The Compton Spectrometer and Imager (COSI)

Exploring nuclear astrophysics of the Milky Way in the MeV band

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The COSI-SMEX Collaboration

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Naval Research Laboratory
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Goddard Space Flight Center
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Clemson University
- D. Hartmann, M. Leising, M. Ajello

Northrop Grumman

Collaborators

Every day, COSI will cover the entire sky, resulting in a sensitive all-sky map in the 0.2-5 MeV range
Previous missions have had poor sensitivity in the 0.1-20 MeV range.

Discovery space where there is known to be interesting physics:
- Nuclear line emission
- 511 keV annihilation line
- Gamma-ray transients (GRBs, flaring blazars)
COSI-SMEX Science Objectives

- Pinpoint the sources of Galactic positrons
- Reveal sites of element formation
- Probe the physics in extreme environments with polarimetry
- Find counterparts to merging neutron stars and high-energy neutrino events
Compton Telescopes: from COMPTEL to COSI

CGRO/COMPTEL:
• ~40 cm³ resolution
• $\Delta E/E \sim 10\%$
• up to 0.4% efficiency

COSI:
• <1 mm³ resolution
• $\Delta E/E \sim 0.2\%-1\%$
• up to 16% efficiency
• bandpass covers 511 keV
• polarization

COSI-SMEX has 16 detectors (one more layer than pictured here)

Each detector is 8cm x 8cm

30+ years of development through NASA R&D
Astrophysics Research and Analysis (APRA) Balloon Program Heritage

- Proof of concept demonstrated with COSI-APRA
- Successful flights with 2 detectors in 2005 and 10 detectors in 2009
- Instrument with 12 GeDs flew for 46 days in 2016

Germanium double-sided strip detectors (GeDs)

**Imaging** a GRB (Lowell+), the Crab nebula (Sleator+), 511 (Siegert+), and more

**Real-time GRB reporting**

Spectrum of 511 keV emission (Kierans+, Siegert+)

Polarization measurement capabilities proven (Lowell+)
16 GeDs in vacuum cryostat operating at <80K

Active shielding for background rejection
- Bismuth germanate (BGO) scintillators read out by PMTs
Near-equatorial orbit to avoid South Atlantic Anomaly to minimize background

North-South repointing every 12 hours to cover the whole sky every day

Capability for targets of opportunity (TOOs)
- Expected to be <10% of observing time

Rapid transient alerts
- GRB localizations to <1 deg in <1 hr (<15 min goal)

Spacecraft: Northrop Grumman LEOStar-2 bus
## COSI-SMEX Performance Estimates

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<th>Characteristic</th>
<th>Performance</th>
<th>Rationale</th>
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<tr>
<td>Energy Range</td>
<td>0.2-5 MeV</td>
<td>Polarization/511/nuclear lines</td>
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<tr>
<td>Sky Coverage</td>
<td>25% sky FOV 100% per day</td>
<td>All-sky maps; source monitoring; GRBs</td>
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<tr>
<td>Energy Resolution</td>
<td>0.2-1%</td>
<td>511 keV and nuclear line science</td>
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<tr>
<td>Angular Resolution @1809 keV</td>
<td>1.5° (FWHM)</td>
<td>Compare to 3.8° for COMPTEL</td>
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<tr>
<td>Narrow Line Sensitivity (2 years, 3σ)</td>
<td></td>
<td>Galactic flux ~ 10⁻³ cm⁻² s⁻¹ (~125x)</td>
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<tr>
<td></td>
<td>511 keV</td>
<td>Galactic flux ~ 7x10⁻⁴ (&gt;400x)</td>
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<tr>
<td></td>
<td>1809 keV</td>
<td></td>
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<tr>
<td>Flux limit for polarization</td>
<td>15 mCrab</td>
<td>Reaches bright AGN; Galactic black hole transients often &gt;100 mCrab</td>
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<tr>
<td>Fluence limit for GRB polarization (50% MDP)</td>
<td>4x10⁻⁶ erg cm⁻²</td>
<td>Expect COSI to obtain polarization measurements for ~40 GRBs in 2 yr</td>
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Galactic flux of 511 keV: E.g., Skinner+15, Siegert+16
Galactic flux of 1809 keV and COMPTEL: Schonfelder+93, Oberlack+96
Galactic Positrons

- Origin of Galactic positrons remains uncertain despite five decades of study

- INTEGRAL/SPI image shows a bright bulge and a fainter disk
  - $^{26}$Al decay is at least a contributor to the disk emission

- COSI will:
  - Determine if there are point sources or sub-structure
  - Constrain the positron propagation distance by comparing to $^{26}$Al distribution
  - Measure the disk scale-height and determine the total Galactic positron production rate

INTEGRAL/SPI: Jean+2006
Revealing Element Formation

- $^{60}$Fe (1173, 1333 keV)
  - $t_{1/2} = 2.6$ Myr
  - Only released into the ISM by CCSNe
  - COSI will make the first $^{60}$Fe map

- $^{26}$Al (1809 keV)
  - $t_{1/2} = 720$ kyr
  - Produced by high-mass stars during their lifetime
  - Higher resolution map compared to COMPTEL

- $^{44}$Ti (1157 keV)
  - $t_{1/2} = 60$ yr
  - COSI will survey the Galaxy for young SNe

$^{26}$Al 1809 keV with COMPTEL for the Cygnus region

Based on locations of known OB associations

COSI
Polarization measurements provide unique diagnostics for determining emission mechanisms and source geometries.

Most recent progress on GRB polarization by POLAR mission (Zhang+19).

COSI will measure the polarization of ~40 GRBs in a 2-year mission.

~a dozen GRBs with polarization measurements to ±5-10%
Insight into Extreme Environments with Polarization (Pulsars, AGN, Black Hole Binaries)

- Improve over previous high-energy polarization measurements of the Crab and Cyg X-1
  - INTEGRAL (both)
  - AstroSat (Crab)
  - POGO+ (both, but at lower energy)
  - Hitomi/SGD (Crab)

- AGN: Cen A, 3C 273, NGC 4151

- Black hole binaries
  - Several persistent
  - Several transient

AGN (e.g., Cen A)
- High polarization (~60%) for Synchrotron Self-Compton from a jet
- Lower polarization for Compton scattering from a hot tenuous accretion disk corona
Multimessenger Astrophysics

- COSI contributes to MMA with its capability to detect and localize counterparts
  - Short GRBs from merging binary neutron stars (15-20 in 2 yrs)
  - Gamma-ray search for counterparts to high-energy neutrinos

- Compton telescopes combine large FOV with good localization capabilities
  - Covers a different part of the parameter space than coded aperture masks or scintillators

- COSI’s BGO shields
  - ~double the field of view
  - Allow arrival time comparison with GW signal
Examples of Potential TOOs

- Very likely to occur in the 2-year prime mission
  - Several bright transient black hole binaries

- Likely to occur
  - High-energy neutrino events

- Lower probability but large payoff
  - *Nearby core collapse supernova*
  - *Nearby binary neutron star merger*
  - Type Ia SNe within 10-20 Mpc
  - Classical novae

Polarization sensitivities for Survey Mode (SM) vs. Pointed Mode (PM)
- Sensitivities can be reached ~4x faster in PM

*It is important to have a gamma-ray spectrometer ready when these things happen.*
Science Enhancement Options

- Current options
  - Guest investigator program like Fermi’s
    - Specific analysis projects
    - Development of specialized software
    - Target of opportunity proposals
  - Solar studies
  - Improved telemetry for faster reporting of gamma-ray transients

- Open to suggestions
Activity, Project, and Statement of the Profession Consideration White Paper

APC WP discusses how COSI-SMEX addresses science in 15 of the Astro2020 Science White Papers

arXiv:1908.04334

Astro2020 APC White Paper

The Compton Spectrometer and Imager

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Summary and Conclusions

- COSI-SMEX will cover the full sky in a bandpass that has not yet been explored to its full discovery potential.
- The combination of large FOV, excellent energy resolution, and imaging is powerful for studying the 511 keV line and nuclear lines from the Galaxy.
- The addition of polarization sensitivity opens a new window on extreme environments.
- COSI-APRA has provided an excellent opportunity to develop the required hardware and software (MEGAlib, Zoglauer+06).
References