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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Northrop Grumman

Collaborators

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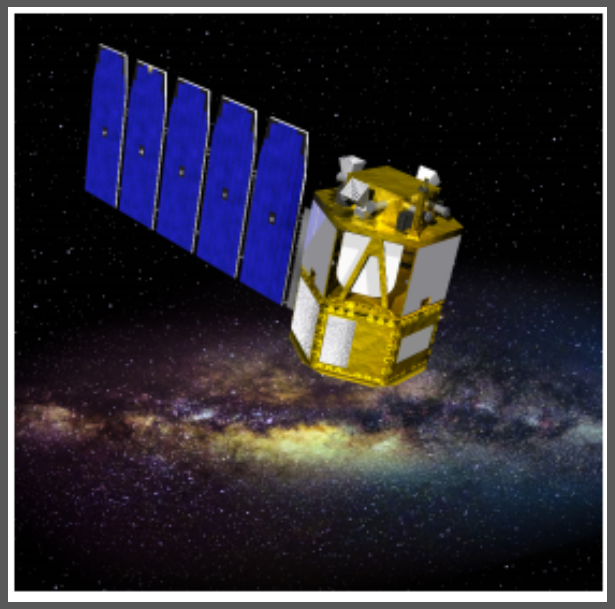
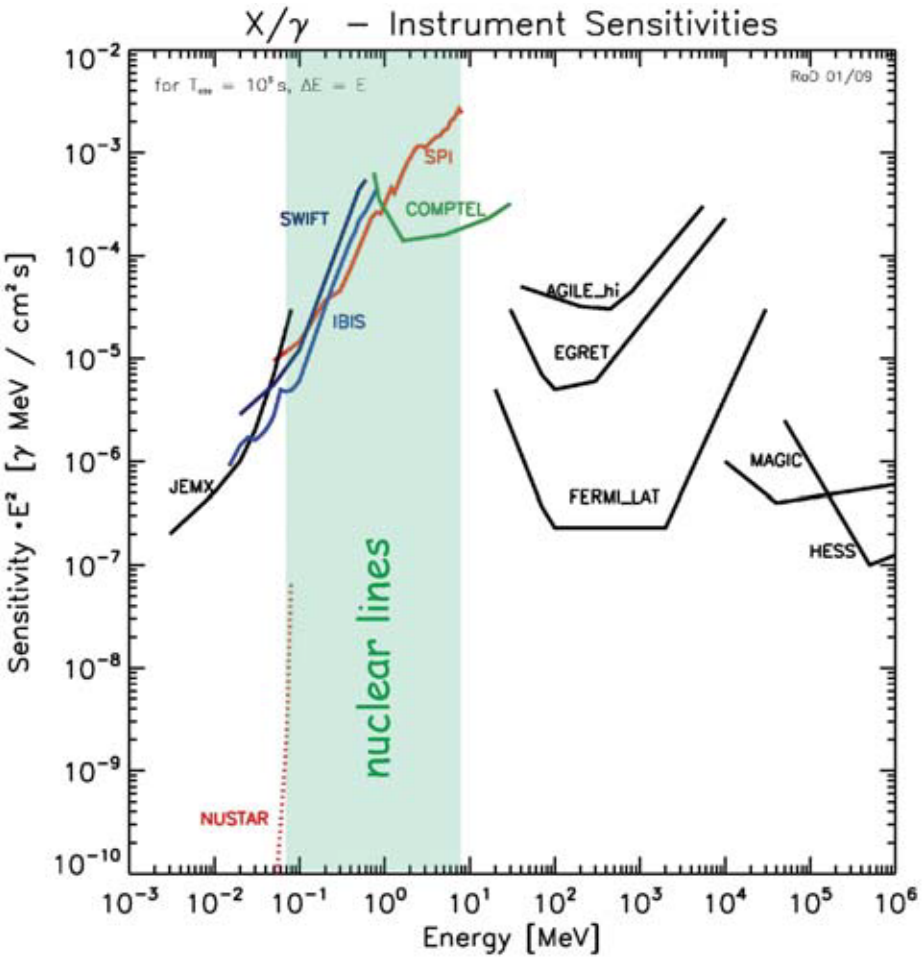


Every day, COSI will cover the entire sky, resulting in a sensitive all-sky map in the 0.2-5 MeV range

The MeV Gap

- 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)

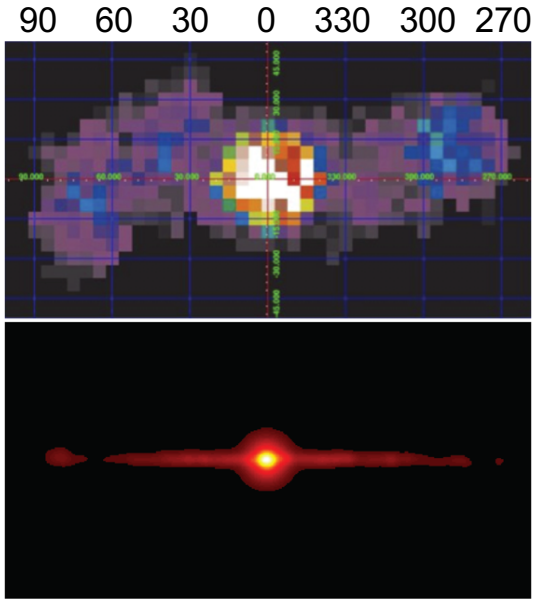


Diehl+13

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

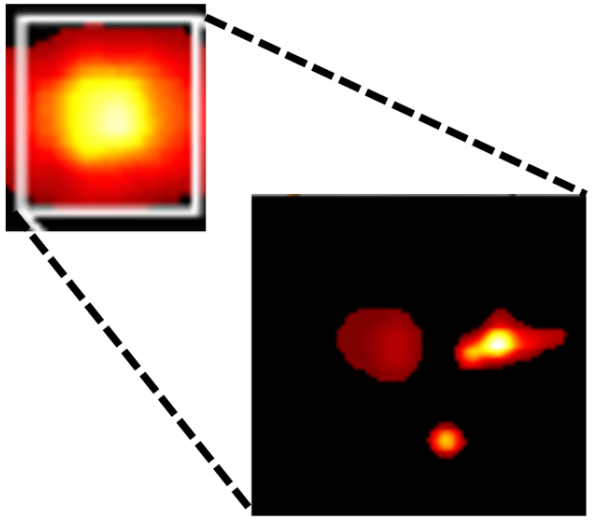
511 keV with INTEGRAL (Bouchet+10)



Now

COSI

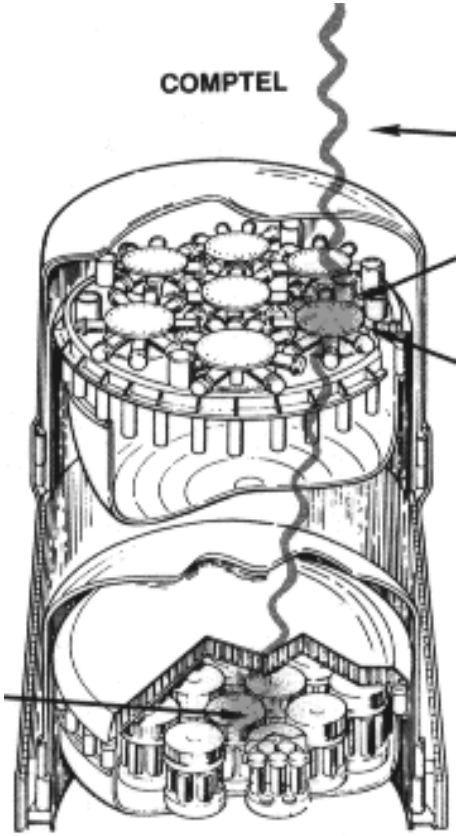
^{26}Al 1809 keV with COMPTEL



Now

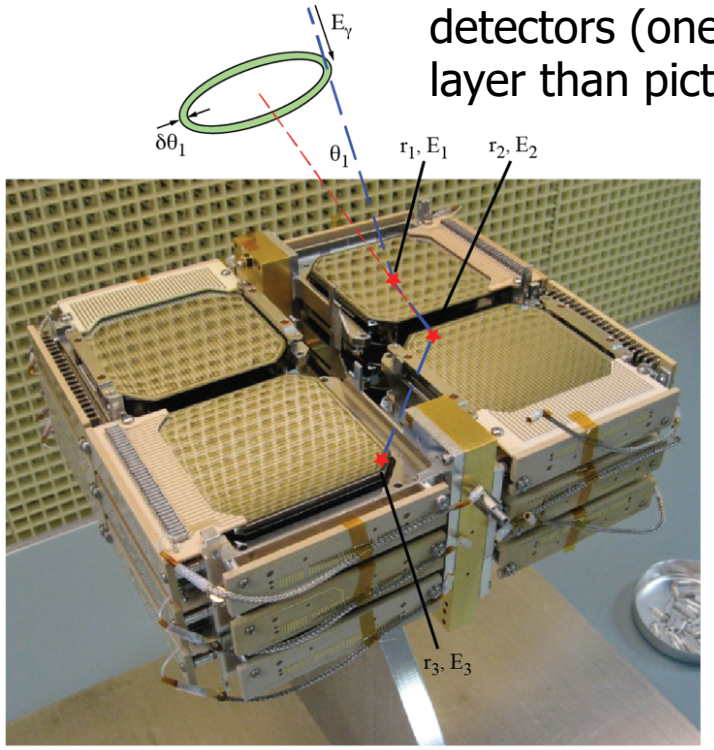
COSI

Compton Telescopes: from COMPTEL to COSI



30+ years of development through NASA R&D

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



Each detector is 8cmx8cm

CGRO/COMPTEL:

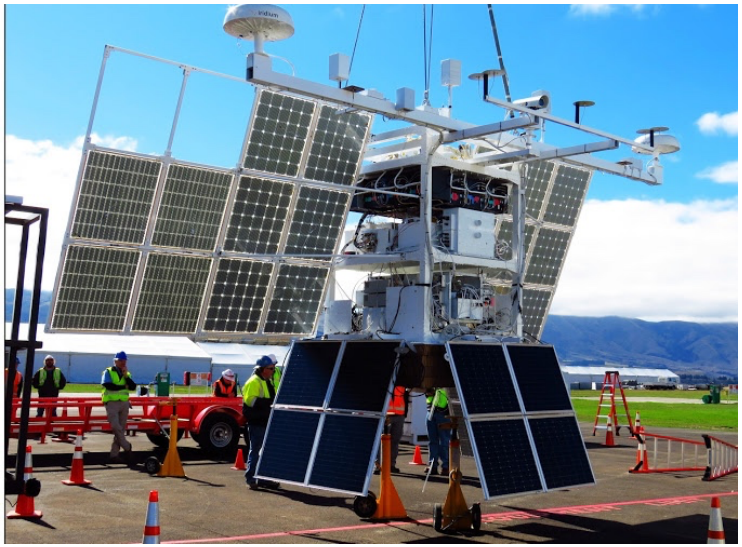
- ~40 cm^3 resolution
- $\Delta E/E$ ~10%
- up to 0.4% efficiency

COSI:

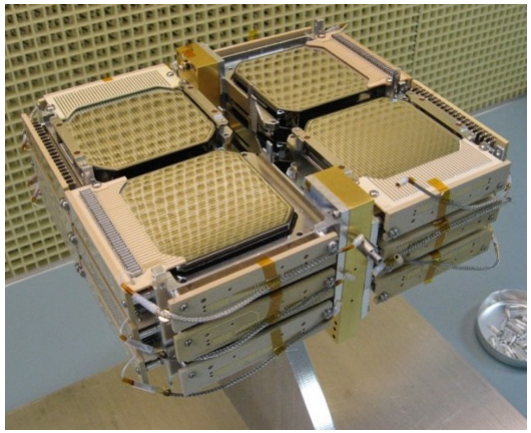
- <1 mm^3 resolution
- $\Delta E/E$ ~0.2-1%
- up to 16% efficiency
- bandpass covers 511 keV
- polarization

- Vastly improved performance with a fraction of the mass and volume

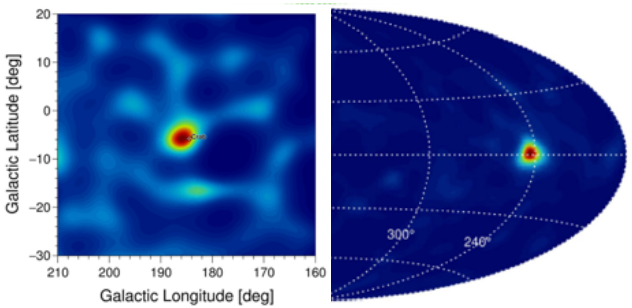
Astrophysics Research and Analysis (APRA) Balloon Program Heritage

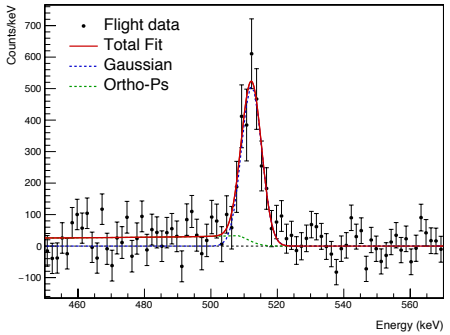


- Proof of concept demonstrated with COSI-APRA
- Successful flights with 2 detectors in 2005 and 10 detectors in 2009
- Instrument with 12 GeDs flew for 46 days in 2016



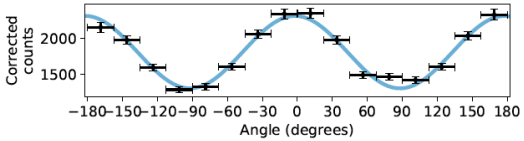
Germanium double-sided strip detectors (GeDs)





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

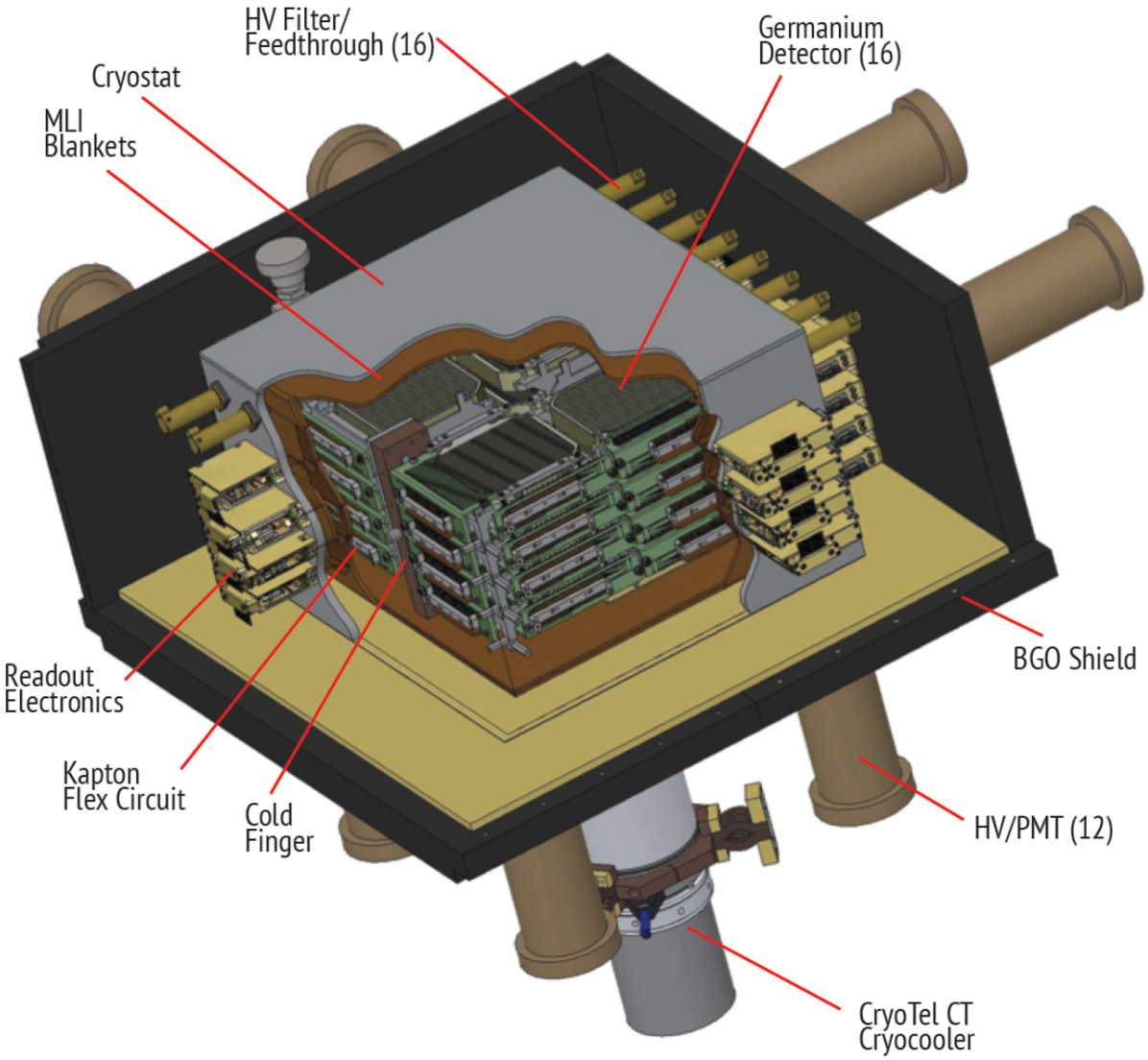
- **Imaging** a GRB (Lowell+), the Crab nebula (Sleator+), 511 (Siegert+), and more
- **Real-time GRB reporting**



Polarization measurement capabilities proven (Lowell+)

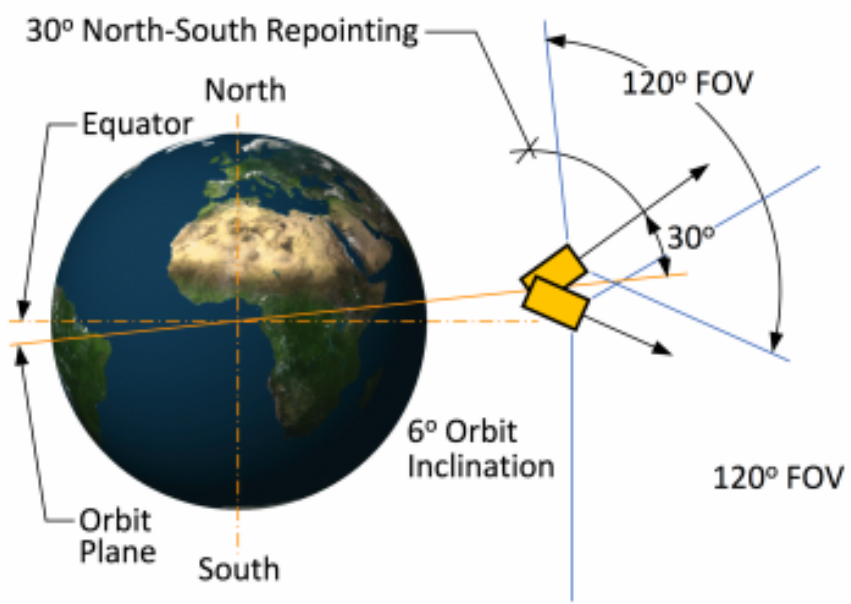
COSI-SMEX Instrument

- 16 GeDs in vacuum cryostat operating at <80K
- Active shielding for background rejection
  - Bismuth germanate (BGO) scintillators read out by PMTs

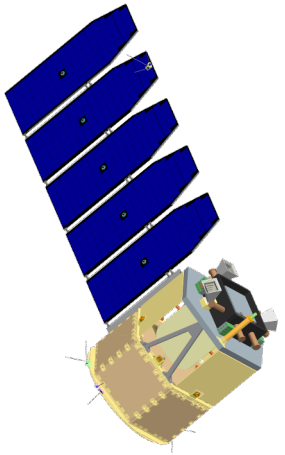


COSI-SMEX Orbit and Operations

- 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

Characteristic	Performance	Rationale
Energy Range	0.2-5 MeV	Polarization/511/nuclear lines
Sky Coverage	25% sky FOV 100% per day	All-sky maps; source monitoring; GRBs
Energy Resolution	0.2-1%	511 keV and nuclear line science
Angular Resolution @1809 keV	1.5° (FWHM)	Compare to 3.8° for COMPTEL
Narrow Line Sensitivity (2 years, 3σ) 511 keV 1809 keV	[photons cm^{-2} s^{-1}] 7.9×10^{-6} 1.7×10^{-6}	 Galactic flux ~ 10^{-3} cm^{-2} s^{-1} (~125x) Galactic flux ~ 7×10^{-4} (>400x)
Flux limit for polarization	15 mCrab	Reaches bright AGN; Galactic black hole transients often >100 mCrab
Fluence limit for GRB polarization (50% MDP)	4×10^{-6} erg cm^{-2}	Expect COSI to obtain polarization measurements for ~40 GRBs in 2 yr

Performance Estimates: Tomsick+19, arXiv:1908.04334, Astro2020 APC White Paper

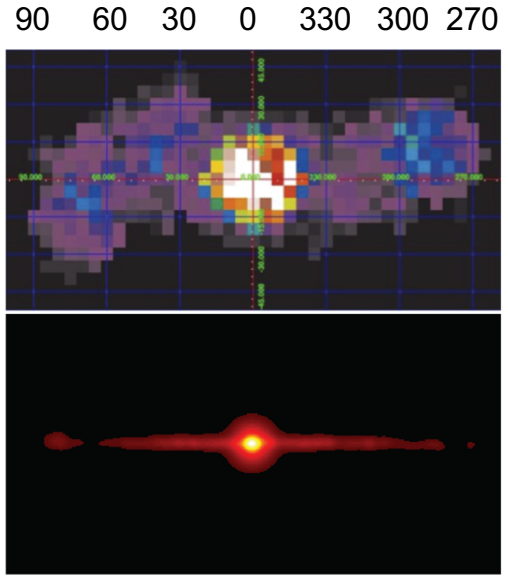
Galactic flux of 511 keV: E.g., Skinner+15, Siegert+16

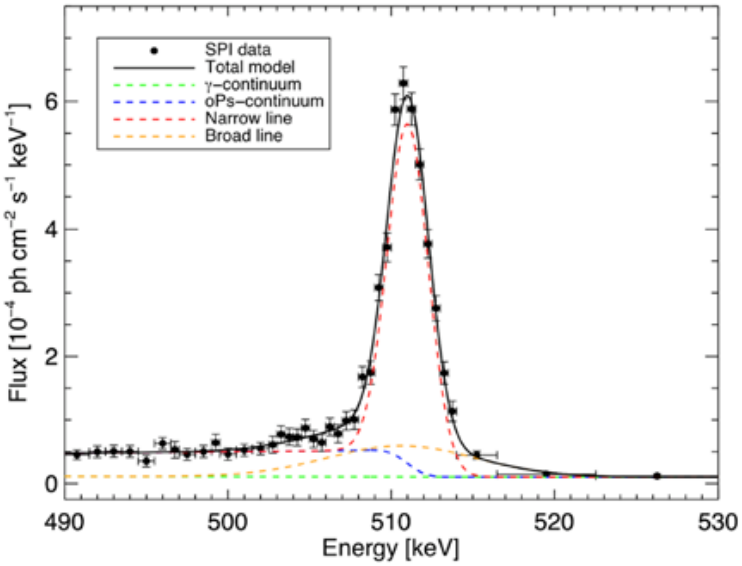
Galactic flux of 1809 keV and COMPTEL: Schonfelder+93, Oberlack+96

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

511 keV with INTEGRAL

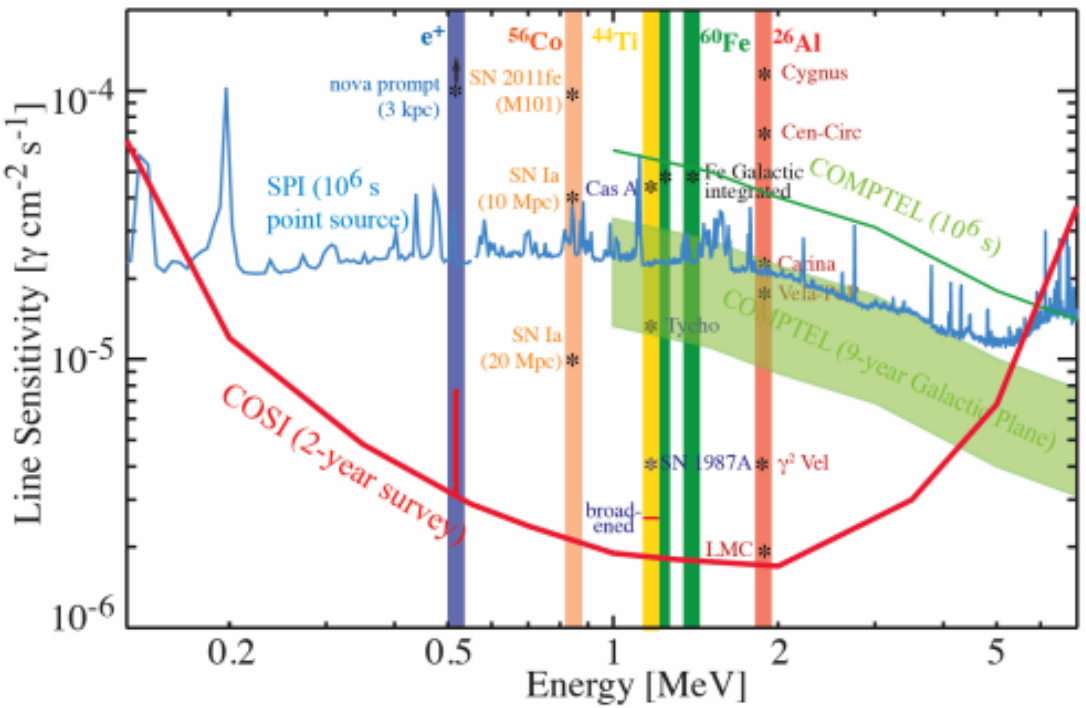




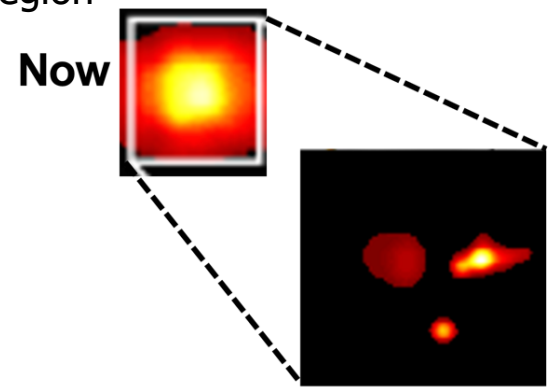
INTEGRAL/SPI: Jean+2006

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



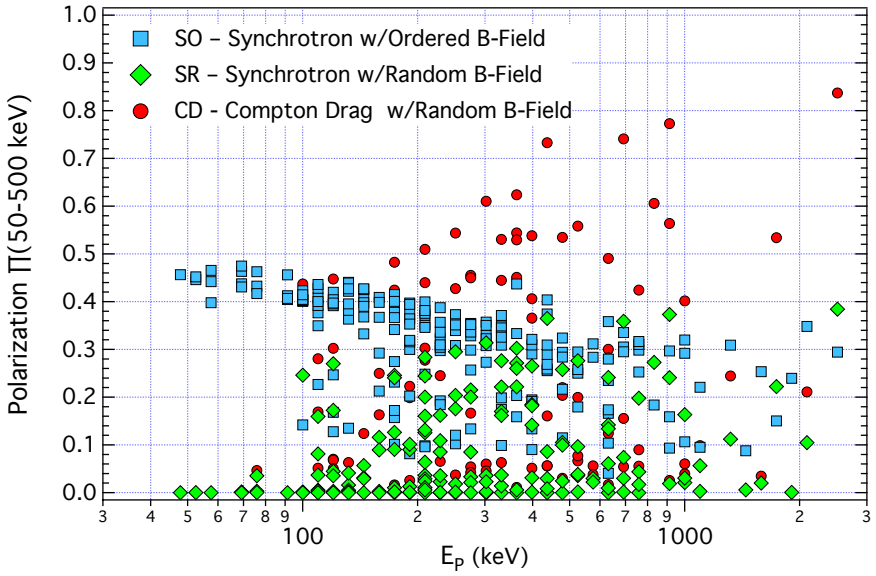
^{26}Al 1809 keV with COMPTEL for the Cygnus region



Based on locations of known OB associations

Insight into Extreme Environments with Polarization (GRBs)

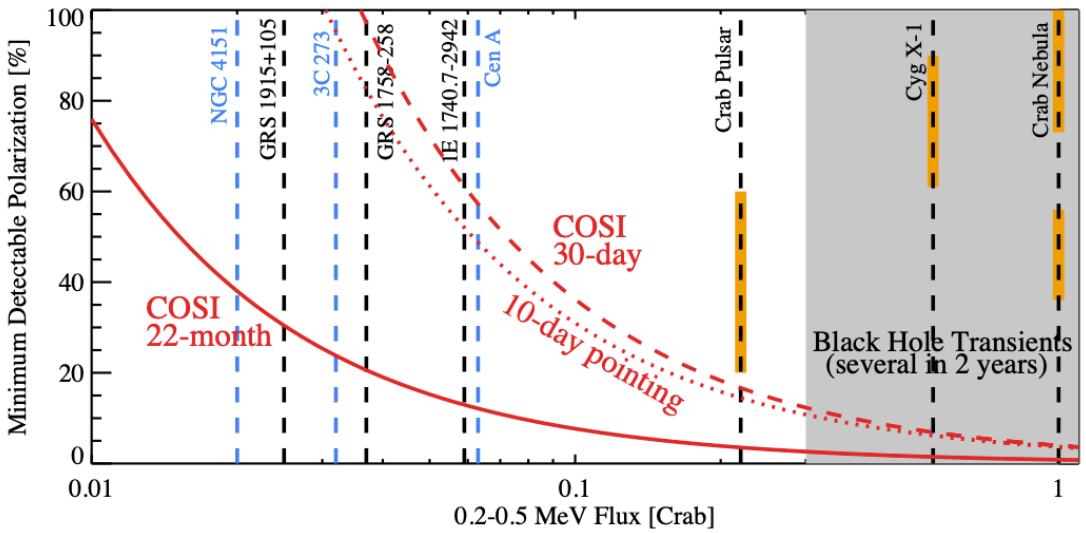
- Polarization measurements provide unique diagnostics for determining emission mechanisms and source geometries
- Most recent progress on GRB polarization by POLAR mission (Zhang+19)
- COSI will measure the polarization of ~40 GRBs in a 2-year mission
- ~a dozen GRBs with polarization measurements to ±5-10%

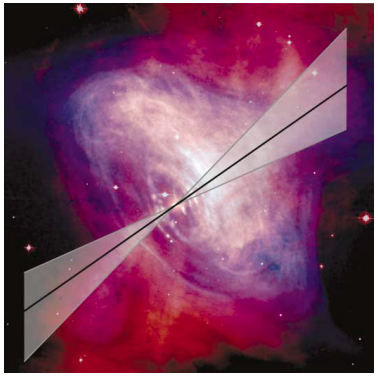


Toma+09;
McConnell+16

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





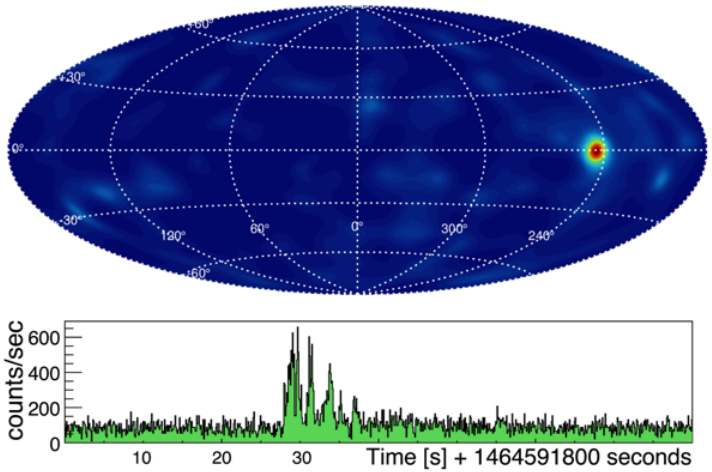
Crab pulsar and nebula (Dean+08)

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

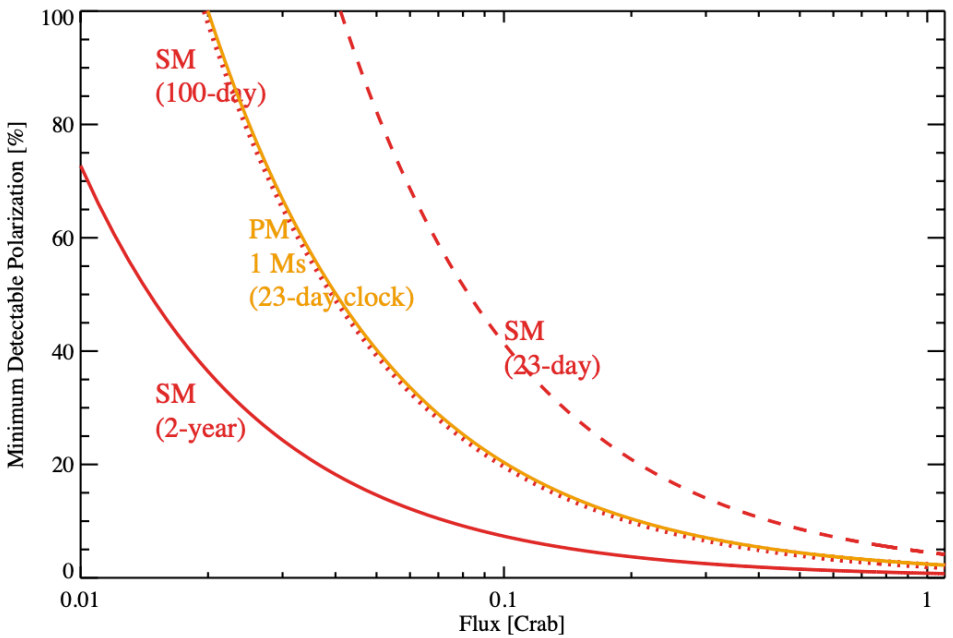
- COSI contributes to MMA with its capability to detect and localize counterparts
  - Short GRBs from merging binary neutron stars (15-20 in 2 yrs)
  - Gamma-ray search for counterparts to high-energy neutrinos
- Compton telescopes combine large FOV with good localization capabilities
  - Covers a different 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



GRB 160530A: real-time reporting by COSI in 2016 (GCN#19473)

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

Astro2020 APC White Paper for Additional Information

- arXiv:1908.04334
- 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

Astro2020 APC White Paper

The Compton Spectrometer and Imager

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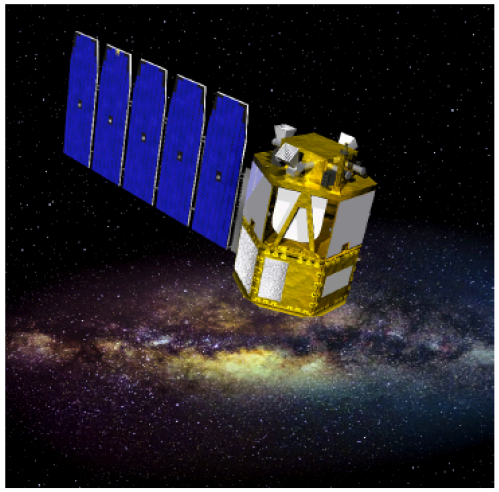

Summary and Conclusions

- 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)

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