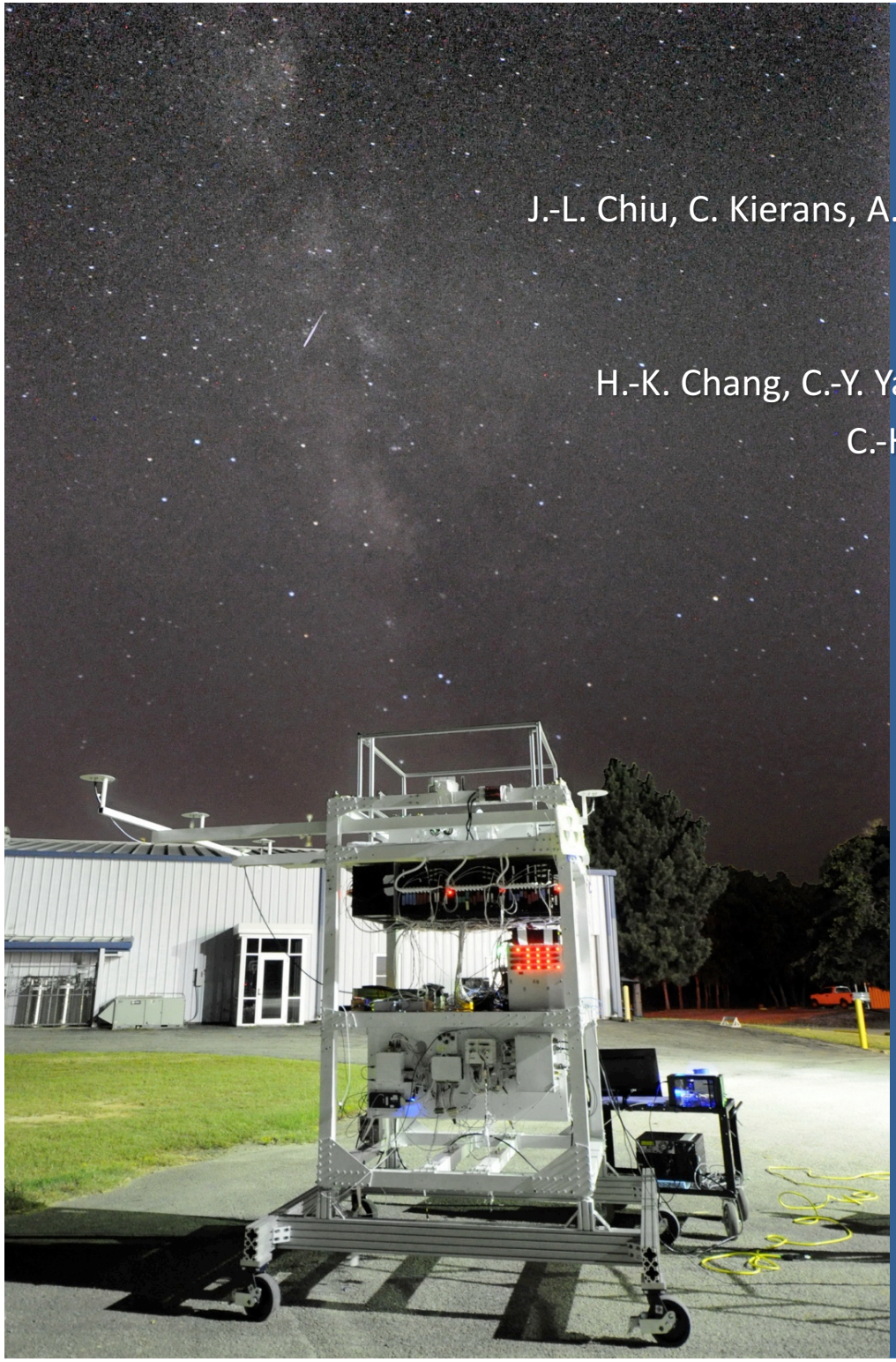

# The Compton Spectrometer and Imager

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


**John Tomsick**

**UC Berkeley/Space Sciences Lab**

**for the COSI collaboration**



# The COSI Collaboration: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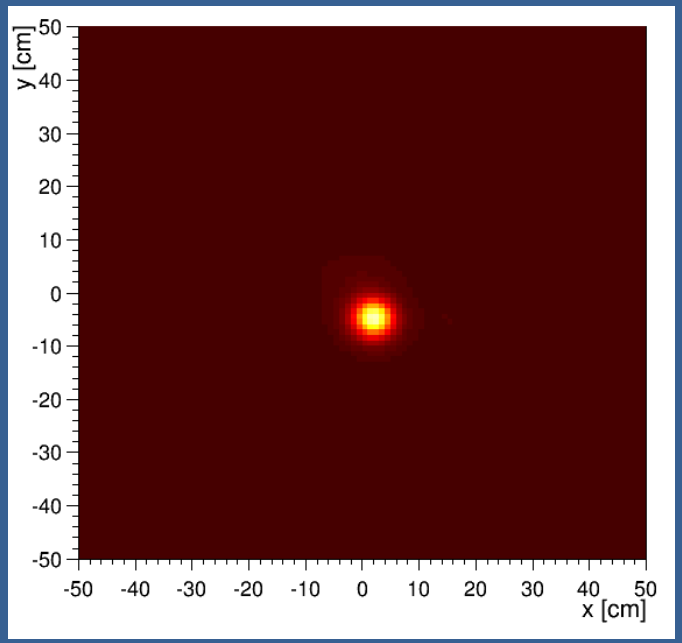
P. Jean, P. von Ballmoos *(IRAP, France)*

H.-K. Chang, C.-Y. Yang, C.-H. Tseng, C.-Y. Chu, Y.-C. Chang *(NTHU, Taiwan),*

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



*COSI US is supported through grants by NASA*

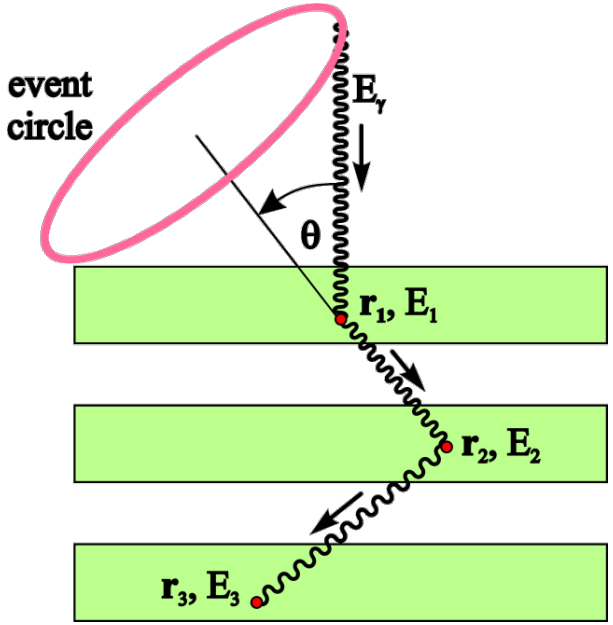

Calibration image of a 662 keV $^{137}$Cs source ~56 cm above the instrument.

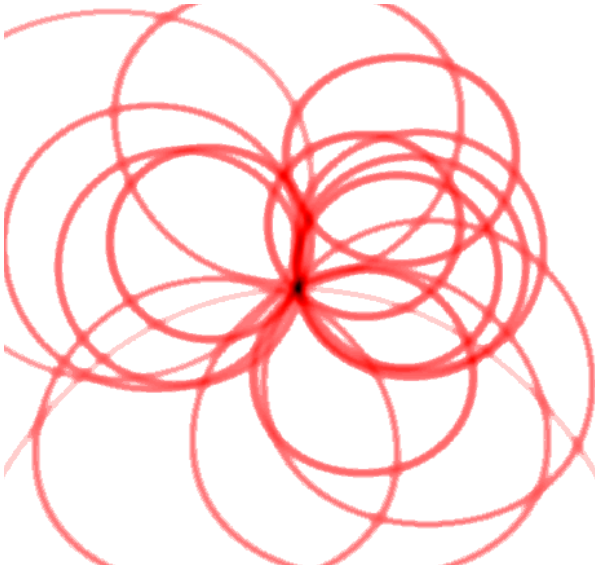
# Talk Overview

- COSI introduction
  - Including instrument and science goals
- 2016 balloon flight
- Results from 2016 flight
  - Including GRB 160530A, the Crab Nebula, and 511 keV emission
- Conclusions

# Operating Principle

## of COSI-style Compton telescopes



- Photons interact multiple times in detectors.
- The interaction sequence can be determined from information such as scatter angles, absorption probabilities, scatter probabilities.
- The origin of a gamma-ray can be restricted to the "event circle."
- The photon originated at the point of all overlap.

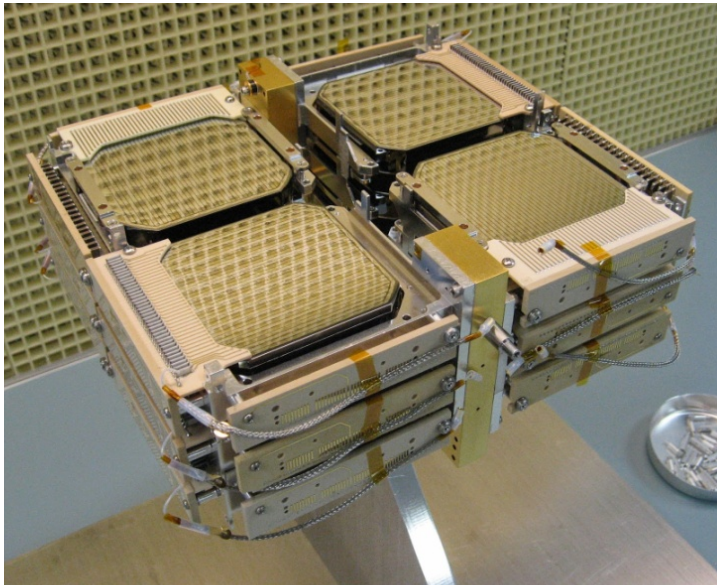
# Instrument & Campaigns

Instrument:

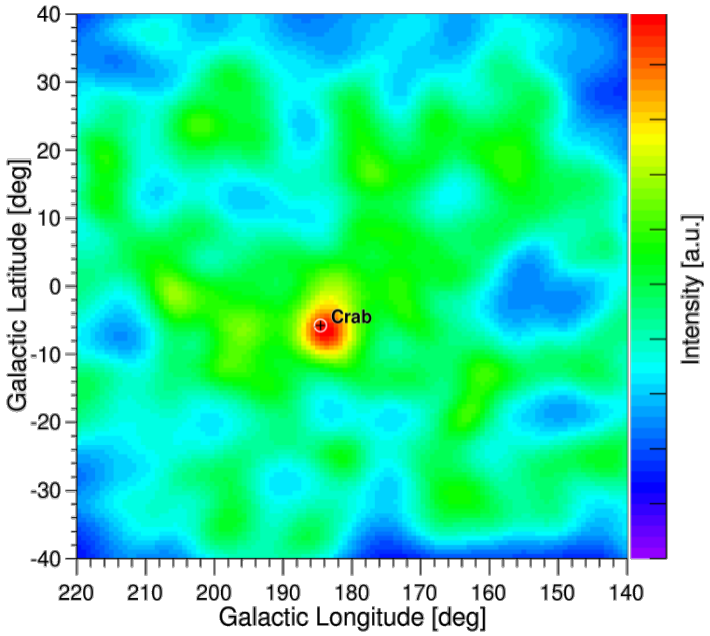
- Energy range: 200 keV – several MeV
- 12 high-purity Ge double-sided strip detectors
- Energy resolution: ~2.5 keV FWHM
- Large field-of-view:  almost 1/4 of sky
- Angular resolution: ~4° FWHM

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 $cm^2$

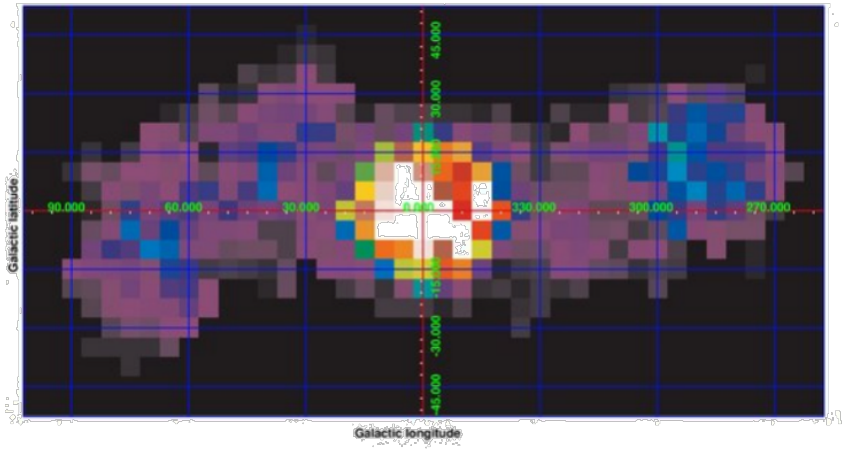



From 2009 flight (Bandstra et al. 2011)

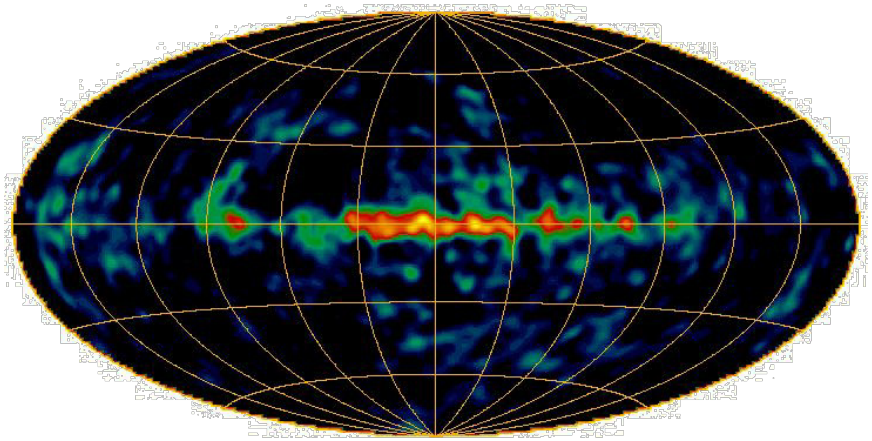
# COSI Science Goals

- 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 ($e^+e^-$) | $3.8\times10^{-5}$ |
| 1.157 MeV ($^{44}$Ti) | $8.9\times10^{-6}$ |
| 1.173/1.333 MeV ($^{60}$Fe) | $6.0\times10^{-6}$ |
| 1.809 MeV ($^{26}$Al) | $8.5\times10^{-6}$ |
| BH 100% Polarization (200 days, 3σ, threshold sensitivity) | 23 mCrab |
| GRB 100% Polarization (3σ, threshold sensitivity) | $1.2\times10^{-5}$ erg cm$^{-2}$ |




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

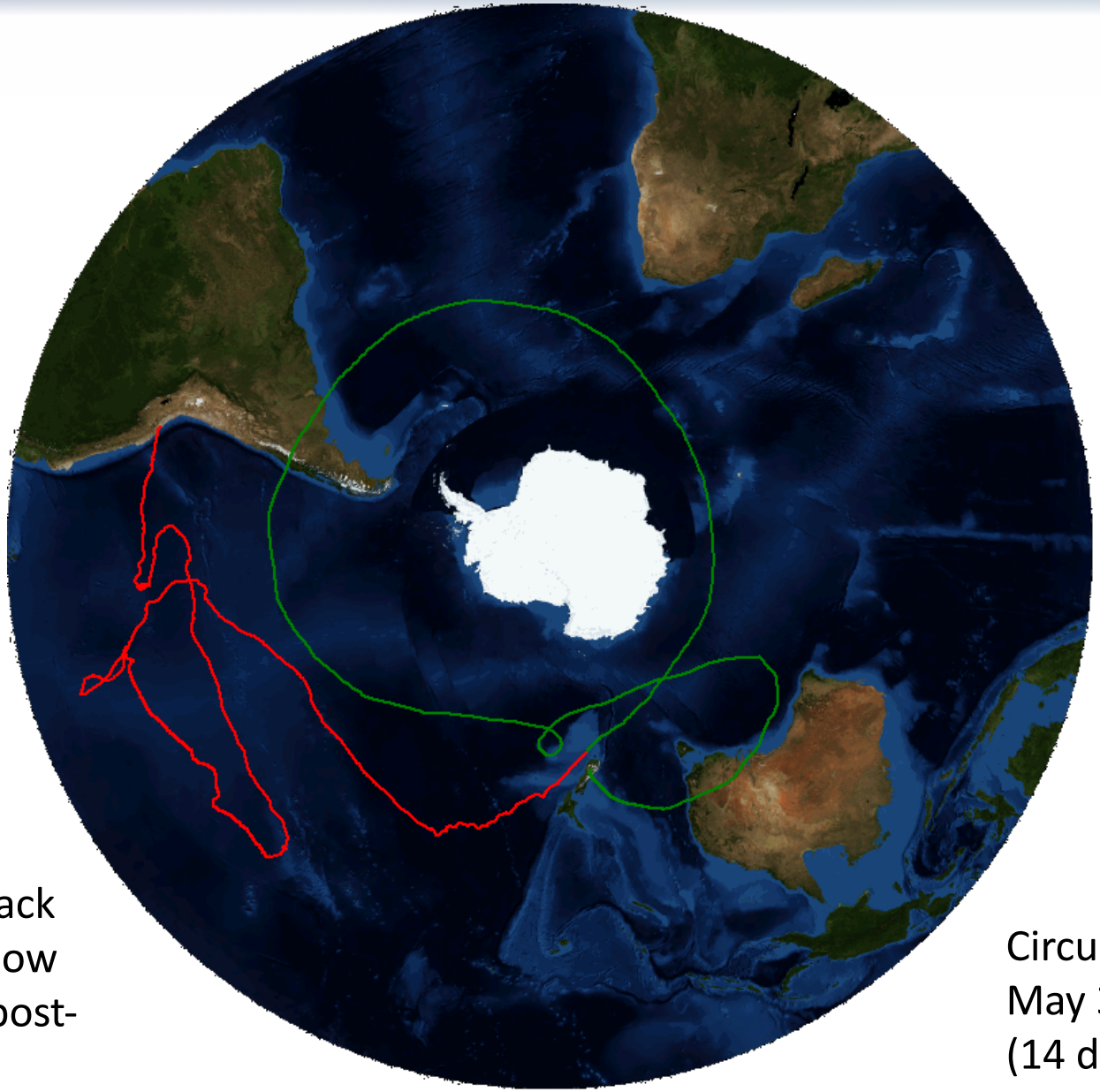


COMPTEL map of $^{26}$Al emission (1.809 MeV) *(Oberlack et al. 1997)*

# COSI Launch from New Zealand: May 16, 2016

# Flight Path

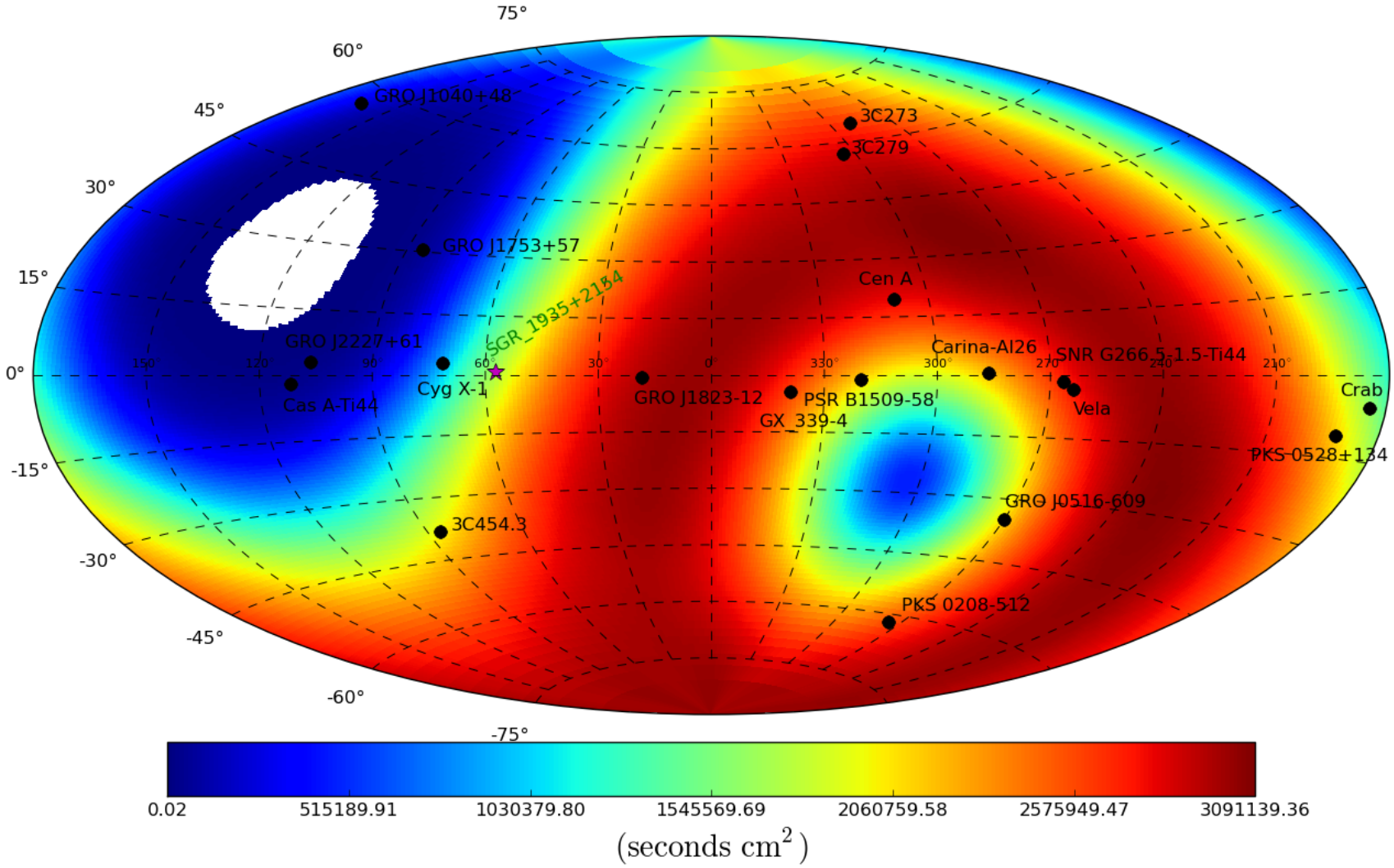
Landed in Peru
on July 2
(46 day flight)



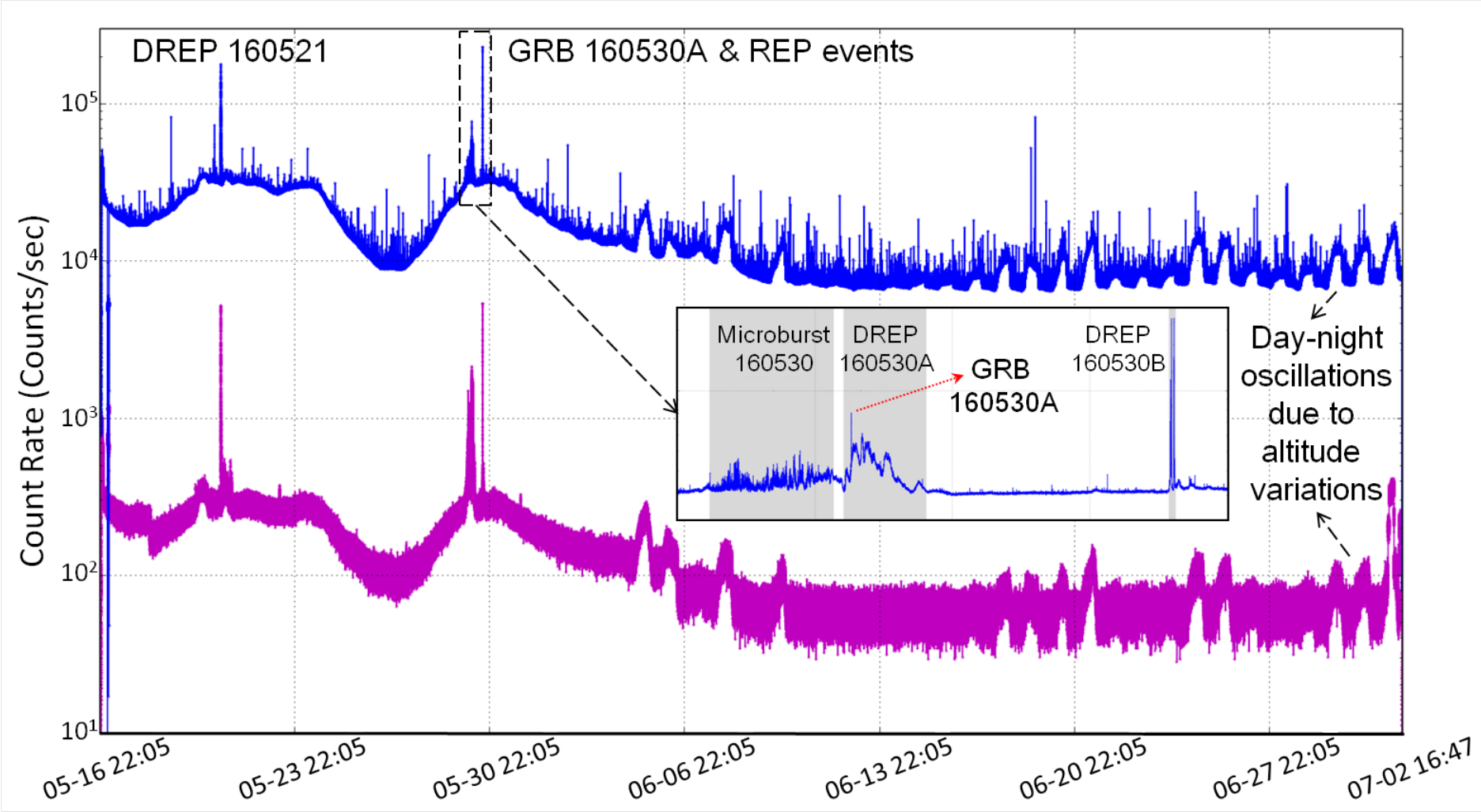
- Successful recovery
- Everything back in Berkeley now undergoing post-flight tests

Circumnavigation on
May 31
(14 days after launch)

# Daily Exposure



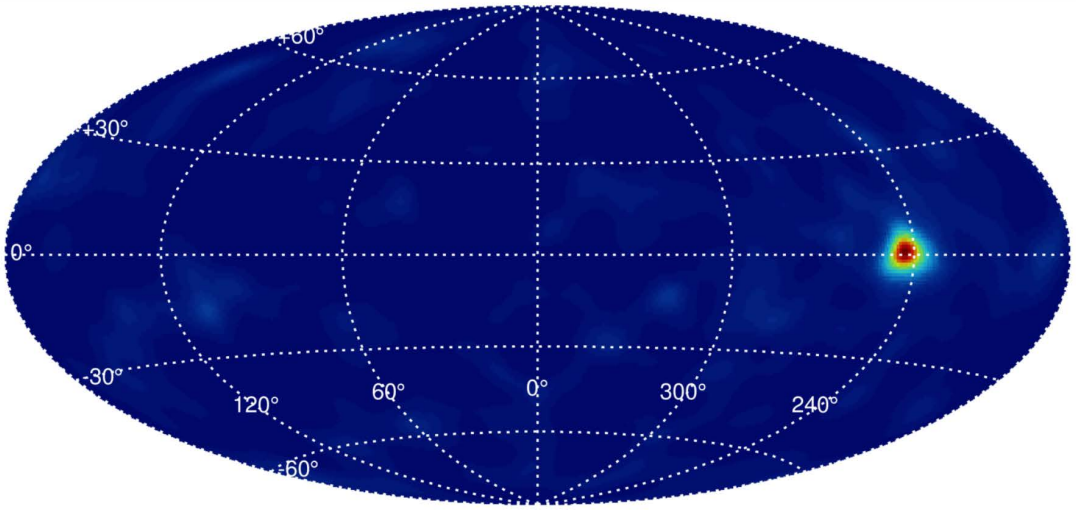
# Shield and GeD Rates – full flight

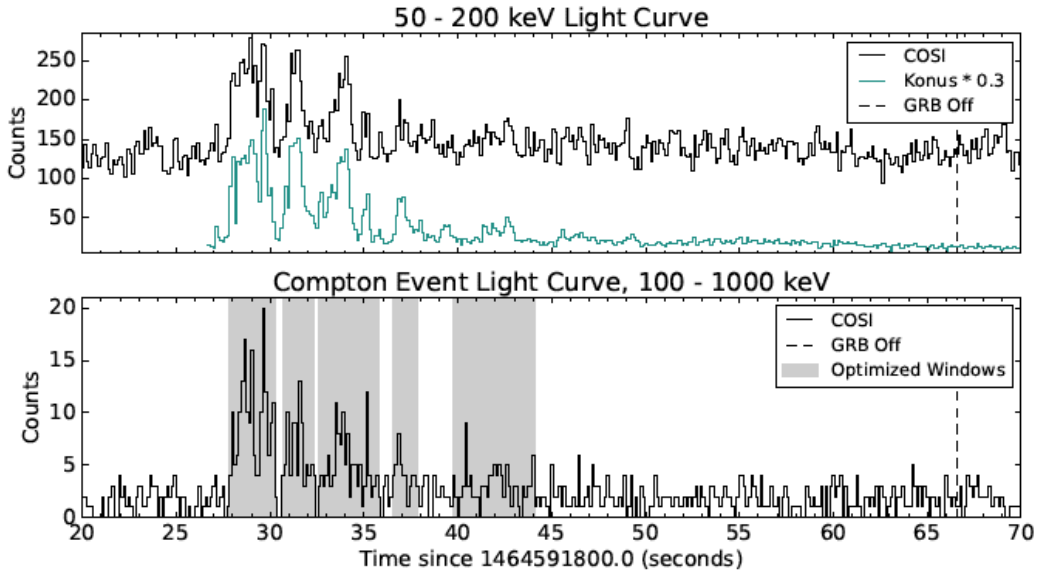



- Great flight, but somewhat high background from radiation belts at the beginning
- …and some day/night altitude changes during the 2nd half

# GRB 160530A

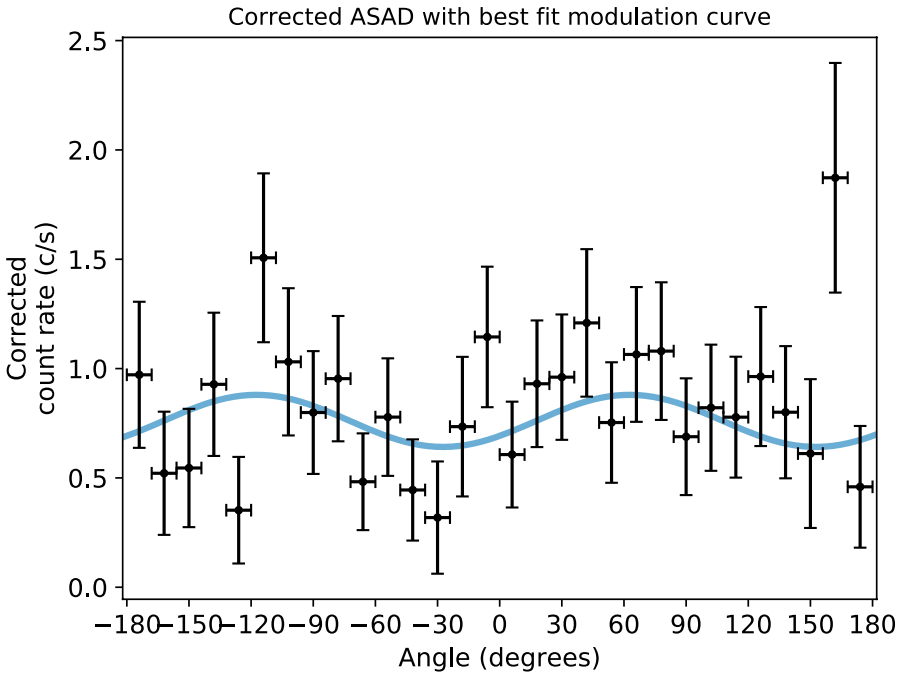
- Found in real time
  - reported in GCN#19473
- Also detected by Konus-Wind, INTEGRAL, and AstroSat
  - Clock, position, and energy spectrum
- Image and light curve from Lowell et al. (submitted to ApJ)



# GRB 160530A Polarization Analysis

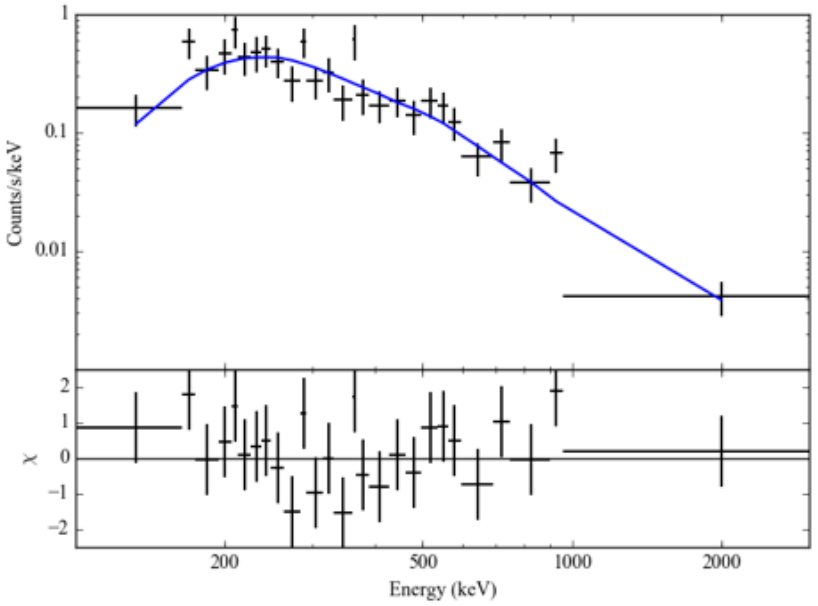
- 390 Compton events collected
- Used standard and maximum likelihood analysis methods
- Did not detect significant polarization, but obtained an upper limit of <53% (90% confidence)
- Constraining, but all models predict a distribution of polarization amplitudes




Azimuthal Scattering Angle Distribution (ASAD) for the Compton events (Lowell et al., submitted to ApJ)

# GRB 160530A Spectral Analysis

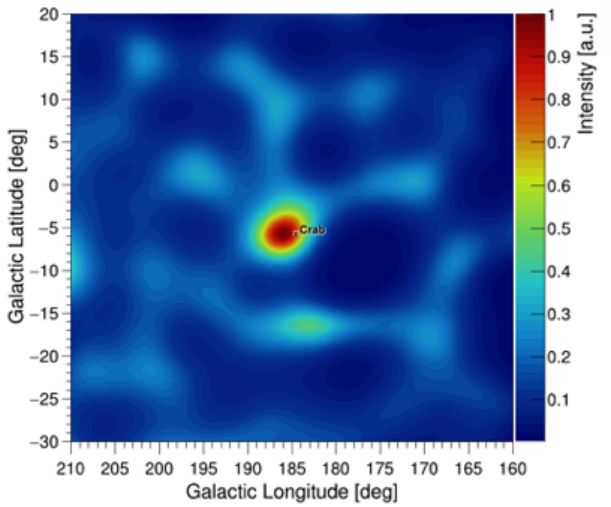
- Produced XSPEC-compatible spectra (response files, backgrounds…)
- Fit COSI spectrum with a Band function
- Konus-Wind: Svinkin+16 (GCN#19477)
- COSI: Sleator et al. (in prep.)




| Parameter | COSI (99% conf.) | Konus-Wind |
|---|---|---|
| $N_H$ (g cm$^{-2}$) | 9.2 (calculated value) | - |
| α | $-1.21\ ^{+0.35}_{-0.42}$ | -0.93 ± 0.03 |
| β | -3.5 (fixed) | <-3.5 |
| $E_c$ (keV) | 638 (fixed) | $638\ ^{+36}_{-33}$ |
| 0.02-10 MeV Fluence (erg cm$^{-2}$) | $(1.04\ ^{+0.24}_{-0.16}) \times 10^{-4}$ | $(1.30 \pm 0.04) \times 10^{-4}$ |
| $\chi^2$/dof | 17/22 | 73/73 |

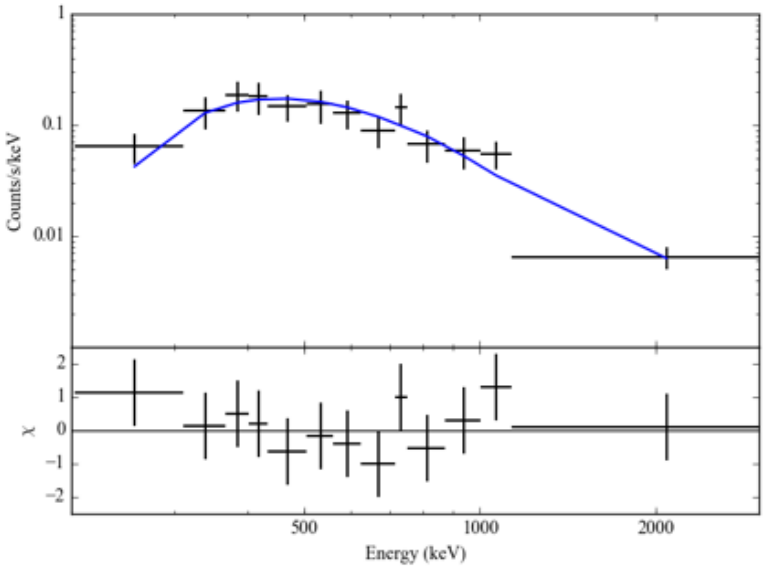
# Crab Image and Spectral Analysis

- Detections of Crab nebula, Cyg X-1, and Cen A
- Crab spectrum:
  - 950 counts in 93 ks
- Sleator et al. (in prep.)



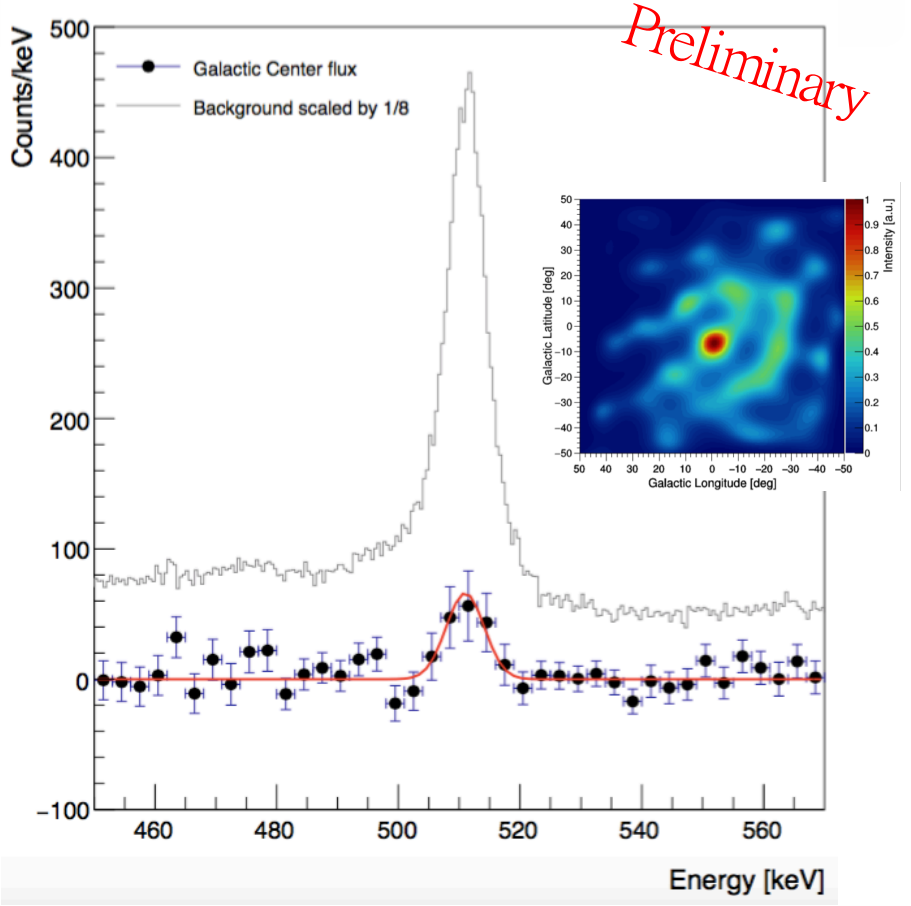

| Parameter | Fit Value |
|---|---|
| $N_H$ (g cm$^{-2}$) | 9.55 (calculated) |
| Power-law index | $2.04\ ^{+0.36}_{-0.32}$ |
| 0.2-3 MeV flux (erg cm$^{-2}$ s$^{-1}$) | $(4.8 \pm 0.7) \times 10^{-8}$ |
| $\chi^2$/dof | 6/11 |

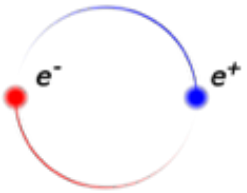
(flux is about a factor of 2 higher than standard values)



# Positron annihilation emission

- First 511 keV image and spectrum with a Compton telescope
- Clear detection, but working on improving event selections
- Also working on exposure correction for the image



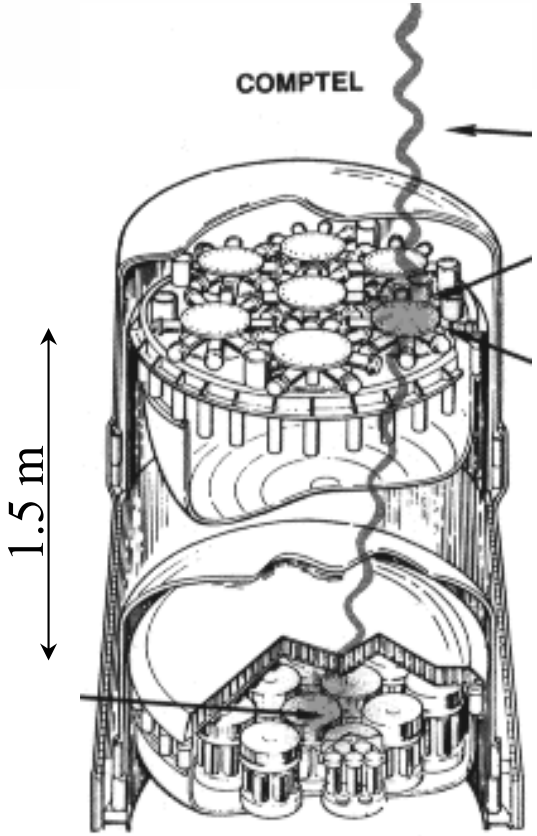

Kierans et al. (in prep.)

# Conclusions

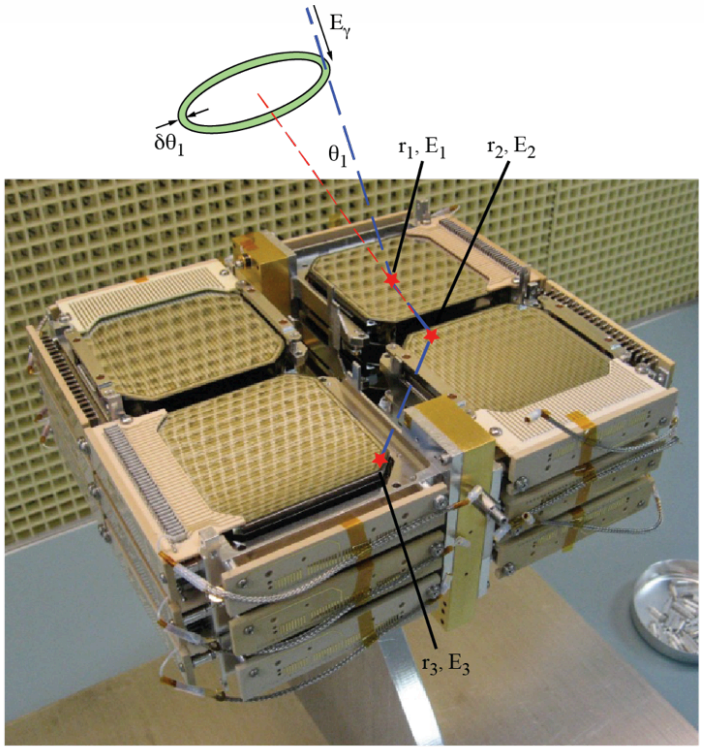
- Summary:
  - Nice flight with COSI functioning well
  - Results demonstrate feasibility of using a compact Compton telescope to study GRBs, compact objects, and diffuse 511 keV emission
- Future:
  - The same COSI instrument could be launched again
  - Upgrade in progress: ASIC (being developed at NRL)
  - Desirable upgrade: finer strip pitch (to improve angular resolution)

# Backup Slides

# Compton Telescopes: From COMPTEL to COSI




*30+ years development*




**CGRO/COMPTEL:**

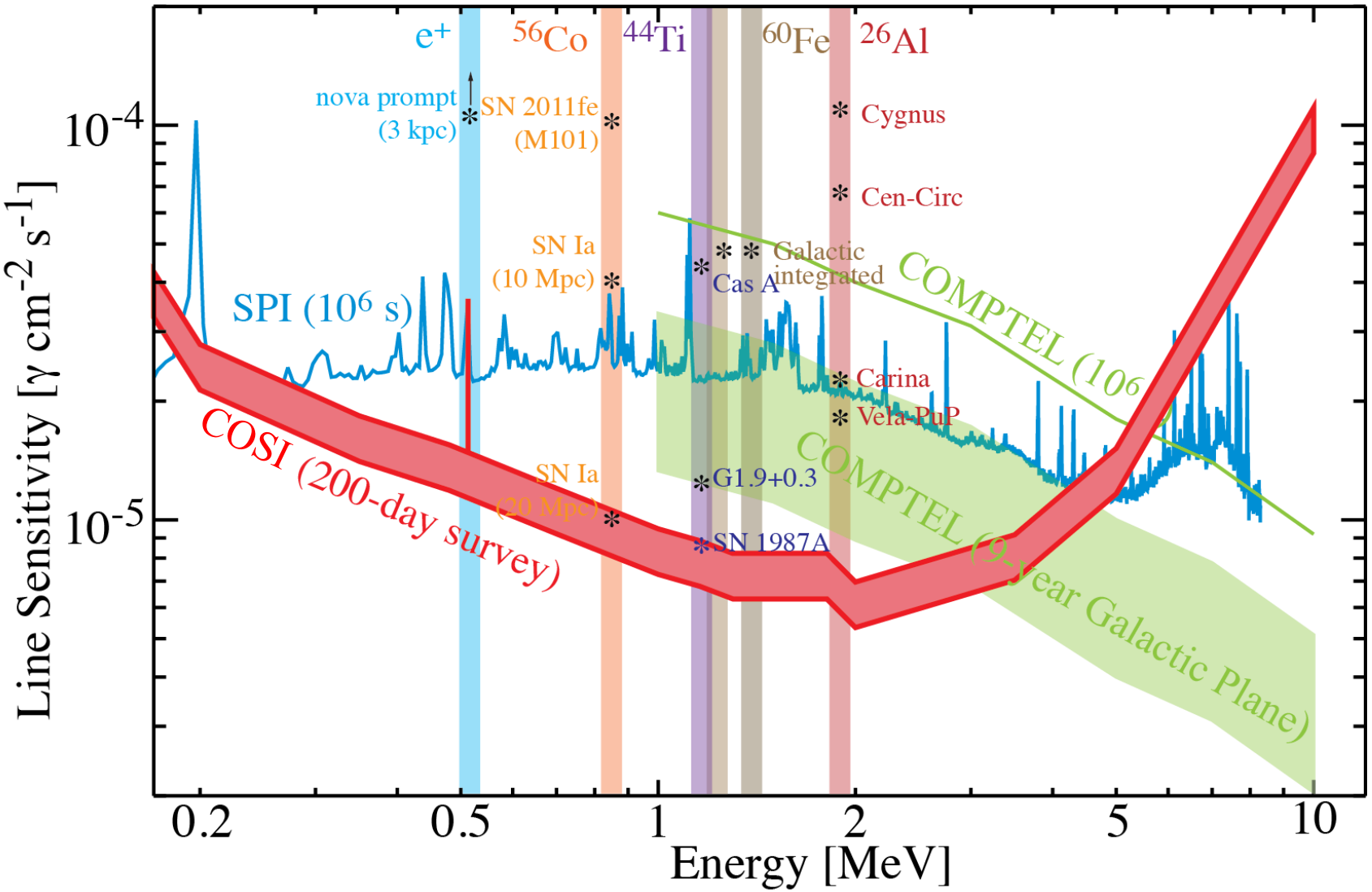
- ~40 cm$^3$ resolution
- $\Delta E/E$ ~10%
- Up to 0.4% efficiency

**COSI:**

- 1 mm$^3$ resolution
- $\Delta E/E$ ~0.2-1%
- Up to 16% efficiency
- Background rejection
- Polarization, bandpass

➢ Improved performance with a fraction of the mass and volume

# Nuclear Line Science

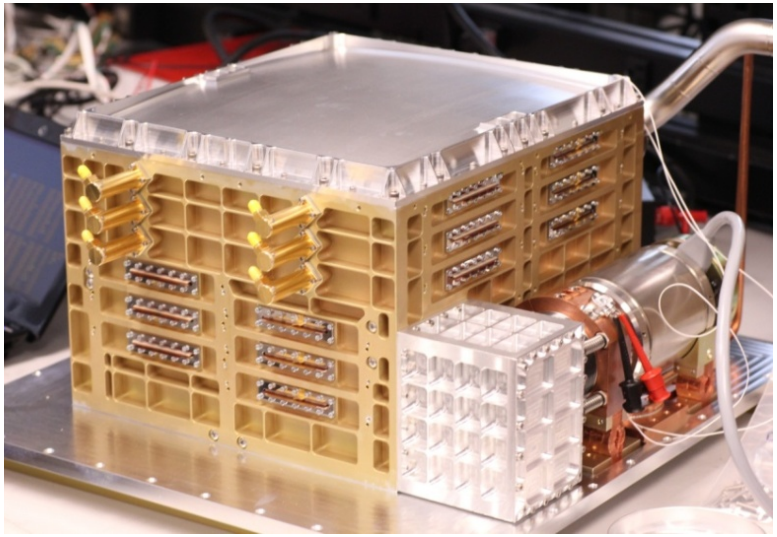


# More COSI Upgrades from NCT

## Mechanical cooler

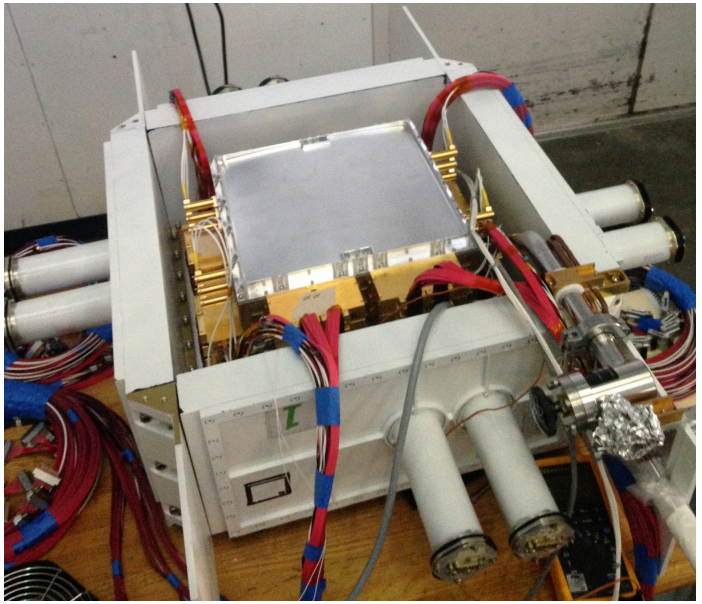
-Sunpower CryoTel 10 W lift for 160 W input

-Enables long flights



## New CsI shielding

-More space available for detectors



# Polarization Calibration