The Compton Spectrometer and Imager (COSI) Project
-- One Year after the 2016 SPB Flight --

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on behalf of the COSI collaboration
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The COSI Collaboration

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Overview: Instrument & Campaigns

Instrument

- Balloon-borne Compton telescope
- Energy range: 0.2 – 5 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: 38-hour flight of 10 GeD instrument, Ft. Sumner, 2009
- NCT: Failed launch attempt from Alice Springs, Australia, 2010
- COSI: 1.5-day flight from McMurdo, 2014
- COSI: 46-day flight from Wanaka, New Zealand on super-pressure balloon, 2016

The first reported detection of an astrophysical source by a Compact Compton Telescope (CCT)
Overview: Science Goals

- Mapping 511 keV positron annihilation emission near 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

**COSI Performance**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>0.2-5 MeV</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>0.2-1% FWHM</td>
</tr>
<tr>
<td>Field of View (FoV)</td>
<td>25% sky</td>
</tr>
<tr>
<td>Sky Coverage</td>
<td>50% sky</td>
</tr>
<tr>
<td>Angular Resolution (662 keV)</td>
<td>~5° FWHM</td>
</tr>
<tr>
<td>Narrow Line Sensitivity (200 days, 3σ)</td>
<td>$[7 \text{ cm}^{-2} \text{s}^{-1}]$</td>
</tr>
<tr>
<td>0.511 MeV (e⁺e⁻)</td>
<td>$3.8 \times 10^{-5}$</td>
</tr>
<tr>
<td>1.157 MeV ($^{44}$Ti)</td>
<td>$8.9 \times 10^{-6}$</td>
</tr>
<tr>
<td>1.173/1.333 MeV ($^{60}$Fe)</td>
<td>$6.0 \times 10^{-6}$</td>
</tr>
<tr>
<td>1.809 MeV ($^{26}$Al)</td>
<td>$8.5 \times 10^{-6}$</td>
</tr>
<tr>
<td>BH 100% Polarization</td>
<td>23 mCrab</td>
</tr>
<tr>
<td>(200 days, 3σ, threshold sensitivity)</td>
<td></td>
</tr>
<tr>
<td>GRB 100% Polarization</td>
<td>$1.2 \times 10^{-5}$</td>
</tr>
<tr>
<td>(3σ, threshold sensitivity)</td>
<td>erg cm$^{-2}$</td>
</tr>
</tbody>
</table>

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 COMTEL to COSI

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

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

Improved performance with a fraction of the mass and volume
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 skymaps.

Data Analysis & Simulation Scheme of COSI: MEGAlib (A. Zoglauer, 2006)
The COSI Instrument

Germanium Detector (GeD)
- Size: 8 x 8 x 1.5 cm³
- 37 orthogonal strips per side
- 2 mm strip pitch
- Deplete voltage: 1000-1500 V

2x2x3 detector geometry
- Wide field-of-view
- Good polarimetry

Mechanical cooler
- Constant temperatures
- Enables ULDB flights

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

Gondola
- Automated platform for SPB

Detector surrounded by CsI shields (4 sides & bottom) to veto dominant atmospheric background component
2016 Flight Overview

Launch: May 16, 2016 @ Wanaka, NZ
Landed: July 2, 2016 @ Atacama desert, Peru
Duration: 46 day (Circumnavigation in 14 days)
Drifting North: background dropped → Crab and Cyg X-1 came into our field-of-view
Day/night oscillations: started around June 4 (due to altitude variations)

Night-time dips: Unfortunately during the times when the Galactic Center was visible...

Flight Path

Altitude History

Shield & Detector Rates

CsI Shields

Top GeDs
GRB 160530A

- Observed by COSI on May 30, 2016 (GCN#19473)
- Also detected by Konus-Wind and INTEGRAL/ACS, as well as Astrosat/CZTI & its CsI shield.
- IPN with Konus-Wind and INTEGRAL/ACS for source triangulation.
- Trigger Swift/XRT for afterglow, but no detection…
- Source localization of COSI improved with optimized event reconstruction algorithm.
- Polarization analyzed by COSI.

GCN: #19473
(l, b) = (243.4°, 0.4°)
Duration: ~37 seconds
MDP: 57.8±0.7% (MLM)
Modulation: <53% (90% UL)
Polarization angle: 143° ± 47°
(Alex Lowell+, 2 paper submitted to ApJ)
Exposure Map & Obvious Point Sources

Exposure Map

Cyg X-1
(Galactic black hole)

Cen A
(1 of the closest AGN)

Crab
(pulsar & nebula)

Preliminary

~3 days within field-of-view
Best 2 days of data
Best 2 days of data
511-keV Annihilation Line

Contributions to annihilation peak:
- Atmospheric 511-keV photons
- Internal $\beta^+$-decays + annihilation
- Annihilation of atmospheric positrons
- Galactic 511-keV photons

→ Confirms a detection of the positron annihilation signal from the inner 16° region of the Galactic center

- Analysis of 511-keV line is work in progress (C. Kierans, *in prep*)
- We do see clear 511-keV signature in spectrum and image
- Some differences to SPI in image...
Relativistic Electron Precipitation (REP)

- Relativistic electrons from the radiation belt hit the atmosphere and generate Bremsstrahlung emission (R. M. Millan & R. M. Thorne, 2007)
- COSI for the first time was able to image the gamma-ray emission

(Both figures use 1 second binning and are not dead-time corrected)
Csl Shields Event

- Cosmic ray events
  - single (1 sec) time bin events
    - ~1 per minute
- Several confirmed GRBs
- Soft Gamma-ray Repeaters
  - SGR 1935+2154
  - SGR 1617-5103
Summary and Future Prospect

Summary

• **COSI**: a balloon-borne Compact Compton Telescope utilizing HPGe detector array with excellent $\Delta E$ and polarization capability in 0.2-5 MeV.
• **2016 Flight**: A successful 46-day flight from New Zealand to Peru.
• **GRB 160530A polarization**: a 90% confidence upper limit on the polarization level of 50-60%.
• **Obvious point sources**: detection of Crab, Cen A, and Cyg X-1 from imaging.
• **511-keV emission**: detection from the inner $16^\circ$ region of GC was confirmed. Imaging in progress…
• **Other observations**: REP and CsI shield events to be further analyzed.

Current progress

• Detector recovered in a good shape for future flights. Functionality verification of electronics.
• Working on improvements of data analysis tools and data analysis itself (now, spectral analysis).

Future prospects

• The same COSI instrument could be launched again in 2019.
• Instrument upgrade with a finer GeD strip pitch of 0.58 mm (angular resolution of 1.5° at 1.809 MeV).
• A Germanium Front-End ASIC is being developed by NRL for the finer-strip COSI detectors.
• Enhance our Compton image reconstruction capabilities (*by A. Zoglauer*).
• Propose for future satellite opportunity.
Thank You