COSI
Gamma-ray
Space Explorer

The Compton Spectrometer and Imager

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COSI overview

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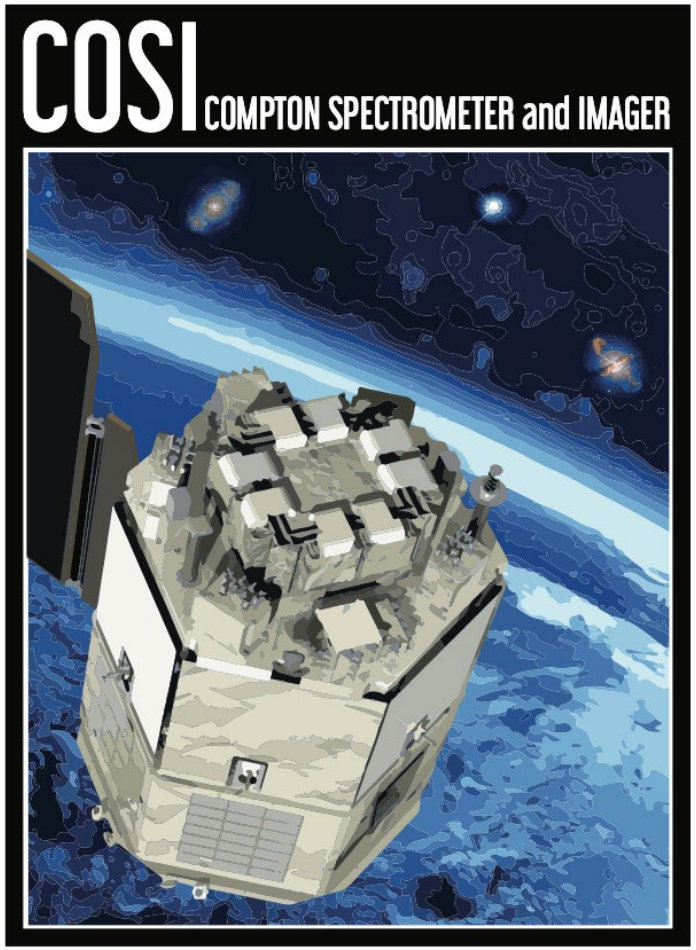
- COSI is a NASA Small Explorer (SMEX) satellite with a planned launch in 2027
  - Critical Design Review completed Dec 4-6, 2024
- Detects 0.2-5 MeV gamma rays
- Unique combination of capabilities
  - Uses germanium detectors cooled to cryogenic temperatures to provide ***excellent energy resolution***
  - Instantaneous field of view is ***>25% -sky*** and covers the whole sky every day
- Designed for studies of nuclear and annihilation emission lines across our Galaxy, while enabling TDAMM science
  - E.g., transient detection and variable source monitoring



Upcoming SMEX mission operating in the energy range between NuSTAR and Fermi/LAT

The MeV gap

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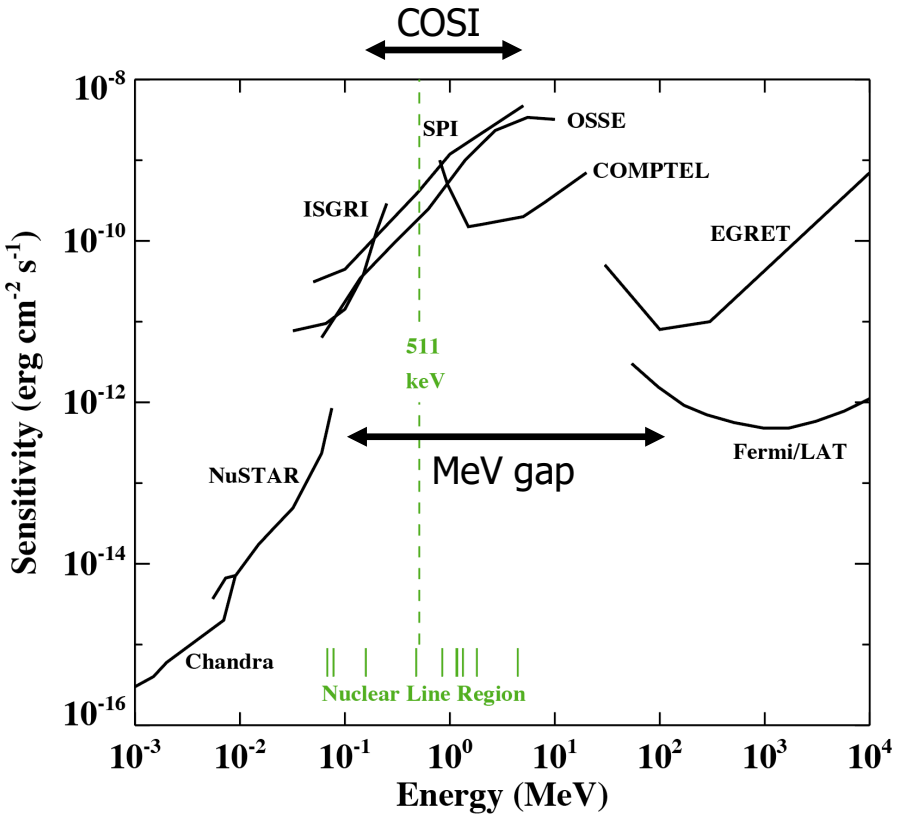
- Previous and current missions have had relatively poor sensitivity in the MeV range
- Discovery space where there is known to be interesting physics
  - Antimatter annihilation line at 511 keV
  - Nuclear lines from unstable products of element formation
  - Accreting black holes
  - Multimessenger astrophysics



Compton telescopes:

- *COMPTEL on CGRO (1991-2000)*
- *COSI is a compact Compton Telescope*

COSI's key science goals

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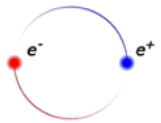
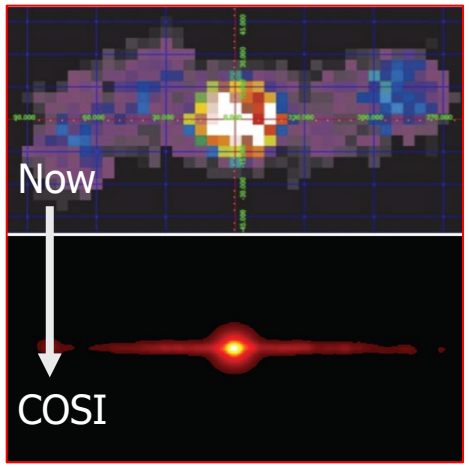
A. Uncover the Origin of Galactic Positrons

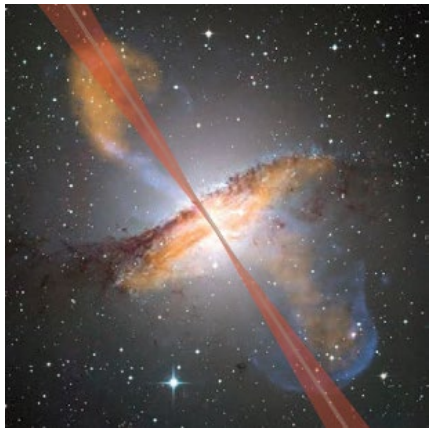


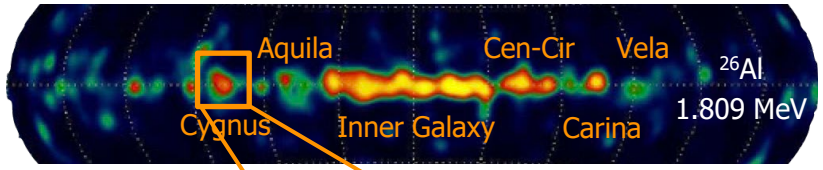
e^-e^+ @ 511 keV



C. Gain Insight into Extreme Environments with Polarization

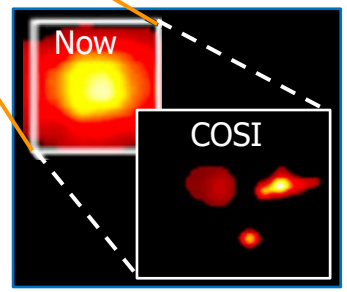
AGN and Galactic black holes @ 0.2-0.5 MeV





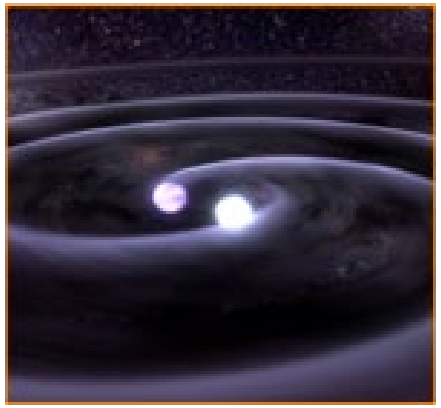
B. Reveal Galactic Element Formation

^{26}Al @ 1.809 MeV
^{60}Fe @ 1.173 and 1.333 MeV
^{44}Ti @ 1.157 MeV



D. Probe the Physics of Multimessenger Events

GRB alerts



Payload design and instrument concept

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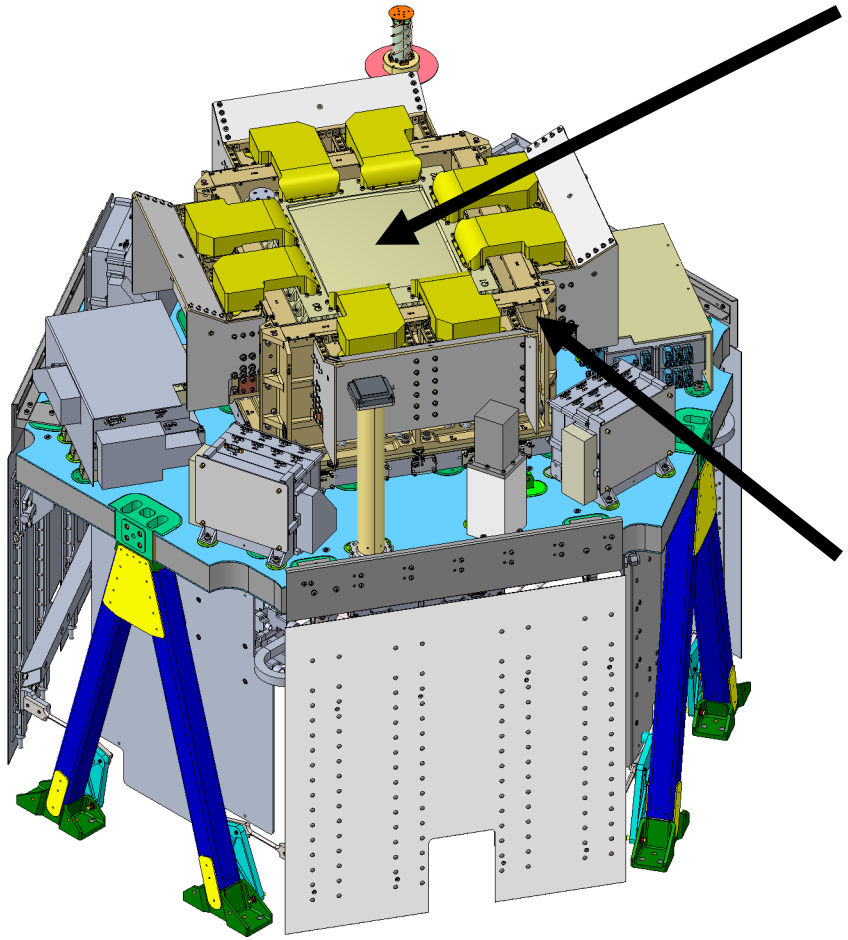
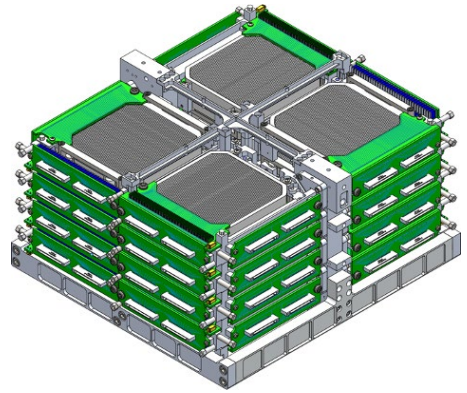


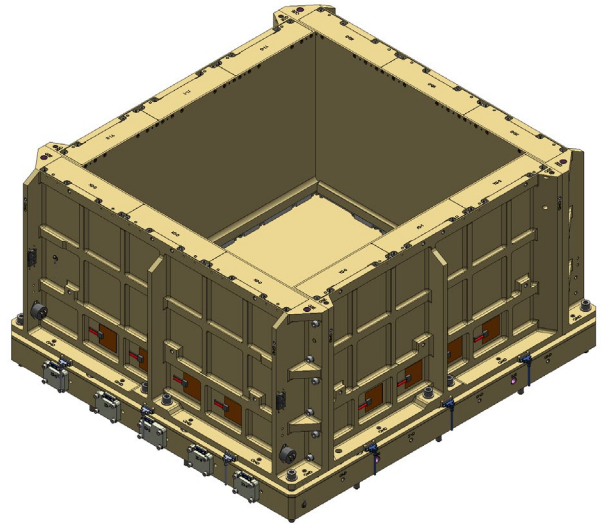
Germanium detector array

- 16 germanium detectors in a cryostat
- 0.2 - 5 MeV
- High-resolution spectroscopy
- Compton imaging
- Compton polarimetry



Anticoincidence subsystem (ACS)

- Bismuth germinate (BGO) scintillator "shields"
- Reducing and monitoring background
- 50 ms light curves at 80 keV - 2 MeV (for GRB alerts)



COSI orbit and operations

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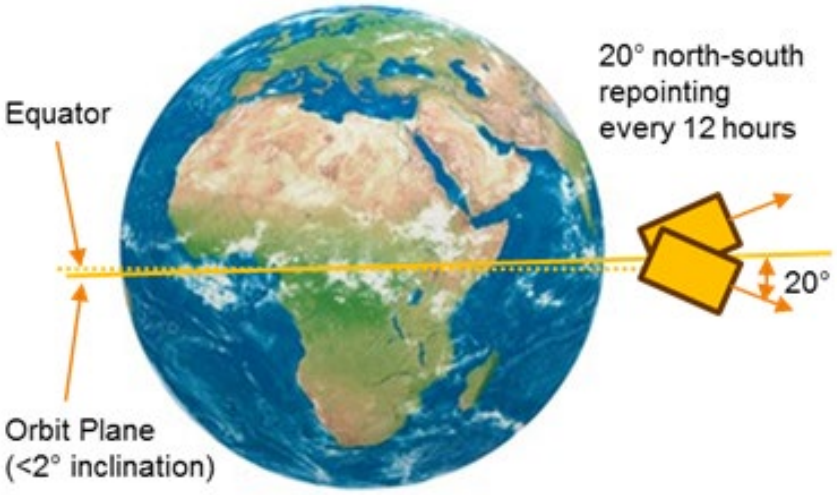
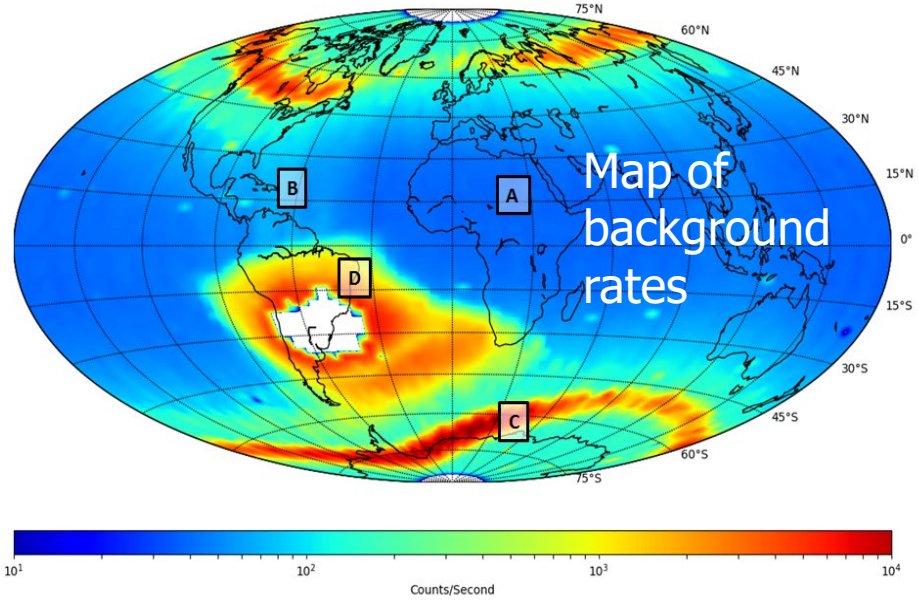
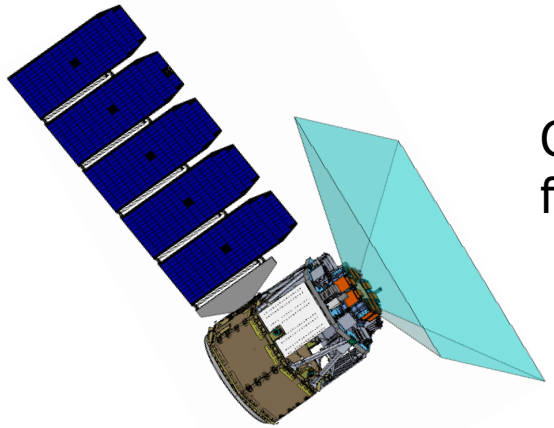
- Equatorial orbit to minimize background
- COSI will spend nearly all of its observing time in "survey mode"
  - North/South zenith offset alternating every 12 hours





Map of background rates



COSI's >25%-sky field of view

Measurement requirements for emission line goals

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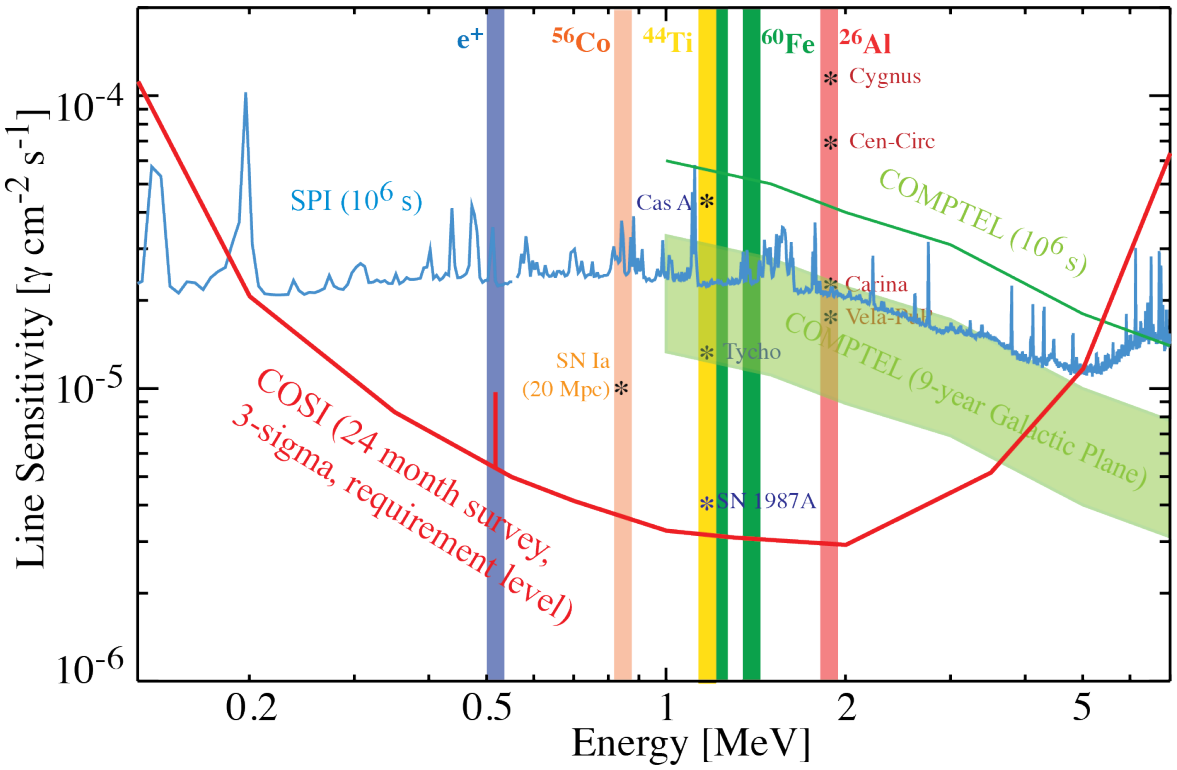
Characteristic	Requirement
Sky Coverage	• >25%-sky instantaneous FOV • 100%-sky each day
Energy Resolution* (FWHM)	• <1.2% @ 0.511 MeV • <0.8% at 1.157 MeV (^{44}Ti)
Narrow Line Sensitivity (2 yr, 3σ, point source)	[photons cm^{-2} s^{-1}] • 1.2x10^{-5} @ 0.511 MeV • 3.0x10^{-6} @ ^{26}Al, ^{60}Fe, and ^{44}Ti
Angular Resolution (FWHM)	• <4.1° @ 0.511 MeV • <2.1° @ 1.8 MeV (^{26}Al)

*Notes on energy resolution:

- For fully reconstructed Compton events (average of 2.5 interactions)
- 1.157 MeV requirement is <0.8% FWHM; capability estimate ~0.5%



COSI will reach the sensitivities shown for every source in the sky

GRBs: One way COSI enables TDAMM science

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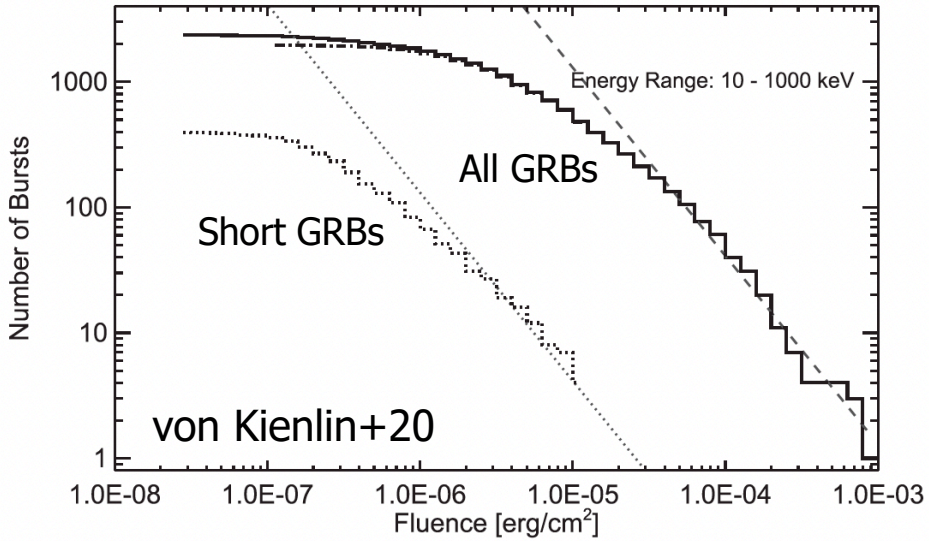
Requirements (short GRBs)

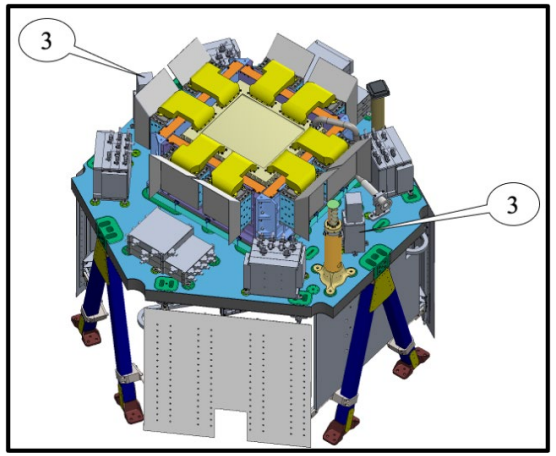
- Localize GRBs to <2.5° (90% confidence error radius)
- Report positions in <1 hr
- Arrival times to an absolute accuracy of <100 ms
- Fluence limit ~6×10^{-7} erg/cm^2 for localizations (expect COSI to detect ~one per 2 months)

Expectations for GRBs beyond requirements

- The alert trigger will also include long GRBs, magnetars, and other gamma-ray transients
- Will use on-board scintillators to extend FOV and obtain rough (several degree) positions
- Expect COSI to measure polarization of ~30 GRBs with minimum detectable polarization <50%

Cumulative distribution for GRBs measured over 10 years by Fermi/GBM





Background and Transient Observer (BTO)

- Student Collaboration project
- Two NaI scintillator detectors
- 30 keV – 2 MeV
- FOV > 60%-sky
- Gulick+24, SPIE paper

Nuclear line transients and COSI – TDAMM report

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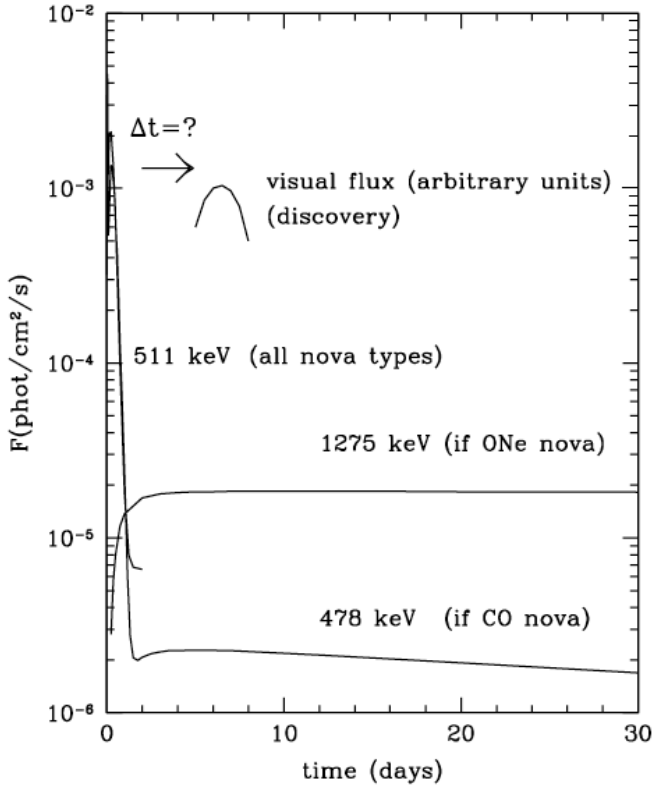
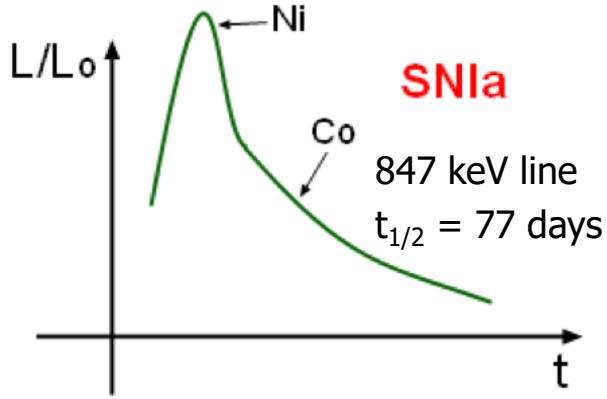
- Classical novae
  - Thermonuclear explosions on accreting white dwarfs
  - 511 keV (^{13}N, ^{18}F)
    - COSI detection rate ~1 per 2 yr
  - 1275 keV (^{22}Na)
    - COSI detection rate ~1 per few yr
- COSI: 2 yr prime mission but may operate for a decade or more
- Thermonuclear SNe
  - Accretion-induced WD collapse or merging WDs
  - 847 keV (^{56}Co)
    - COSI detection rate ~2 per yr
  - Line profiles constrain progenitors and explosion mechanism (Leising+22)

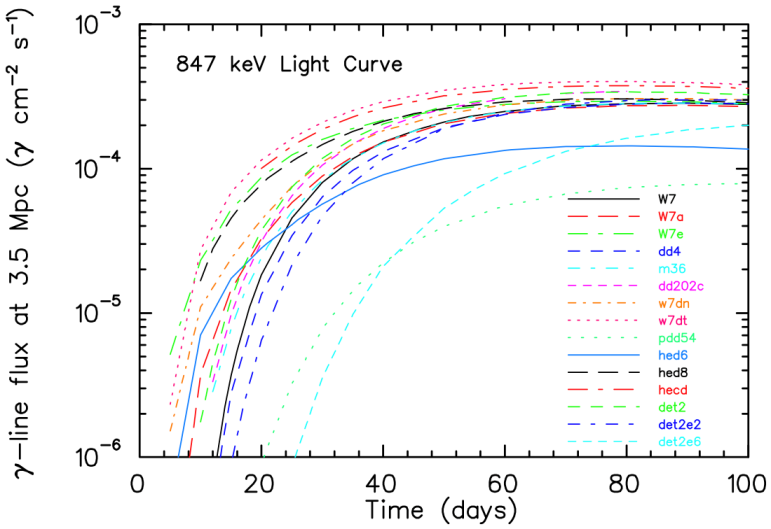
Classical Novae



Predicted flux levels vs. time @ 1 kpc
(Hernanz 2005 and Hernanz 2014)

Thermonuclear SNe





The COSI collaboration

University of California, Berkeley

University of California, San Diego

Naval Research Laboratory

Goddard Space Flight Center

Space Dynamics Laboratory

Northrop Grumman

Italian Space Agency (ASI)

German Aerospace Center (DLR)

French National Space Agency (CNES)

COSI

Institutions of Co-Investigators and Collaborators

- Clemson University
- Louisiana State University
- Los Alamos National Laboratory
- Lawrence Berkeley National Laboratory
- IRAP, France
- INAF, Italy
- Kavli IPMU and Nagoya University, Japan
- JMU/Würzburg and JGU/Mainz, Germany
- NTHU, Taiwan
- Centre for Space Research, North-West University, South Africa
- Deutsches Elektronen Synchrotron (DESY), Germany
- University of Hertfordshire, UK
- LAPTh-CNRS, France
- Yale University
- Michigan Technical University
- Washington University, St. Louis
- Marshall Space Flight Center
- Boston University
- IAA-CSIC, Spain
- Stanford University
- Rice University

NASA

Current activities

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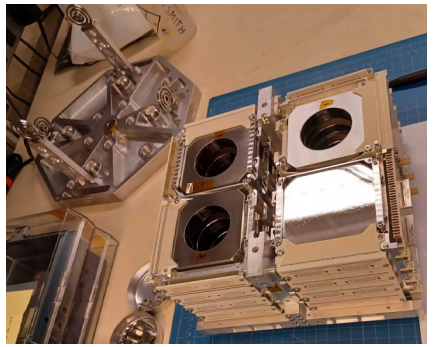
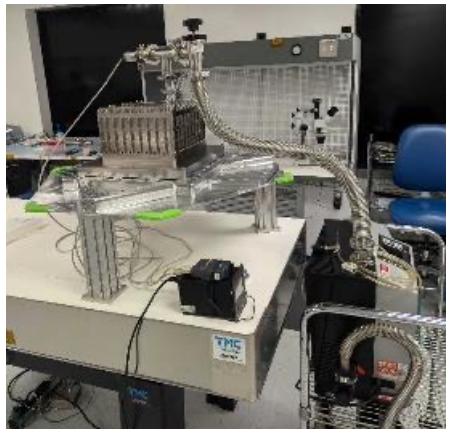
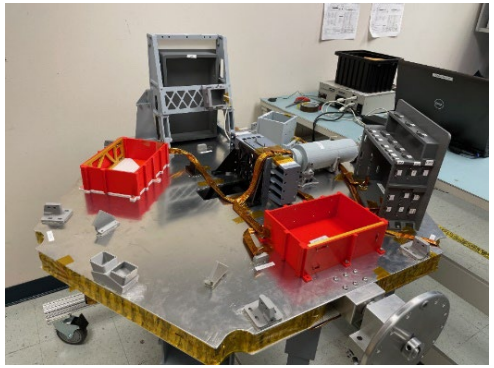
Hardware



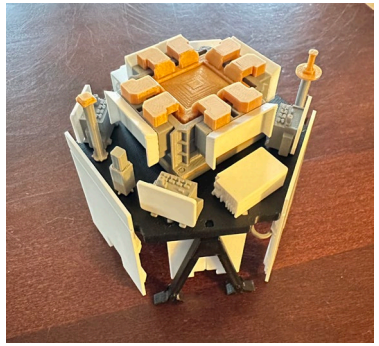
16 detector assembly
(one germanium stack)



EM cryostat

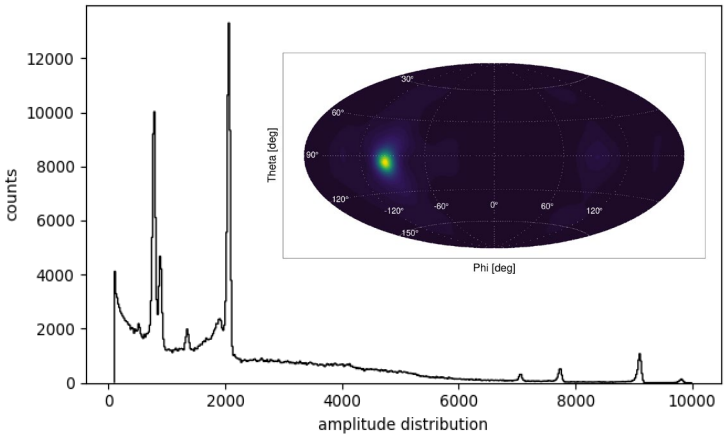


Full-size harnessing mockup



Mini-COSI

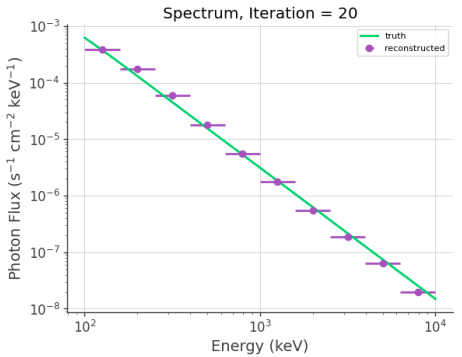
Testing

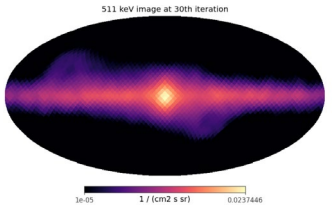


^{133}Ba spectrum and ^{137}Cs first light image both measured with a COSI germanium detector

Software

Yearly Public Data Challenges





Simulated data with realistic sources analyzed with COSItools

(DC-2 available; DC-3 coming soon)

cosi.ssl.berkeley.edu

Path forward for COSI

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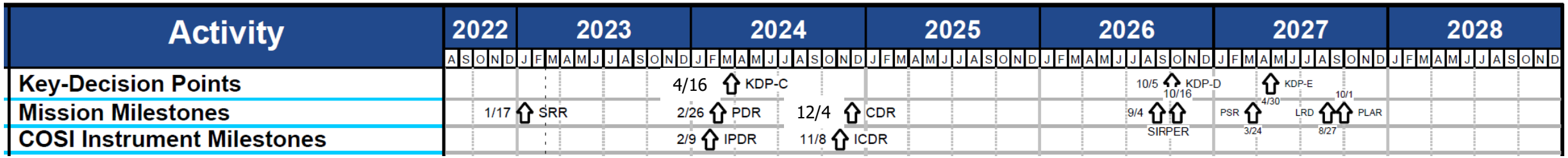
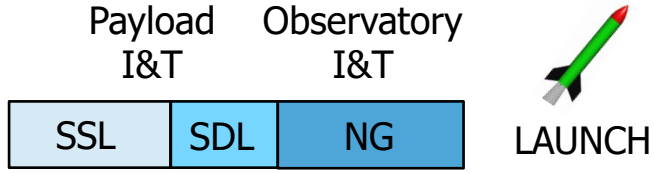


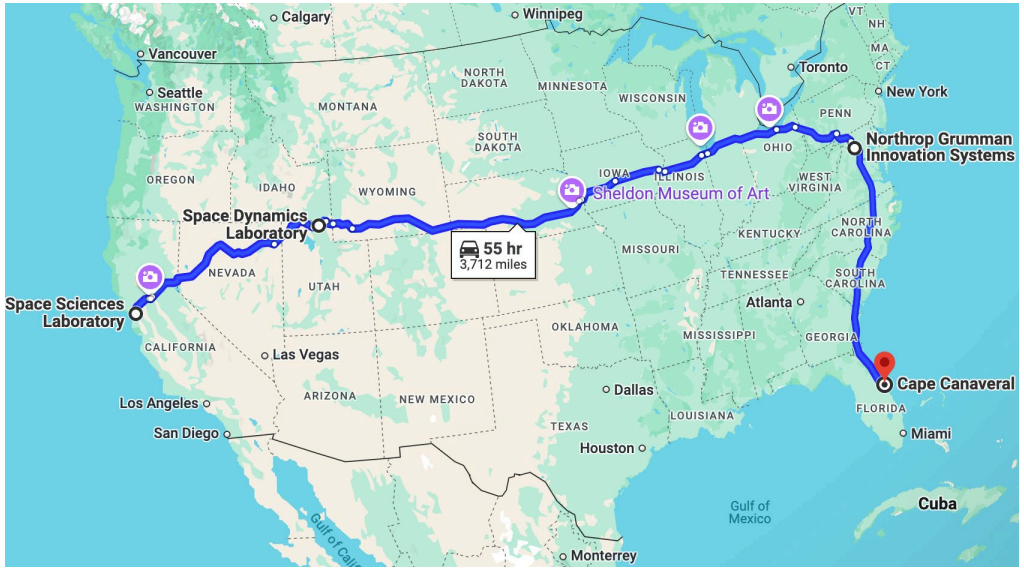
Now

Most recent milestone: Successful Critical Design Review (CDR) on 2024 Dec 4-6



LAUNCH!

What activity?	Where?	When?
Payload I&T - calibration	SSL (Berkeley)	Mid-2025 to Early-2026
Payload I&T - environmental testing	SDL (Utah)	Mid-2026
Observatory I&T	NG (DC area)	Late-2026 to Early-2027
Launch (SpaceX Falcon 9)	Cape Canaveral, Florida	August 2027



COSI fact sheet

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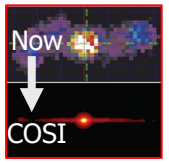
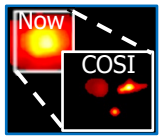


Uncover the Origin of Galactic Positrons

- COSI employs advances in gamma-ray imaging to resolve the distribution of antimatter in the Galaxy

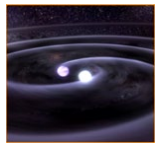


Reveal Galactic Element Formation

- COSI will provide major advances in nuclear line studies, including ^{26}Al, ^{60}Fe, and ^{44}Ti

Gain Insight into Extreme Environments with Polarization

- COSI determines emission mechanisms and geometries in accreting black holes, including Active Galactic Nuclei



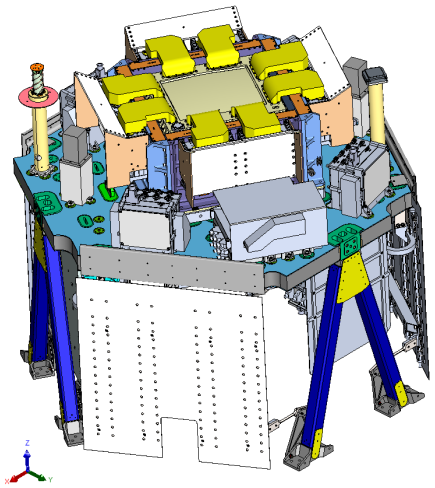
Probe the Physics of Multimessenger Events

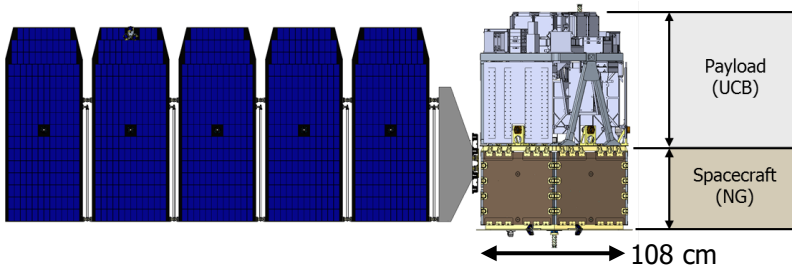
- COSI detects gamma-ray bursts and rapidly reports their positions to allow for follow-up by other observatories

Characteristic	Requirement
Sky Coverage	• >25%-sky instantaneous FOV • 100%-sky each day
Energy Resolution (FWHM)	• <1.2% @ 0.511 MeV • <0.8% at 1.157 MeV (^{44}Ti)
Narrow Line Sensitivity (2 yr, 3σ)	[photons/cm^2/s] • 1.2x10^{-5} @ 0.511 MeV • 3.0x10^{-6} @ ^{26}Al, ^{60}Fe, and ^{44}Ti
Angular Resolution (FWHM)	• <4.1° @ 0.511 MeV • <2.1° @ 1.8 MeV (^{26}Al)
Polarization	• >1.4x10^{-10} erg/cm^2/s
GRB alerts	• 6x10^{-7} erg/cm^2 (<20° off-axis)

Timing requirements
- 5 ms relative
- Photon arrival times to UT to better than 100 ms

Localizing short GRBs
- <2.5° (90% confidence radius)
- Reporting position in <1 hr





- Northrop Grumman: spacecraft (Dulles); structure (Magna)
- UCB/SSL: payload systems, cryostat, electronics, BTO
- Naval Research Lab: ASIC readout electronics and bismuth germanium oxide (BGO) shields
- Lawrence Berkeley National Lab: germanium detectors
- GSFC: Cryostat Heat Removal Subsystem (CHRS)
- Space Dynamics Lab: electronics and I&T support

COSI Mass, Power, and Data	
Mass (372 kg Not to Exceed)	350 kg (Maximum Expected Value, MEV)
Power (732 W generated by Solar Array w/ battery storage)	609 W MEV (including battery recharge and other inefficiencies)
Data (through Malindi Ground Station, provided by ASI)	~1 GB/day S-band
Data (through Tracking and Data Relay Satellite System, TDRSS)	4 kbps S-band GRB Data: 500 kb per alert

Mission Parameters
- Launch scheduled for August 2027
- Launch vehicle SpaceX Falcon 9
- Orbit: 530 km altitude and ~0° inclination
- >2-year mission
- Mission operations at UCB/SSL