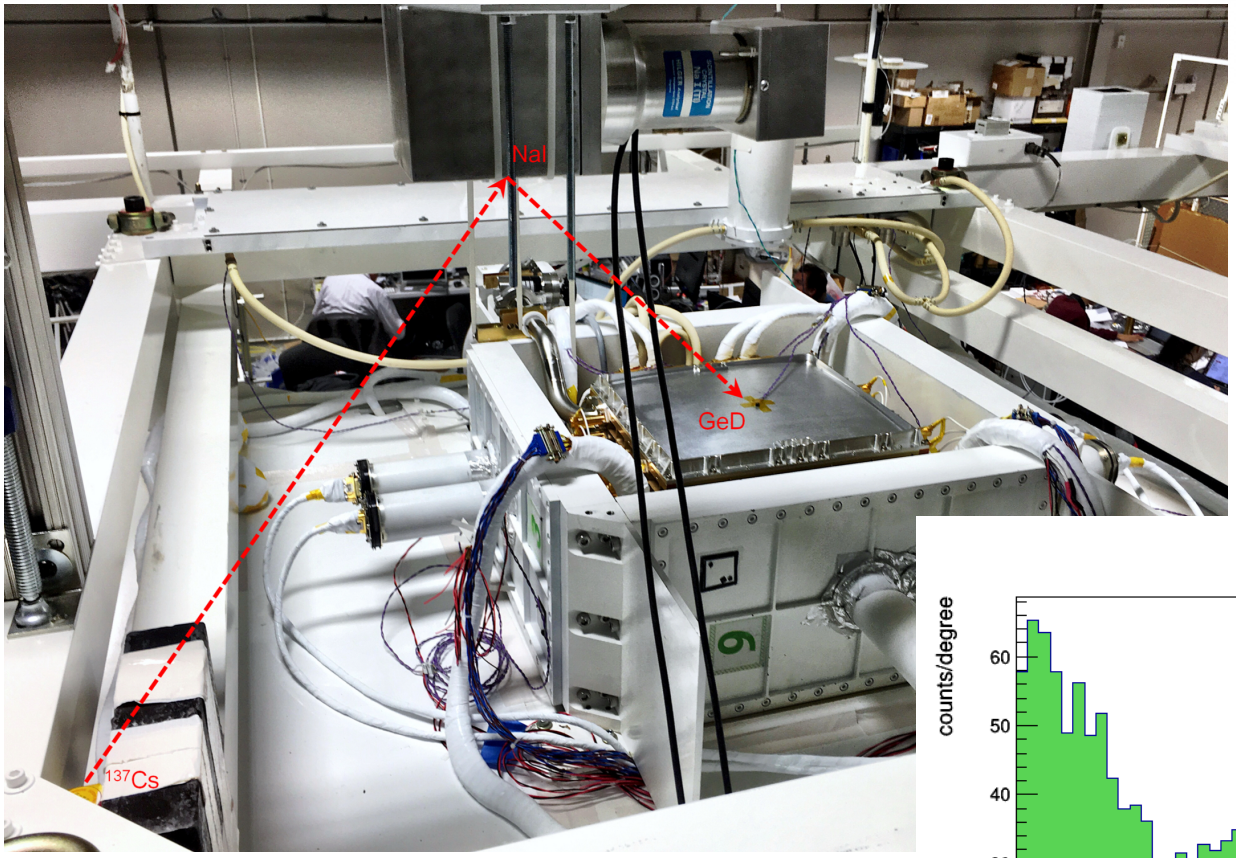
Diffuse Imaging Test

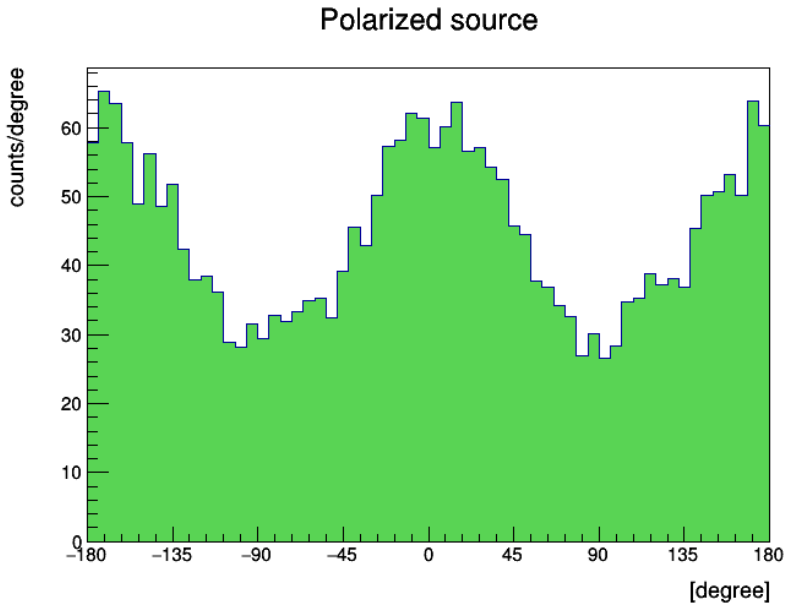




- Image of emission line from the radioactive source

Polarization Calibration

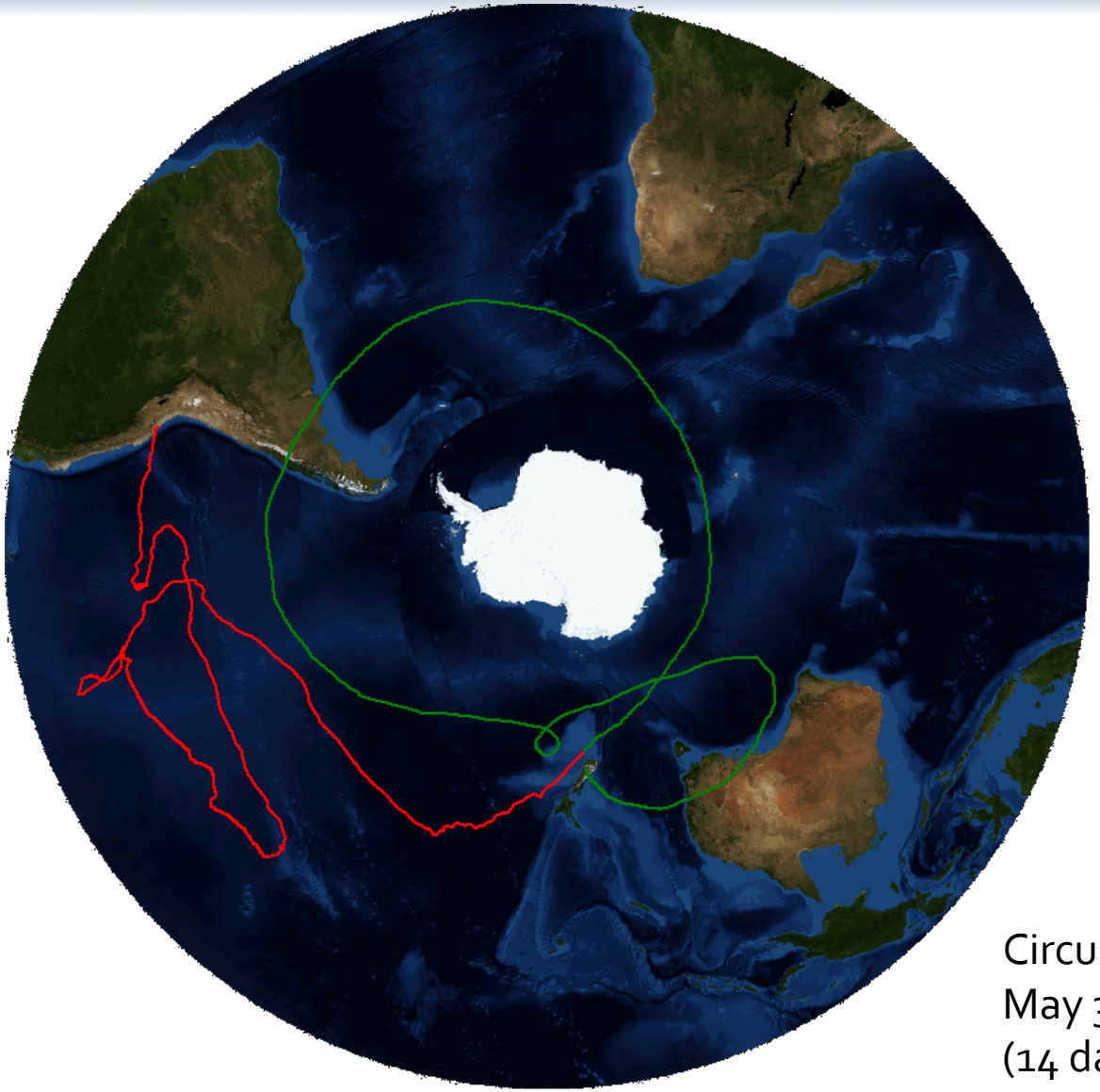




COSI Launch: May 16, 2016

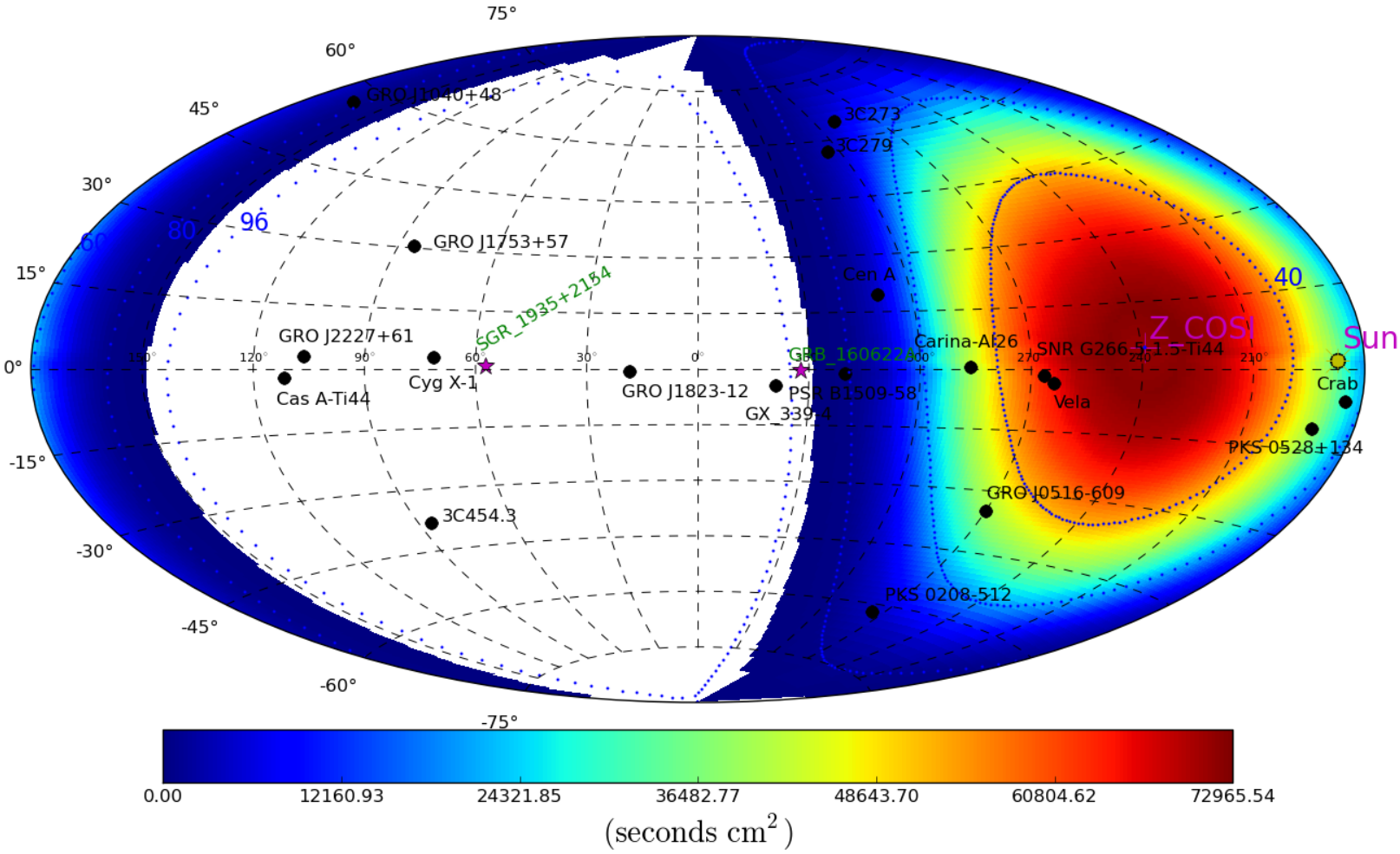
Flight Path

Landed in Peru
on July 2
(46 day flight)

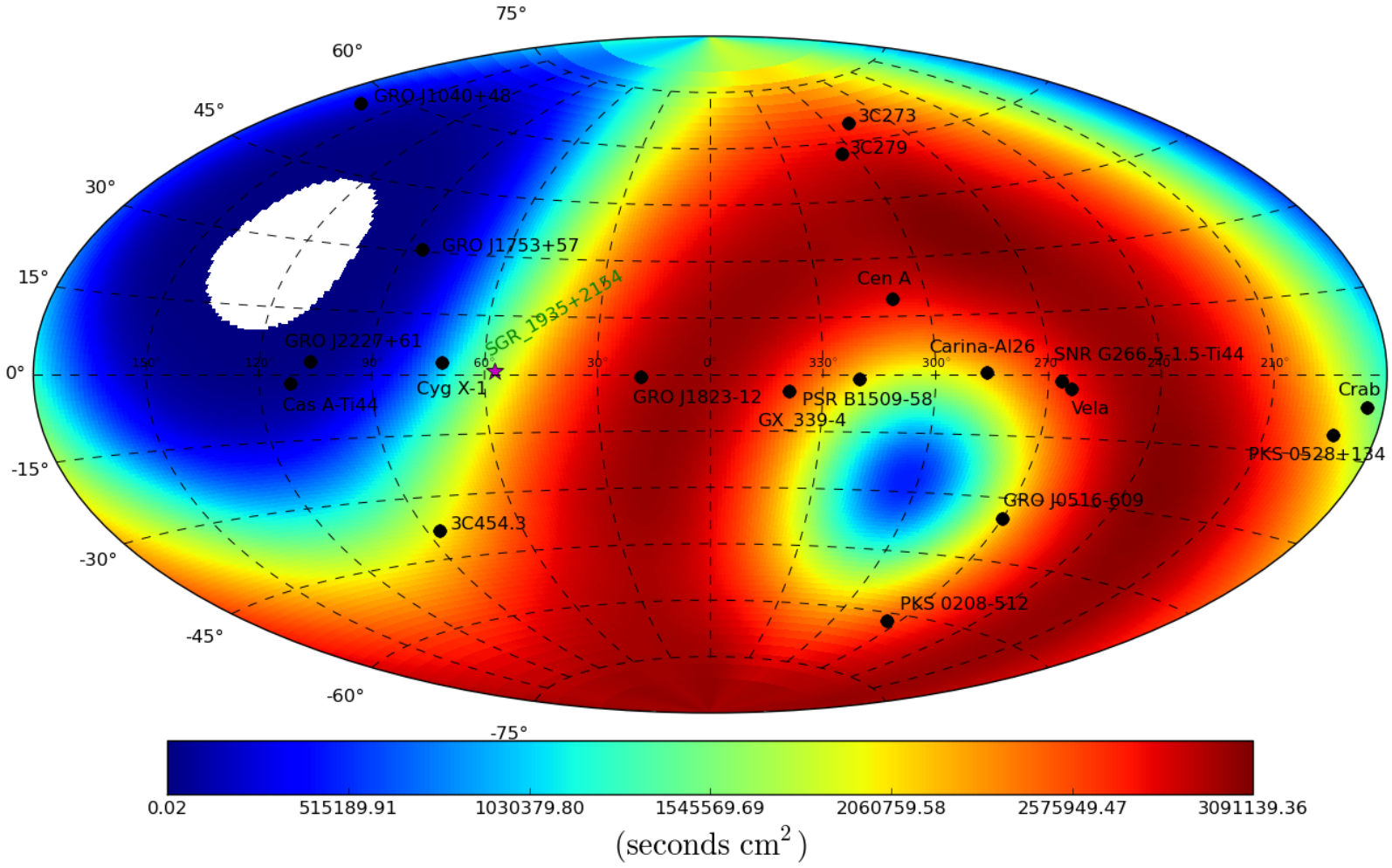


Circumnavigation on
May 31
(14 days after launch)

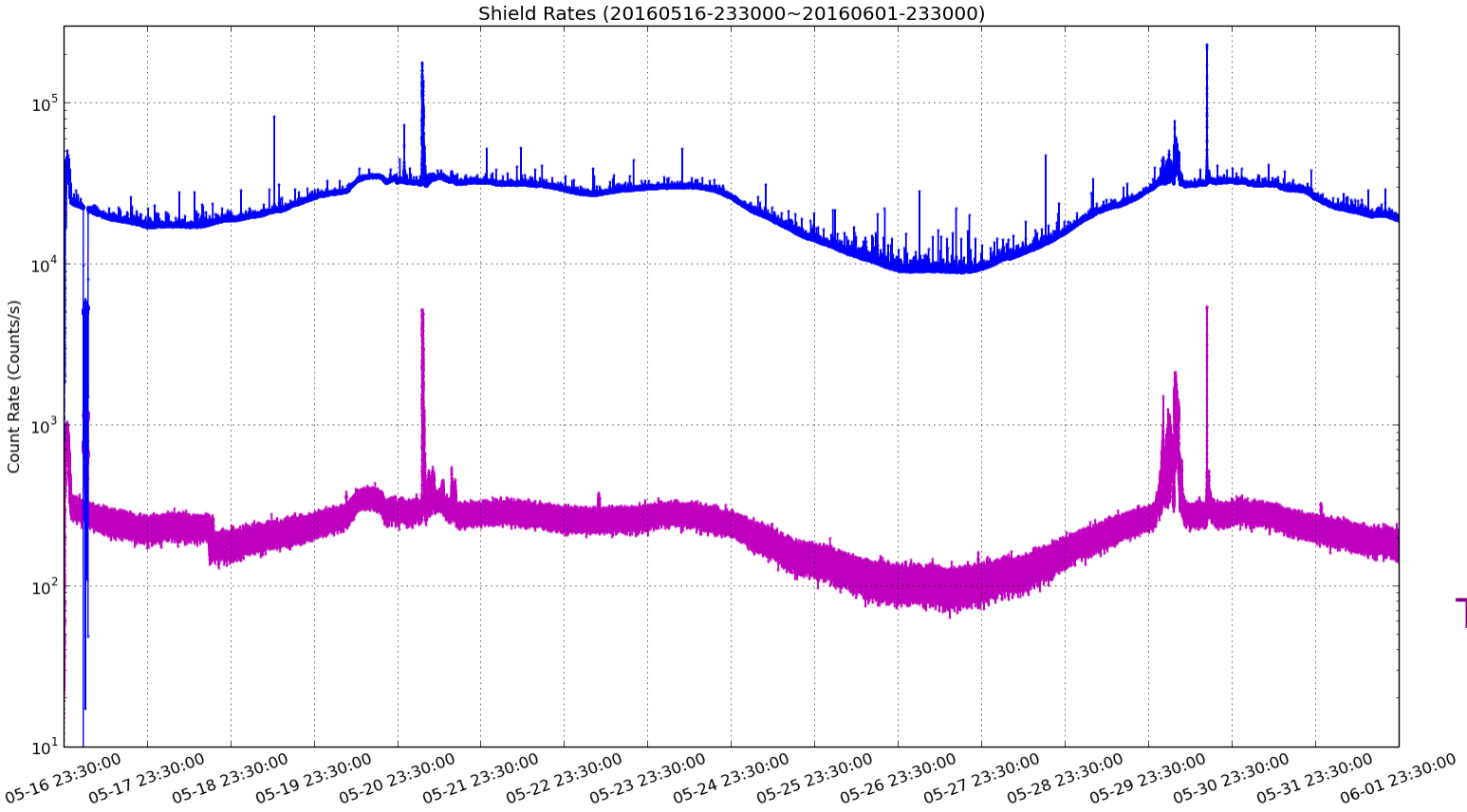
Field of View



Daily Exposure



Shield and GeD Rates – 1st Two Weeks



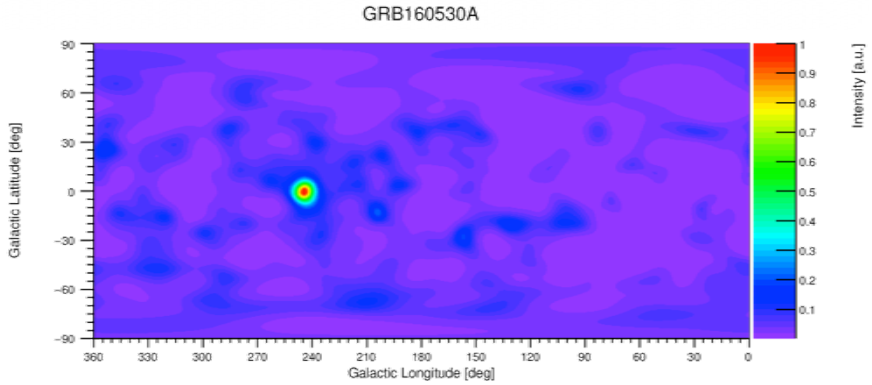
Shields

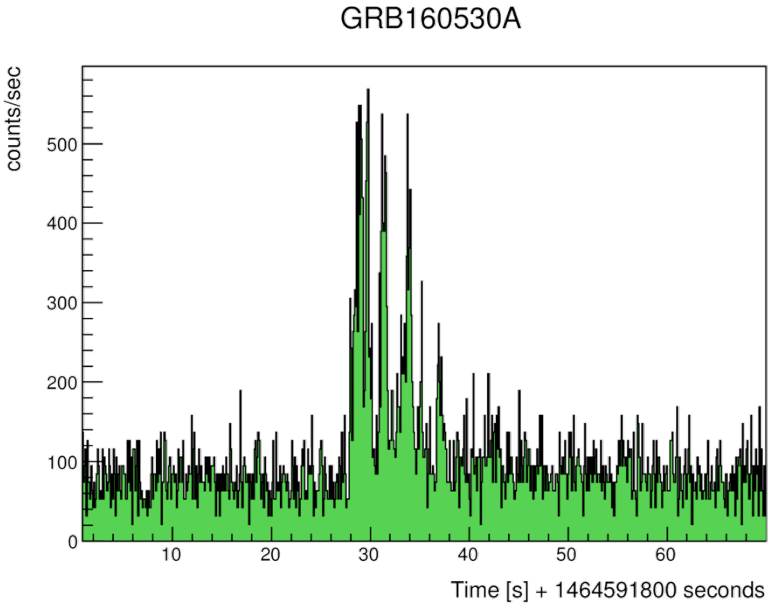
Top GeDs

- Long term increases due to drifting South
- Flares from radiation belt emission on 5/21 and 5/30
- GRB 160530A during relatively high background

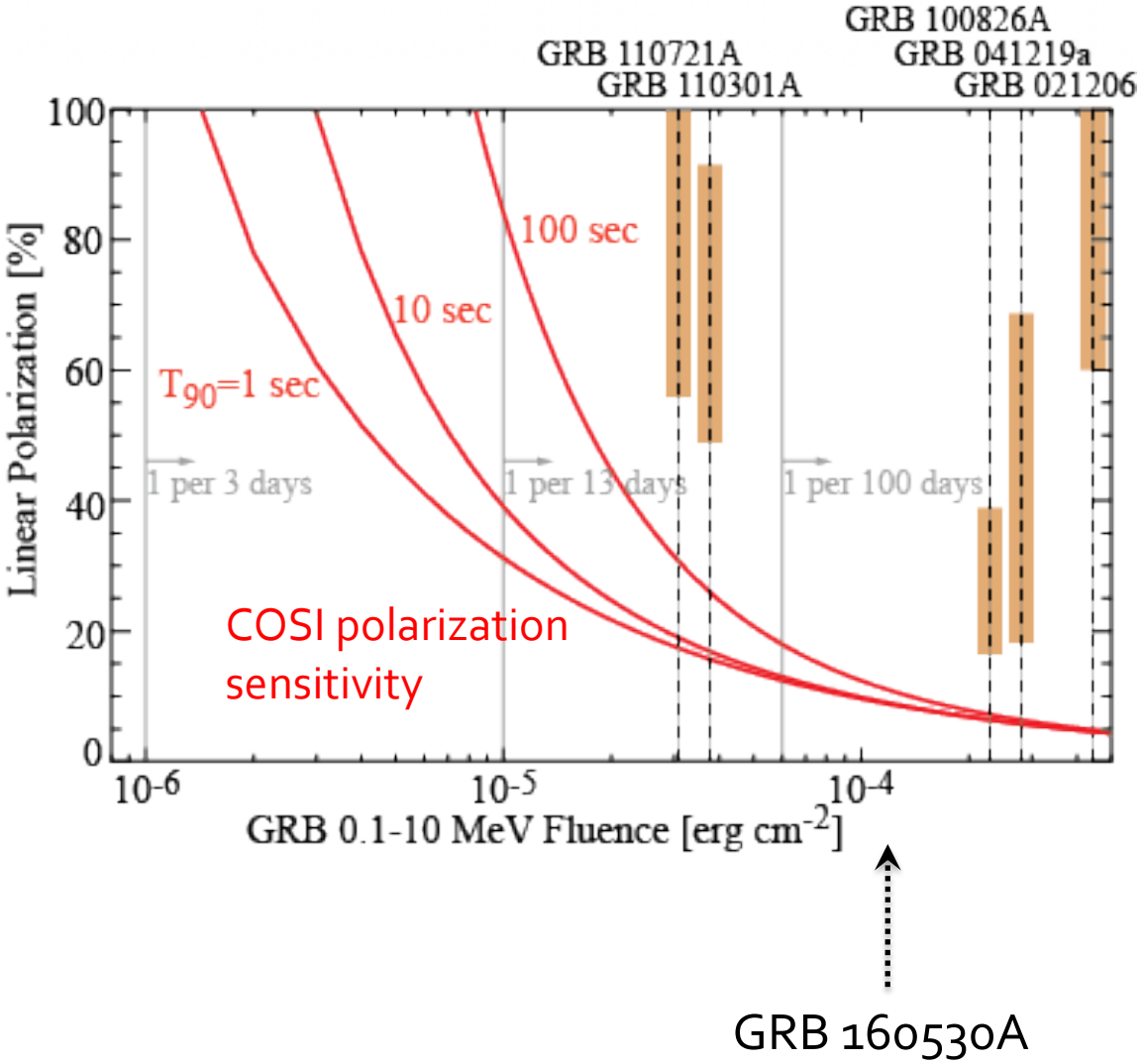
Science Investigations: GRB 160530A

- Data download and 24/7 human monitoring
  - triggered Swift follow-up
  - reported in GCN 19473
  - Interplanetary Network (IPN) and COSI positions consistent (GCN 19476)
- Polarization analysis happening now (Lowell et al., in prep.)



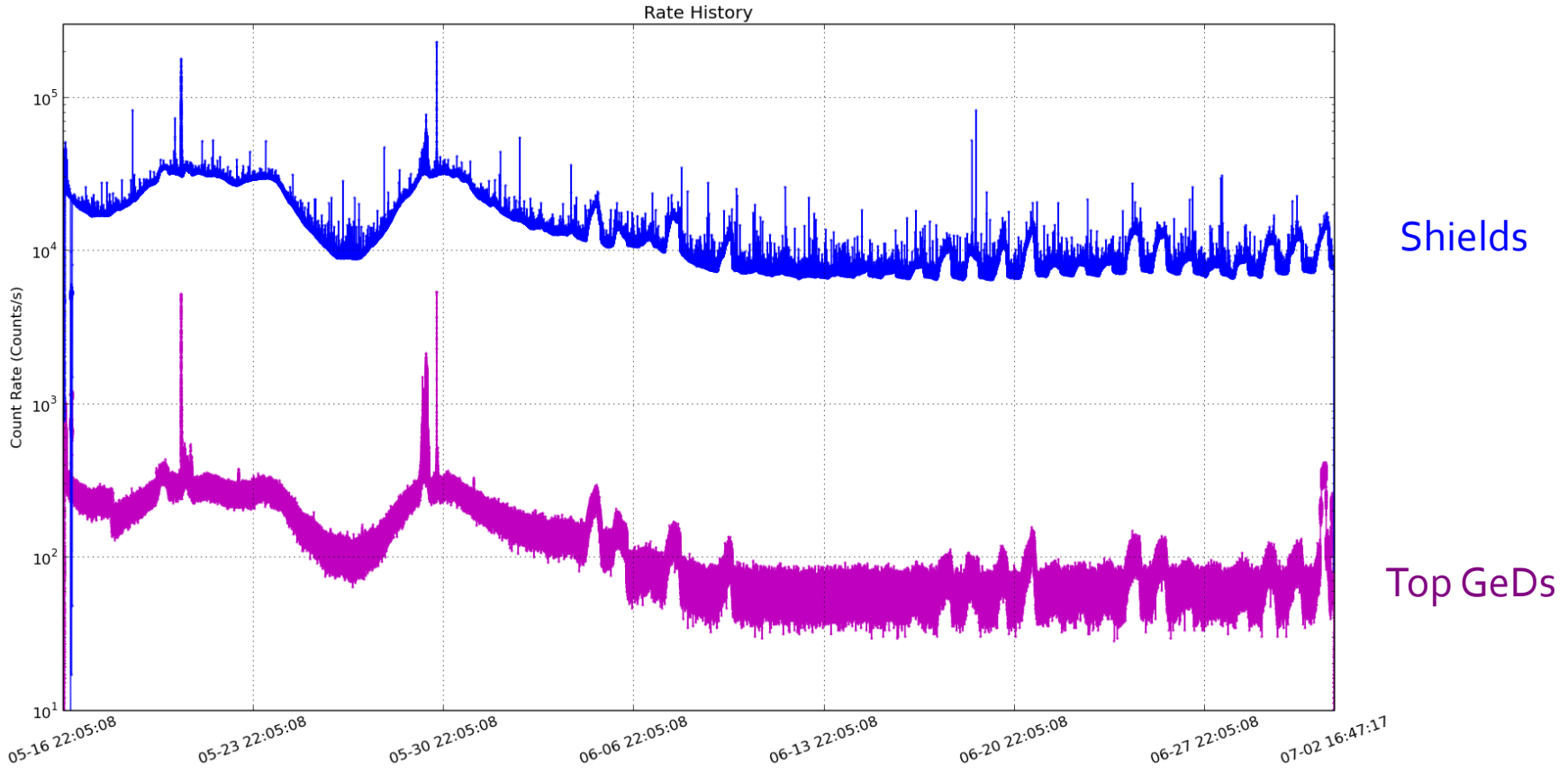


Gamma-Ray Burst Polarization



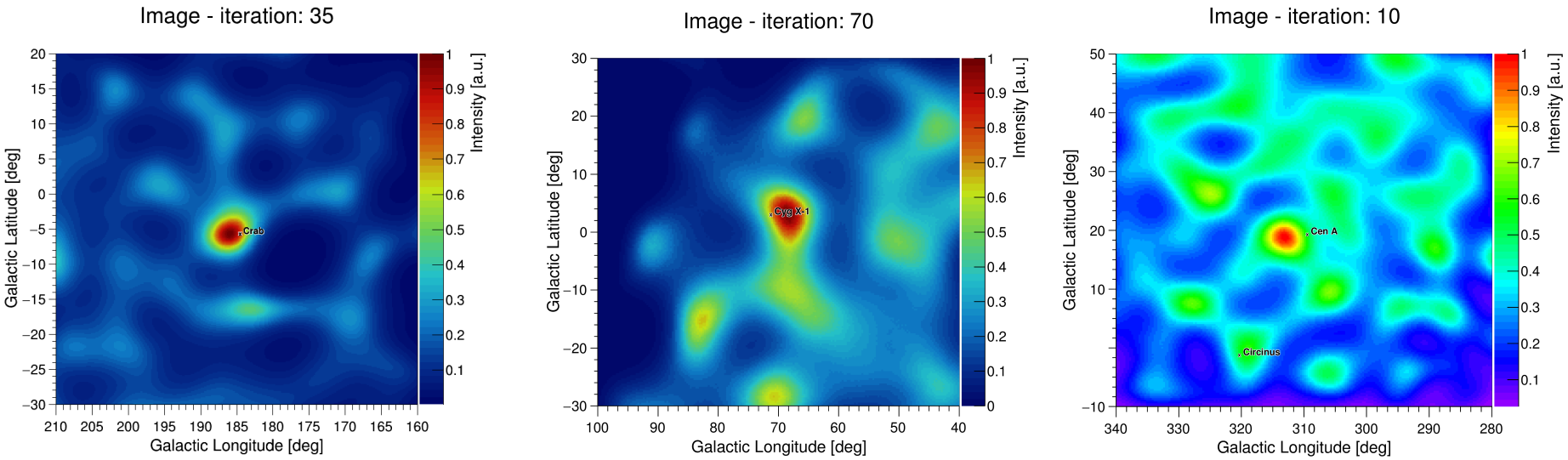
- GRB 160530A detected by COSI, Konus-Wind, INTEGRAL, and Astrosat
- 20 keV – 10 MeV fluence = 1.3×10^{-4} erg/cm^2 (Konus-Wind, GCN 19477)
- COSI/Astrosat arrival times agree
  - 16±12 ms
  - Thanks to Kevin Hurley and Varun Bhalerao

Shield and GeD Rates – Full 46 Days



- As we drifted North, the background dropped, and our coverage of the Crab and Cyg X-1 improved
- Day/night oscillations started around 6/4 (due to altitude variations)

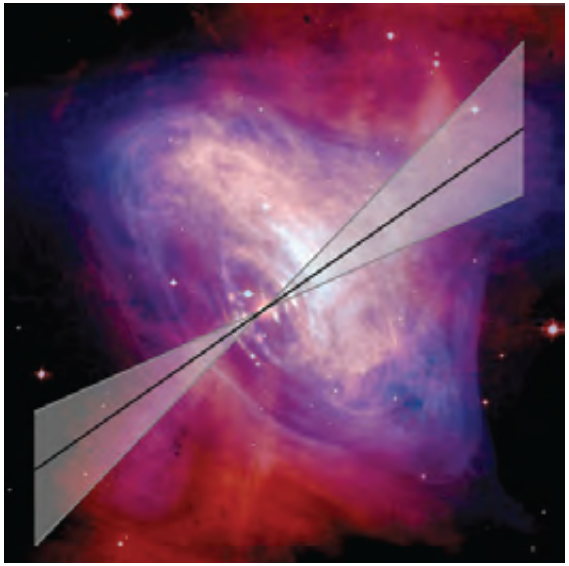
Point Sources



- Crab, Cyg X-1, and Cen A (AGN)
- Working on extracting spectra and determining polarization (COSI team, in prep.)

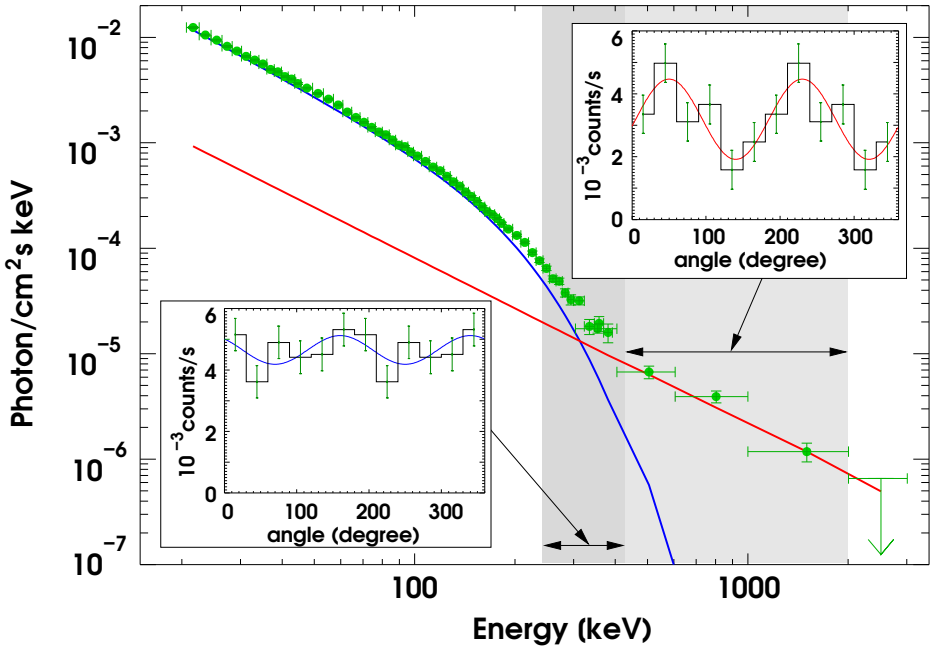
Polarization Measurements with INTEGRAL

Chandra and HST composite image for the Crab with INTEGRAL polarization direction



- SPI (Dean et al. 2008)
- IBIS (Forot et al. 2008)
- Recently, evidence for a change in the polarization direction (Moran et al. 2016)

Cyg X-1 spectrum and modulation curves (from ESA press release)

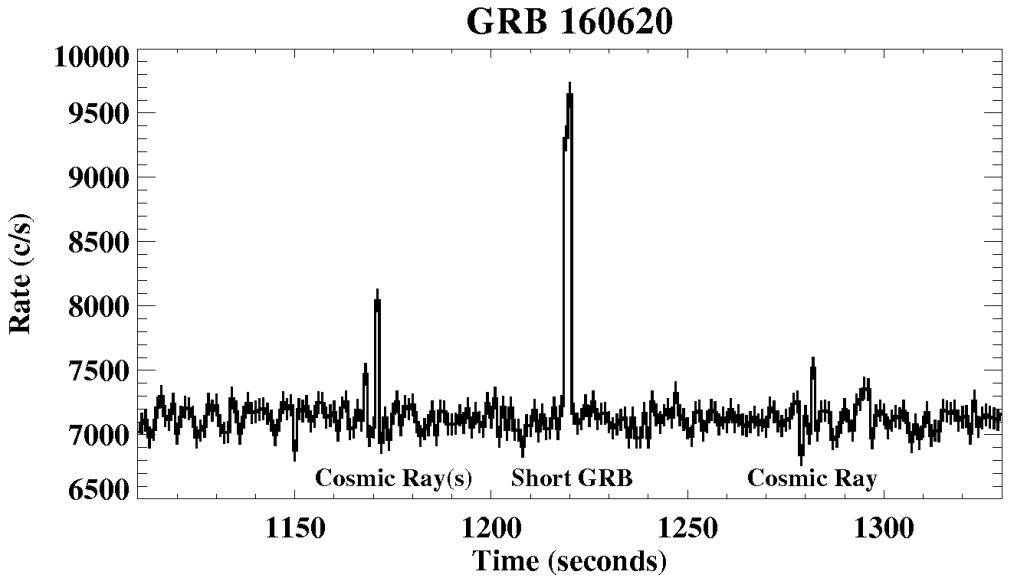


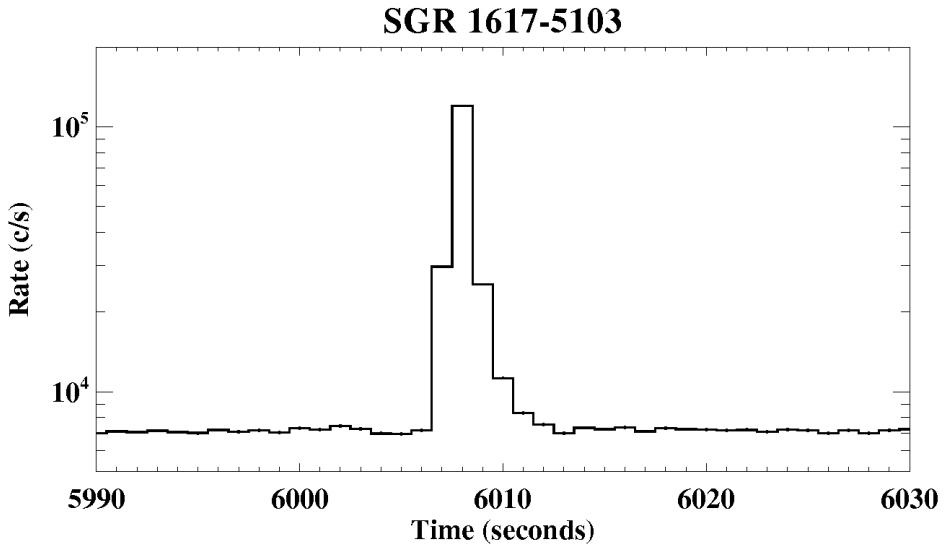
- IBIS (Laurent et al. 2011)
  - 67±30% (0.4-2 MeV)
- SPI (Jourdain et al. 2012)
  - >75% (0.37-0.85 MeV)

• Emission from a jet in the MeV range?

Types of Events Seen in COSI Shields

- Most cosmic rays are single (1 sec) time bin events
  - ~1 per minute
- Several confirmed GRBs
- Soft Gamma-ray Repeaters
  - SGR 1935+2154
  - SGR 1617-5103





Payload Recovery

- Found balloon on July 4
- Found COSI on July 7

- “[NASA] managed to pinpoint [COSI] in an almost inaccessible area”
(Living in Peru)

Found in one piece! Success!

Picture of COSI and the recovery group (including our UC Berkeley representative, Carolyn Kierans)

Payload Recovery

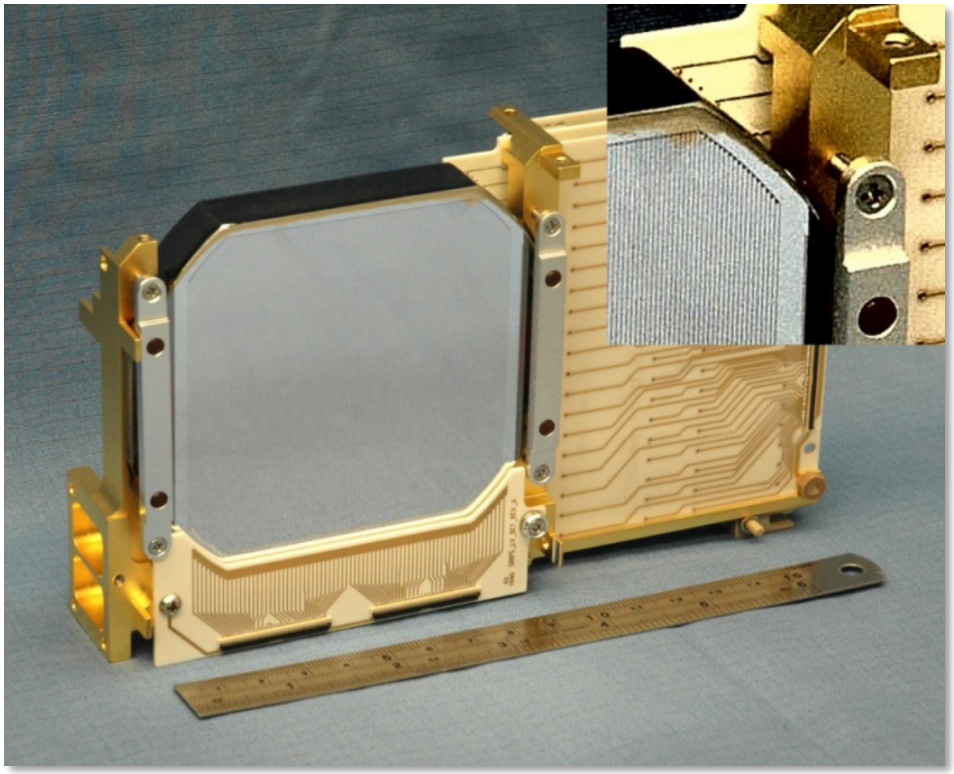
- Left: helicopter lifting COSI from its landing spot
- Right: in good shape after recovery

Work in Progress on the 2016 Data

- GRB polarization (Lowell et al., in prep.)
- Point source spectra and polarization
- Image of 511 keV emission in the Galactic Center region (Kierans et al., in prep.)
- MeV emission from the Galactic Ridge

Future: Developments In Progress

- ✓ Finer strip pitch: improve angular resolution (to ~1.6 degrees) and sensitivity.
- ✓ ASIC read-out: lower power, better resolution (with E. Wulf, NRL)
- ✓ Cryocooler: active damping to lower noise, passive cooling to lower risk



GRIPS Germanium detector

Summary and Conclusions

- Very successful 46 day flight from New Zealand to Peru
- Detections of a GRB, Crab, Cyg X-1, Cen A, Galactic Center, and Galactic Plane in the 0.2-few MeV bandpass
- Payload recovered in good shape for re-flight

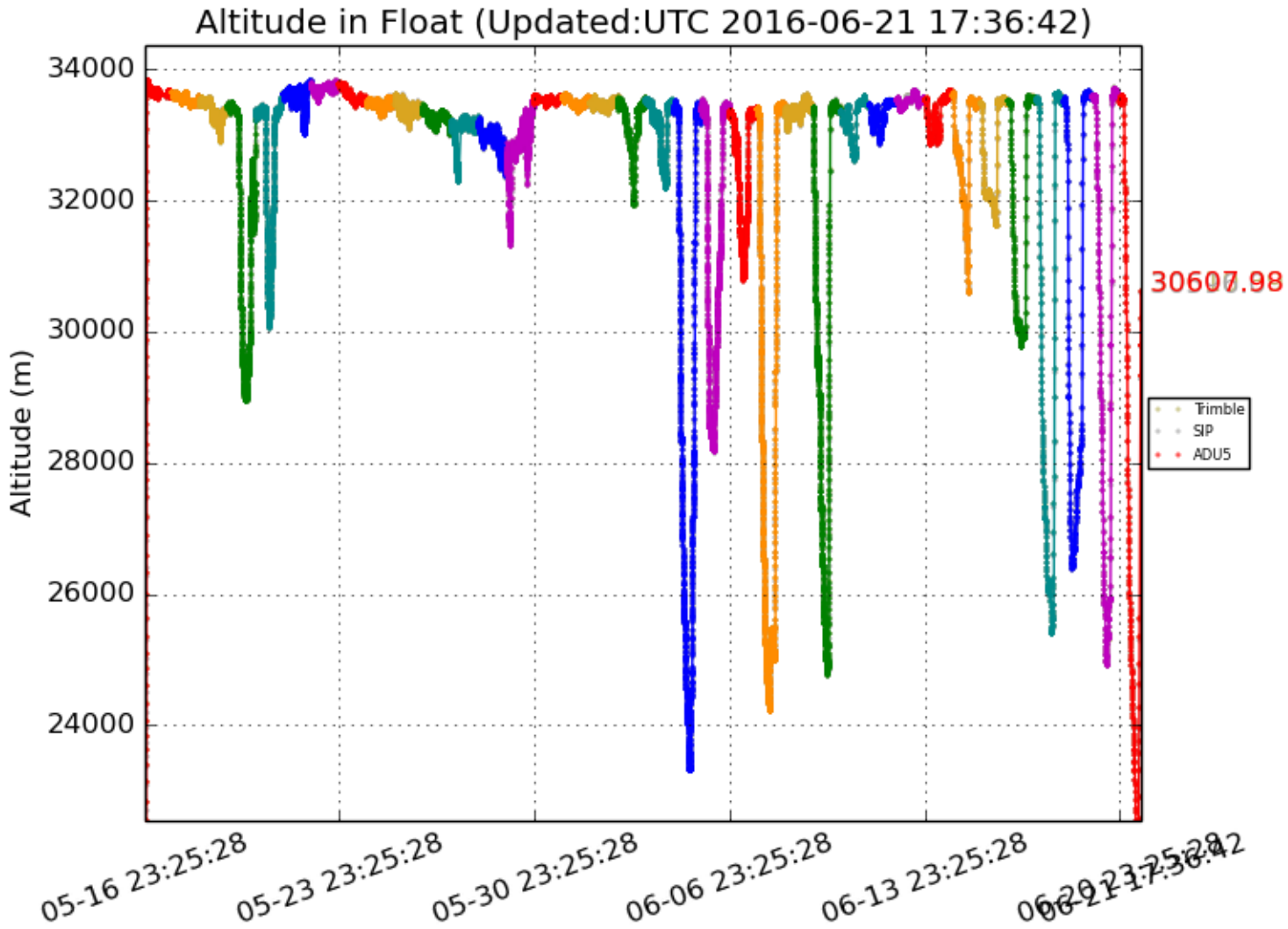
Compton Spectrometer and Imager (COSI) @ Wanaka, New Zealand

Backup Slides

Mission Overview Table

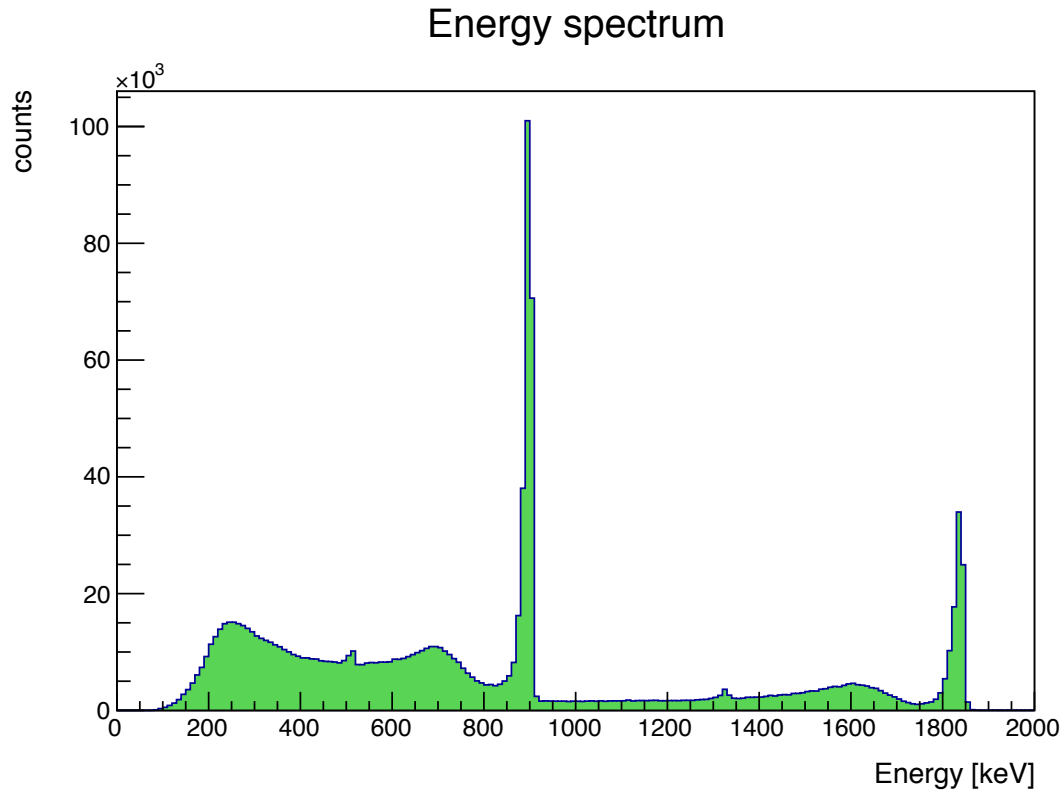
Mission Element	Goal/Spec	Notes
Launch vehicle	18 MCF SPB	COSI designed for 18 MCF SPB.
Altitude	110+ kft	Higher is better, but not X-ray telescope.
Stability	10 kft	Not critical.
Duration	100+ days/14 days min	No expendables, longer duration is better.
Mass	5000 lbs suspended mass	2575 lbs at 2014 Compatibility. 2579 lbs current estimate.
Ballast	861 lbs steel assumed	Gondola can hold up to 1400 lbs.
Power	475 W	Fixed PV array + batteries, 1500 W peak.
Attitude control	Solar oriented	NASA rotator for PV array. Science requires aspect only.
Data rate	40-50 kbps compressed 100-150 kbps LOS	2x Iridium Openport. Primary science data fully available in compressed data stream. Full rate desirable.
Operations	Autonomous normal mode	Monitor health and safety of payload.
Critical events	None	Fully operational at launch.
Thermal control	Passive	Day/night cycles within acceptable range, ~20 controllable heaters.
Pressure vessel	None	
Launch team	8-10	Includes two foreign student collaborators.
Integration footprint	1.5 m × 1.5 m; 2.2 m high	Without solar panels and antenna booms.
Recovery	Yes, please	Not required to meet science goals of this flight.
Launch Date	May 16, 2016	Launch window opened ~ April 1, 2016.

Flight Profile

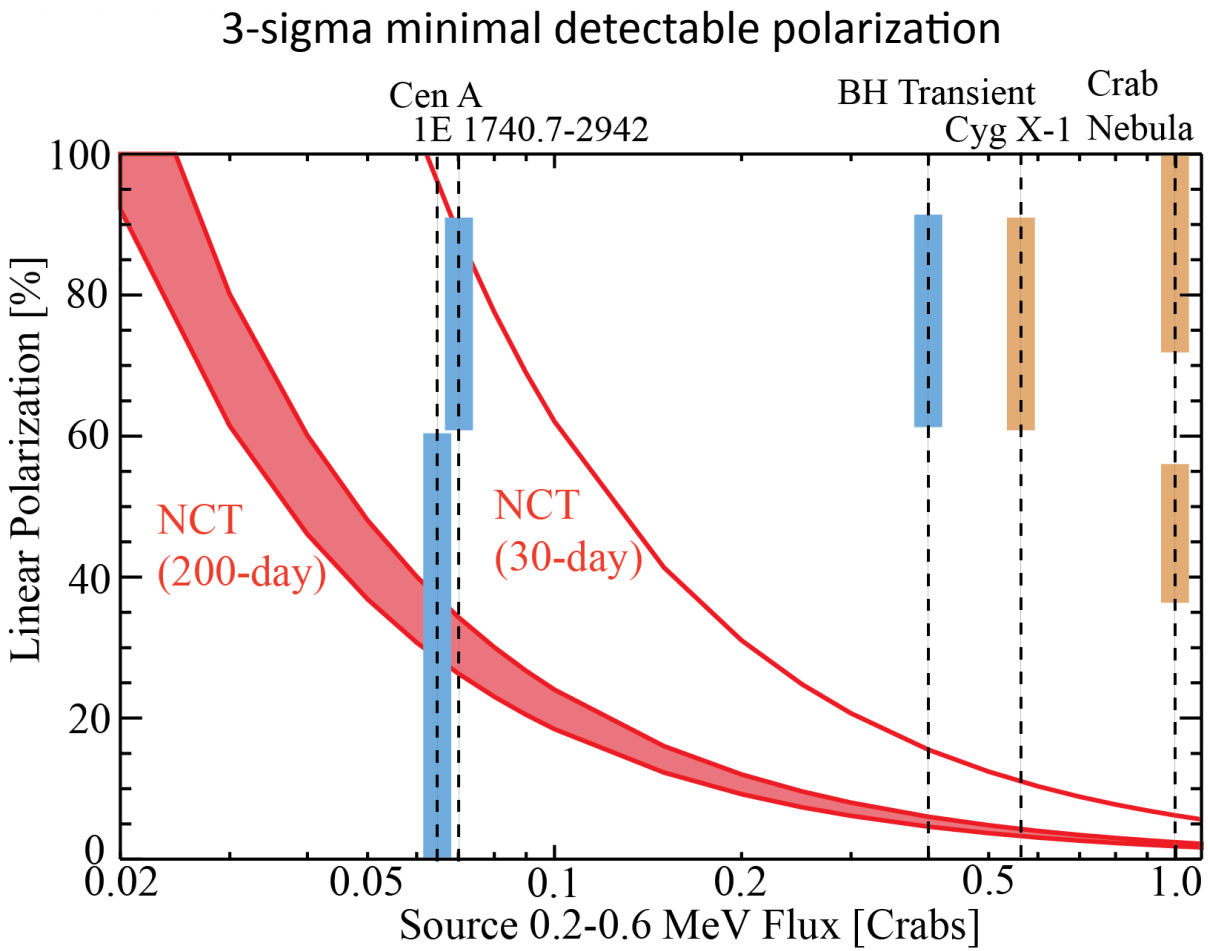


Spectrum from Calibration

- ^{88}Y source



Polarization Performance



Orange: Measured polarization (from Cyg X-1 and Crab)

Blue: Estimated polarization

Continuum Sensitivity

3π, ΔE=E, all 1 Ms pointed, except COMPTEL and NCT