The Compton Spectrometer and Imager (COSI)

Alyson Joens on behalf of the COSI Team

UC Berkeley/ Space Sciences Laboratory

June 20, 2023

COSI Collaboration

University of California

- John Tomsick (Principal Investigator, UCB)
- Bryce Unruh (Project Manager, UCB)
- Steven Boggs (Deputy PI, UCSD)
- Andreas Zoglauer (Project Scientist, UCB)
- J. Martinez Oliveros (Student Collaboration Lead, UCB)
- P. Saint-Hilaire (SEO Lead, UCB)
- A. Joens, H. Lazar, H. Gulick, J. Roberts, F. Rogers, S. Pike

Naval Research Laboratory

- E. Wulf, C. Sleator, L. Mitchell, A. Hutcheson, E. Grove, J. Smith

Goddard Space Flight Center

- C. Kierans, A. Shih, A. Smale
- C. Karwin, I. Martinez Castellanos, E. Neights, M. Negro

Northrop Grumman

Institutions of Co-Investigators and Collaborators

- Clemson University
- Los Alamos National Laboratory
- Louisiana State University
- IRAP, France
- INAF, Italy
- JMU, Germany
- NTHY, Taiwan
- Kavli IPMU and Nagoya University, Japan

Overview

- COSI: a NASA Small Explorer (SMEX) mission launching in 2027

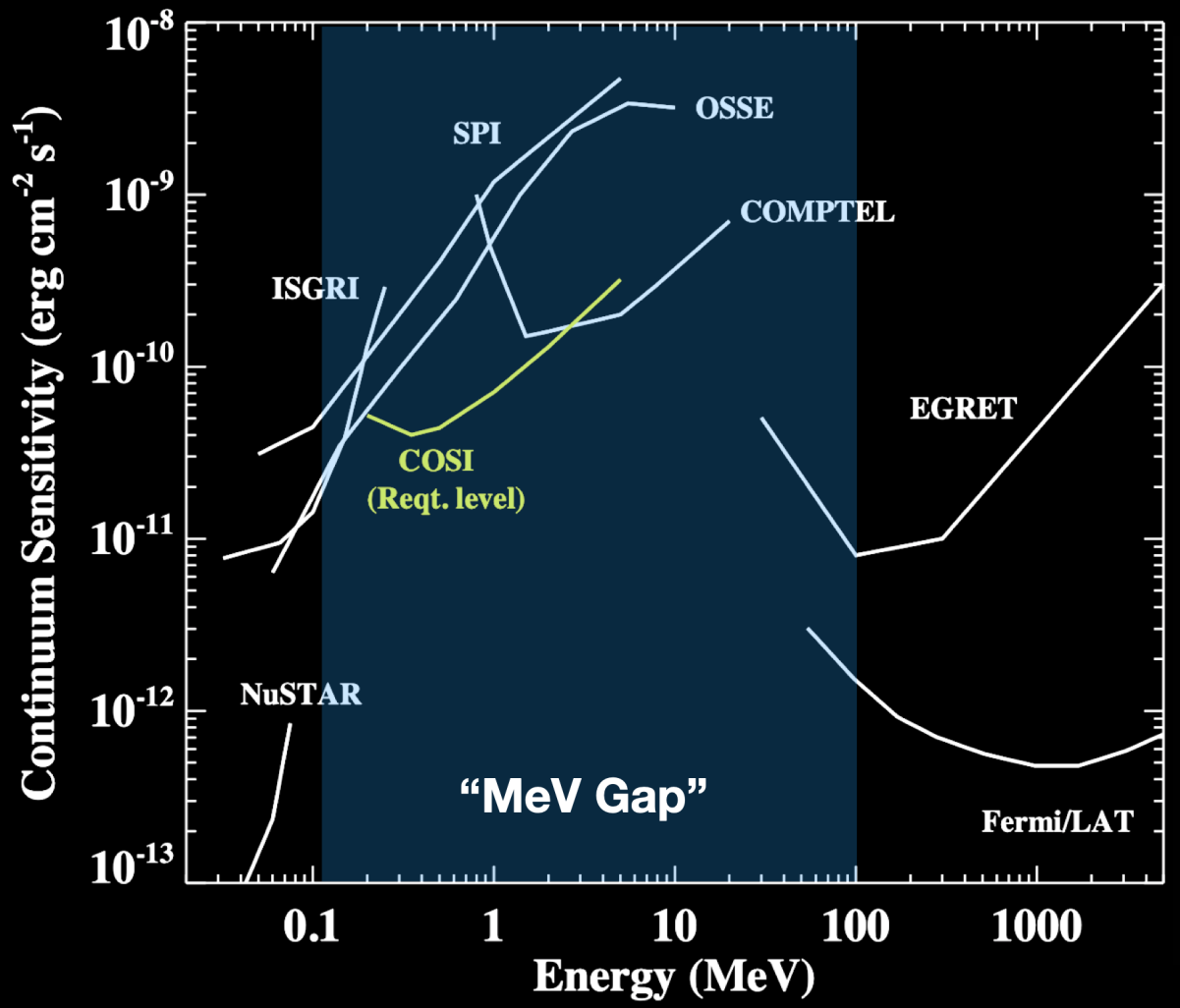
- COSI Instrument: Compact Compton Telescope
  - All-sky imaging, polarimetry, and spectroscopy in the 0.2-5 MeV energy range

- COSI Science Goals: will revolutionize our understanding of the creation and destruction of matter in our Galaxy and beyond

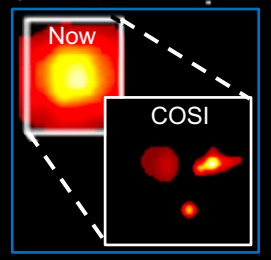
MeV Gap

<u>Science Opportunities in the MeV gap:</u>

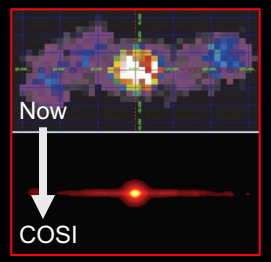
- Nuclear line region
- 511 keV – e^-/e^+ annihilation
- Astrophysical jets
- Compact objects



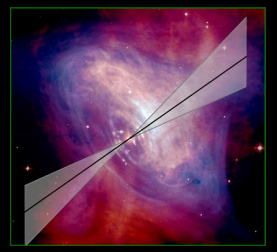
COSI's Science Goals



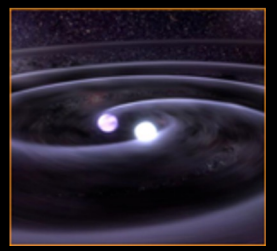
Reveal Galactic element formation



Uncover the origin of Galactic Positrons



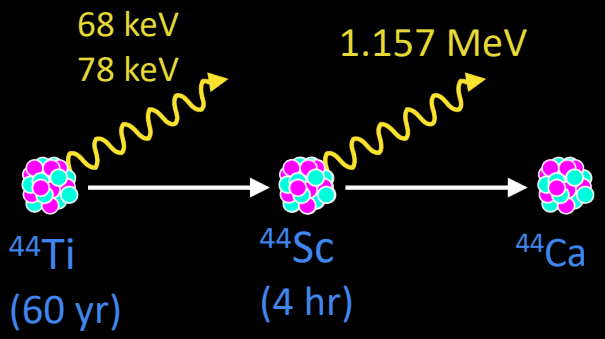
Gain insight into extreme environments with polarization



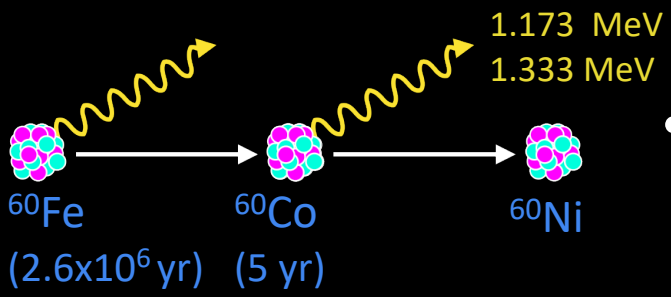
Probe the physics of multimessenger events

Reveal Galactic Element Formation

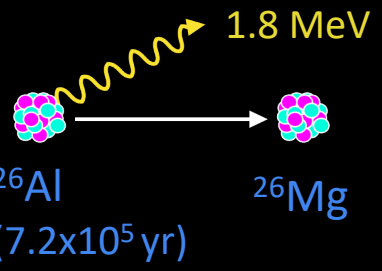
Three isotopes formed through stellar and explosive nucleosynthesis:



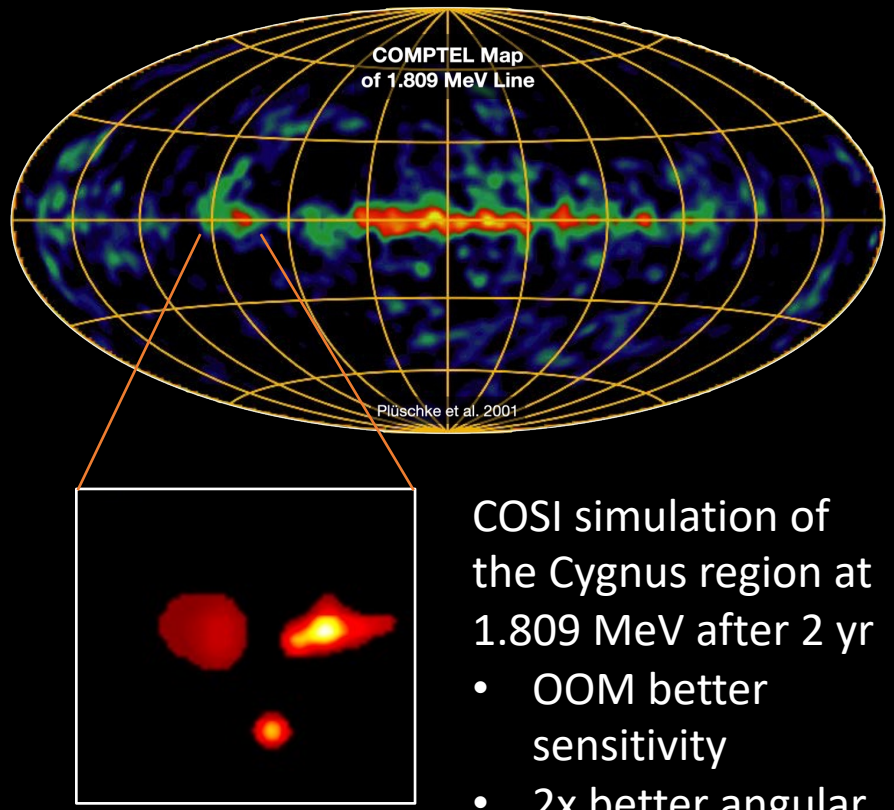
- ^{44}Ti: Traces **recent** SN activity



- ^{60}Fe: Traces SN activity over the **past few million years**



- ^{26}Al: Traces massive stars, including pre-supernova

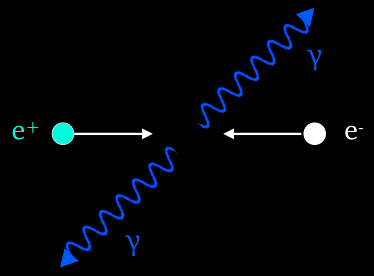


COSI simulation of the Cygnus region at 1.809 MeV after 2 yr

- OOM better sensitivity
- 2x better angular resolution

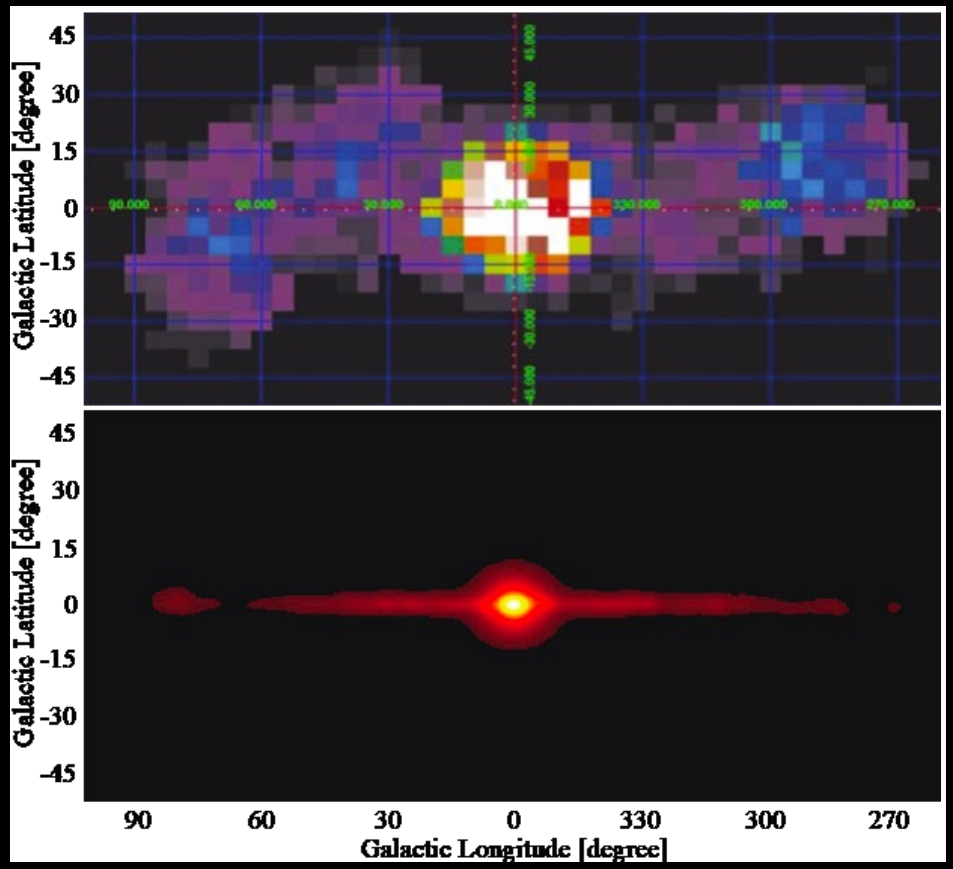
Uncover the origin of Galactic Positrons

- 5 decades since the initial detection of the 511 keV positron annihilation signature in inner Galaxy
  - COSI will address:
    - Origin of bulge emission?
    - What is the nature of the disk emission?
    - How far do positrons propagate in the galaxy?
    - And more!



- COSI's improved angular resolution, continuum sensitivity, and imaging spectroscopy will allow for an enhanced study of the 511 keV emission and will constrain emission features

INTEGRAL/SPI map of the 511 keV emission (Bouchet+10)

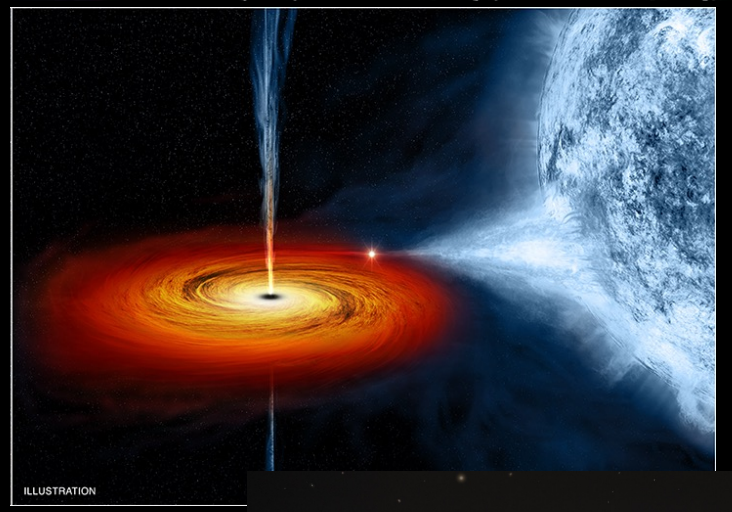


COSI simulation of 511 keV emission

Gain insight into extreme environments with polarization

Polarization measurements constrain high energy emission mechanisms and source geometries

- Galactic Black Holes
  - What is origin of the gamma-ray emission?
- Active Galactic Nuclei
  - Blazars: is emission hadronic or leptonic in origin?
- Gamma-ray Bursts
  - Distinguish between emission models
  - What is the magnetic field structure?



Cygnus X-1

Cen A

Gain insight into extreme environments with polarization

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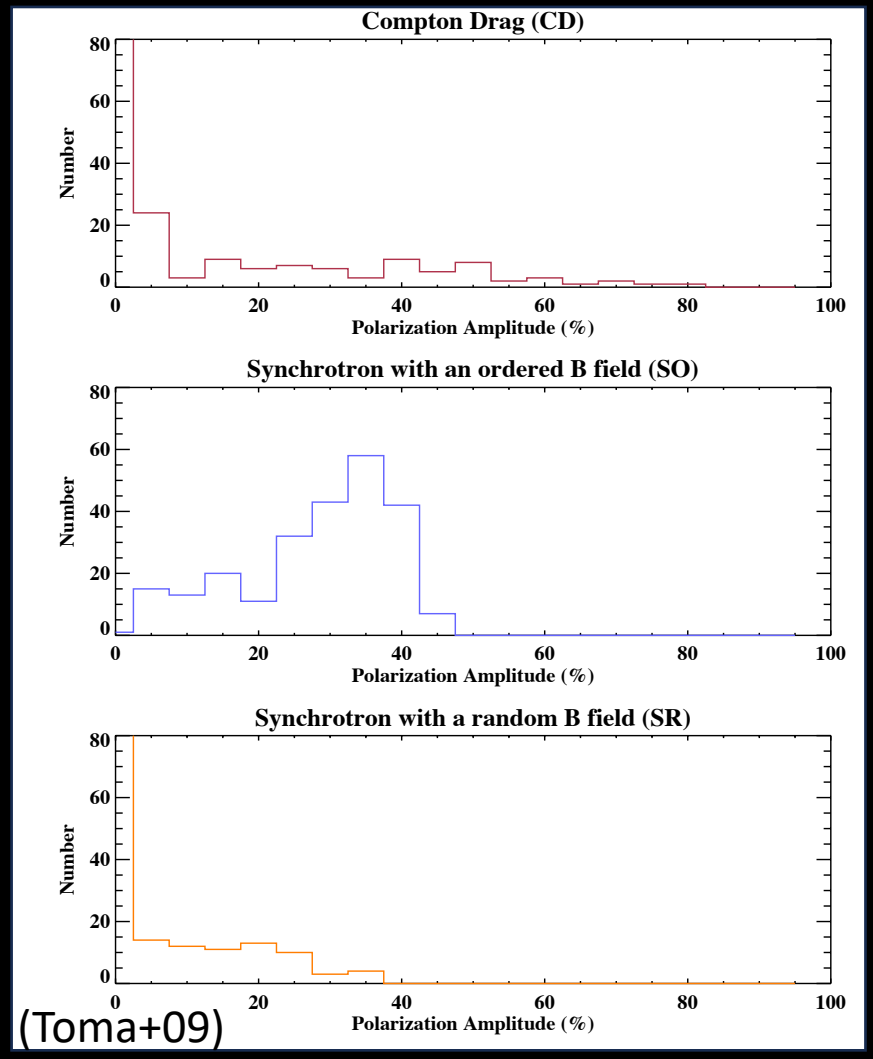
Requires analysis of distribution of polarization amplitudes



(Toma+09)

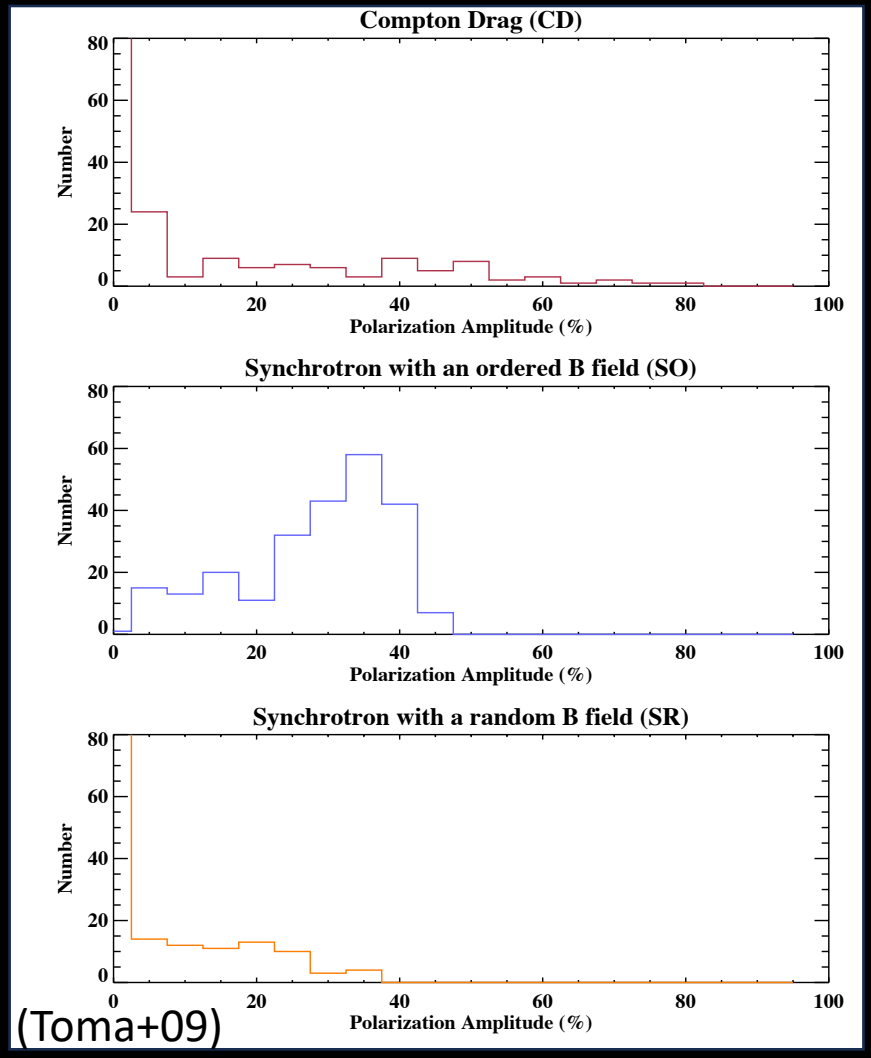
Gain insight into extreme environments with polarization

Goal: COSI will measure polarization (MDP≤50%) of ≥30 GRBs in a 2-year mission

- Gamma-ray Bursts
  - Distinguish between emission models
  - What is the magnetic field structure?

Requires analysis of distribution of polarization amplitudes

- COSI's goal of 30 GRB polarization measurements would distinguish between the Synchrotron with Ordered B-field (SO) and the remaining two distributions

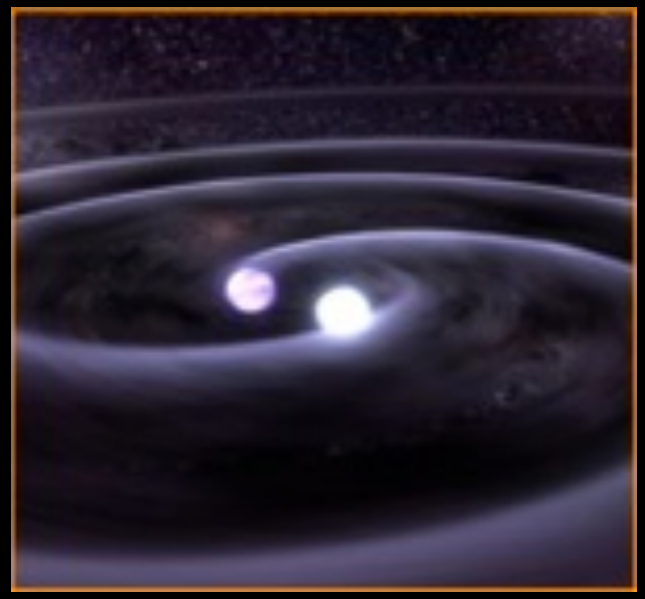


(Toma+09)

Probe the physics of multimessenger events

Gamma-ray observations have played crucial role in all MMA observations

- neutrinos + γ-rays from SN1987A
- gravitational waves + γ-rays from GW170817/GRB 170817A
- neutrinos + γ-rays from TXS 0506+056



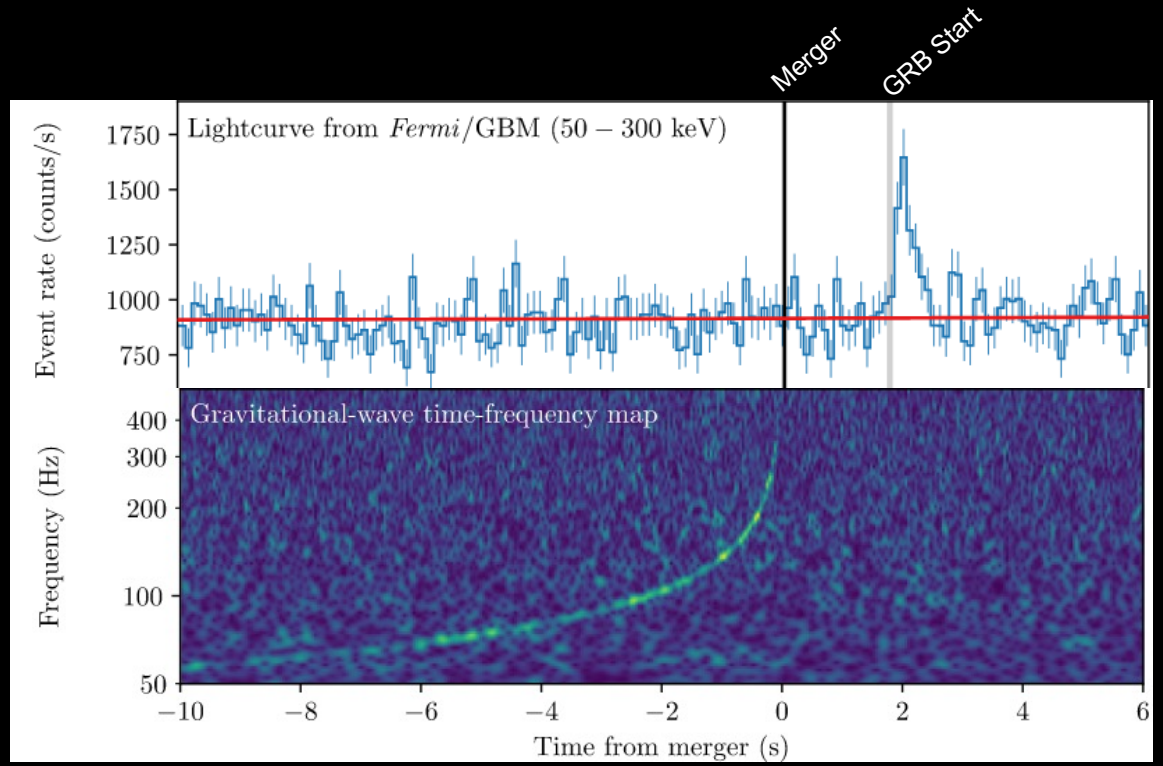
MMA gives unique insights into:

- the origin of high energy neutrinos
- the origin of heavy elements
- tests of fundamental physics

Probe the physics of multimessenger events

Goal: COSI will detect and localize ≥10 SGRBs in a 2-year mission

- COSI's <1.0° localizations provided in <1 hr will enable robust follow-up campaigns of GRB afterglows and kilonovae



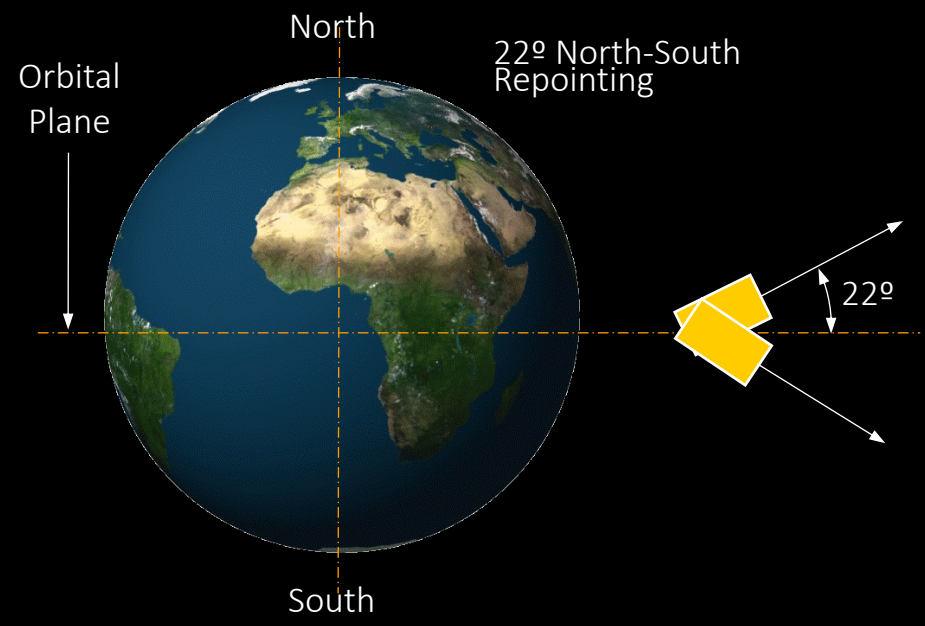
Abbott, et. al. 2017 arXiv:1710.05834

COSI Requirements & Measurement Goals

	Characteristic	Requirement or measurement goal
Goals 1&2 Primarily	Energy Resolution (FWHM)	• 6 keV at 511 keV (FWHM/E = 1.2%) • 9 keV at 1.157 MeV (^{44}Ti) (FWHM/E = 0.8%)
	Narrow Line Sensitivity (2 yr, 3σ, point source) 0.511 MeV 1.8 MeV	[photons cm^{-2} s^{-1}] • 1.2x10^{-5} (Galactic bulge is 100x brighter than requirement level) • 3x10^{-6} (Galactic ^{26}Al flux is 230x brighter than requirement level)
	Angular Resolution (FWHM)	• ~2° at 1.8 MeV (^{26}Al, ~2x better than COMPTEL)
Goal 3	Polarization MDP	• 50% for point source fluxes at levels ≥1.4x10^{-10} erg cm^{-2} s^{-1}
	Accreting BH polarization	• Reaches bright AGN in 2 yr: Cen A, 3C 273, NGC 4151 • Reaches several persistent Galactic BHs (plus transients)
	GRB polarization	• >30 GRBs with polarization measurements (goal in 2 yr)
Goal 4	Short GRB detection, localization, and reporting	• ≥10 short GRBs (goal in 2 yr) • <2.5° localizations provided in <1 hr

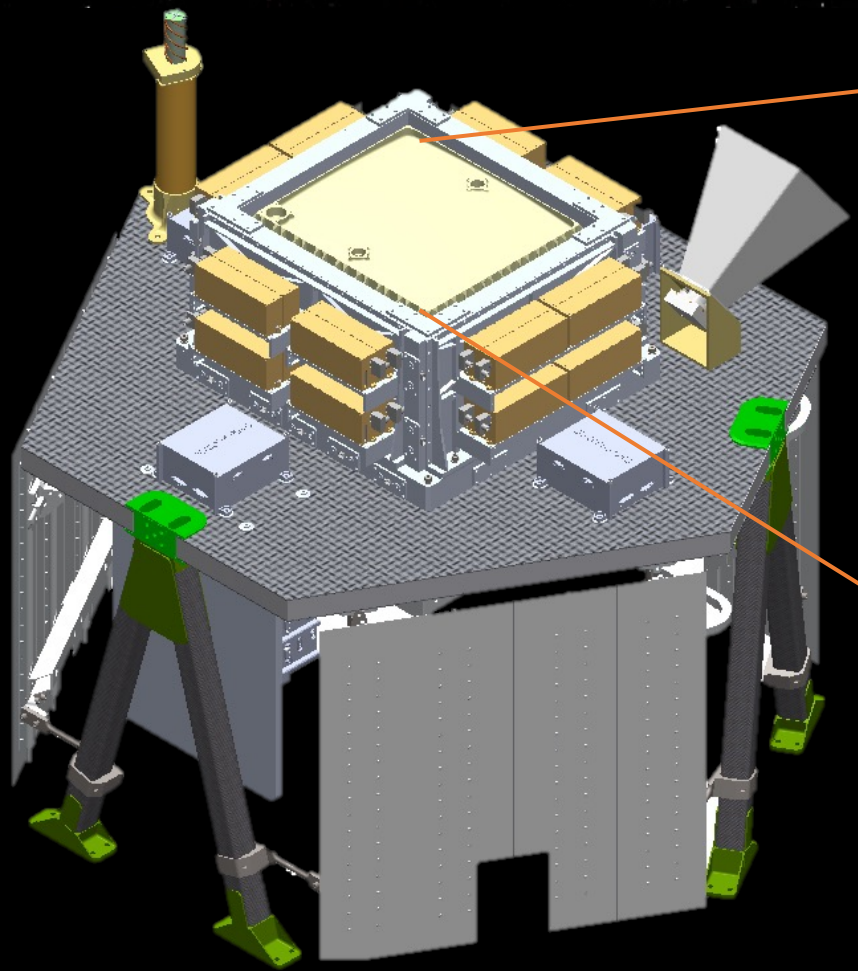
COSI orbit and observing modes

- Near-equatorial and low-Earth orbit to minimize background
  - Targeting 0° orbital inclination
  - 550 km altitude
- Survey mode
  - North-South repointing (±22°) every 12 hours to cover the whole sky every day

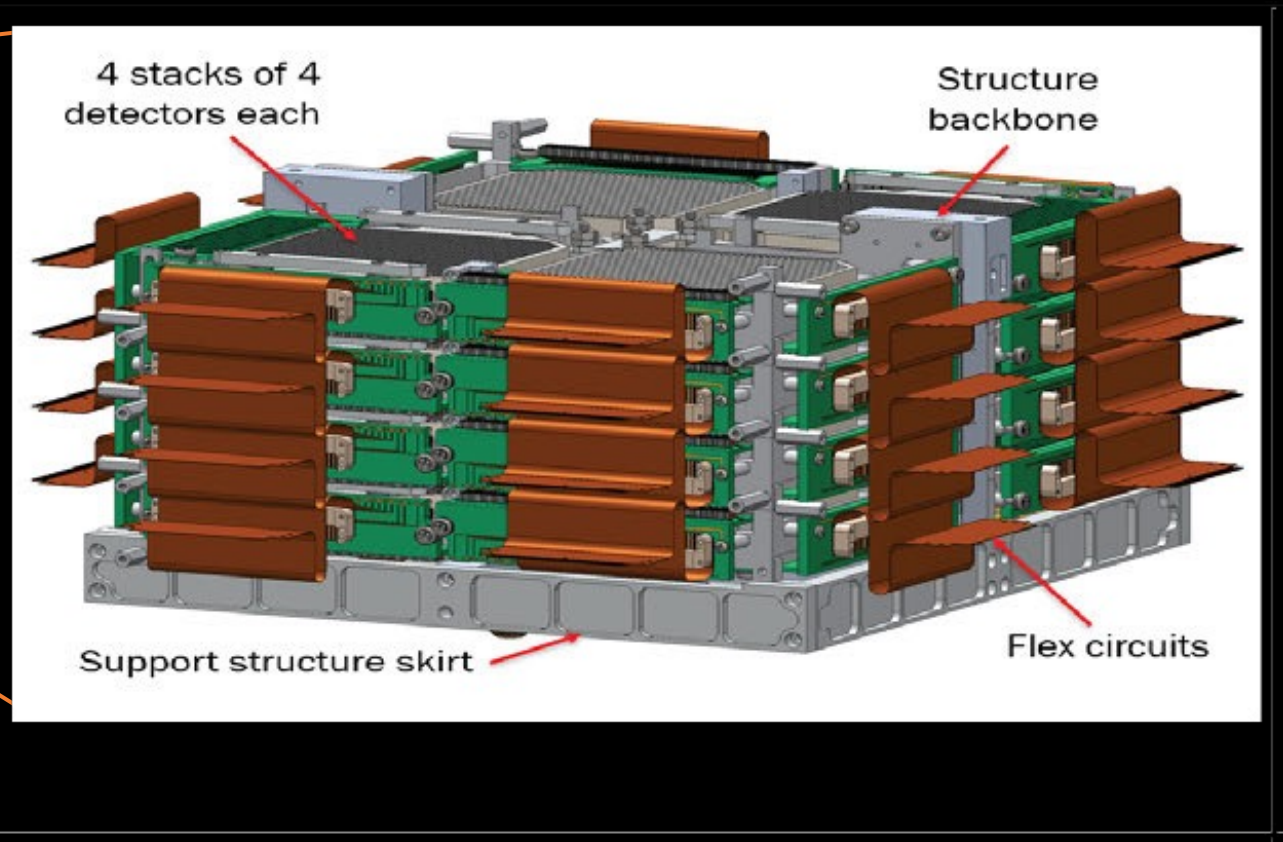


- Constant Zenith Angle (CZA) mode
  - CZA mode will be used to maximize coverage of interesting events
  - Plan to respond to targets of opportunity (TOOs) with CZA mode

COSI Instrument



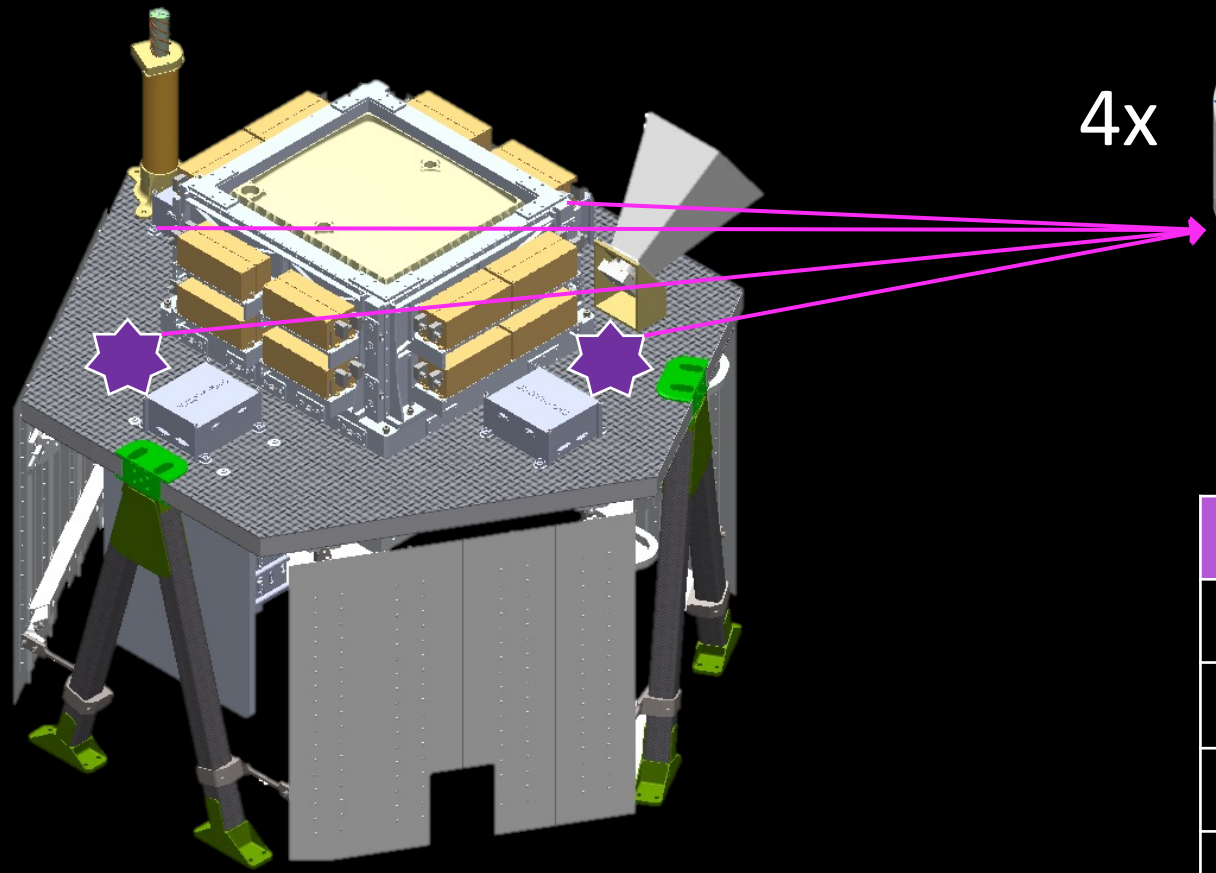
COSI payload and spacecraft



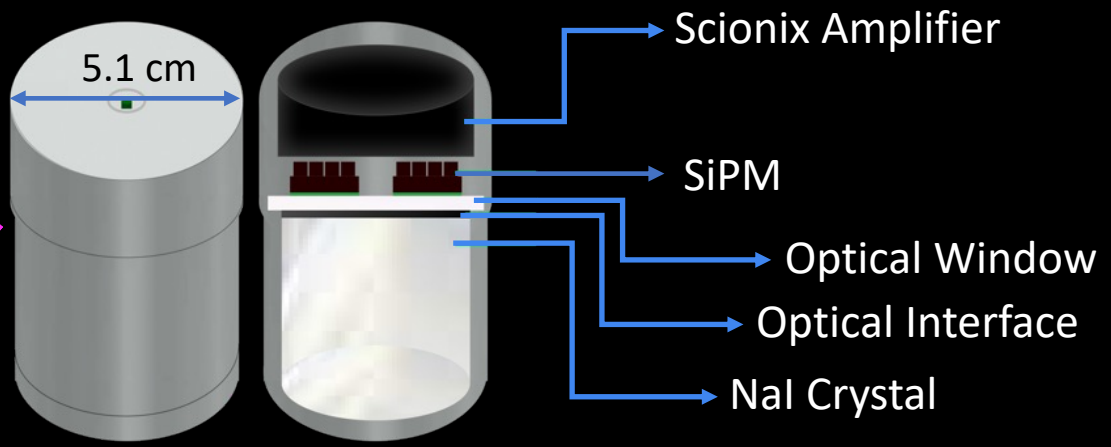
COSI 16 GeDs (64 strips per side)

Background and Transient Observer (BTO)

- Student led collaboration
  - Student lead: Hannah Gulick (UC Berkeley)



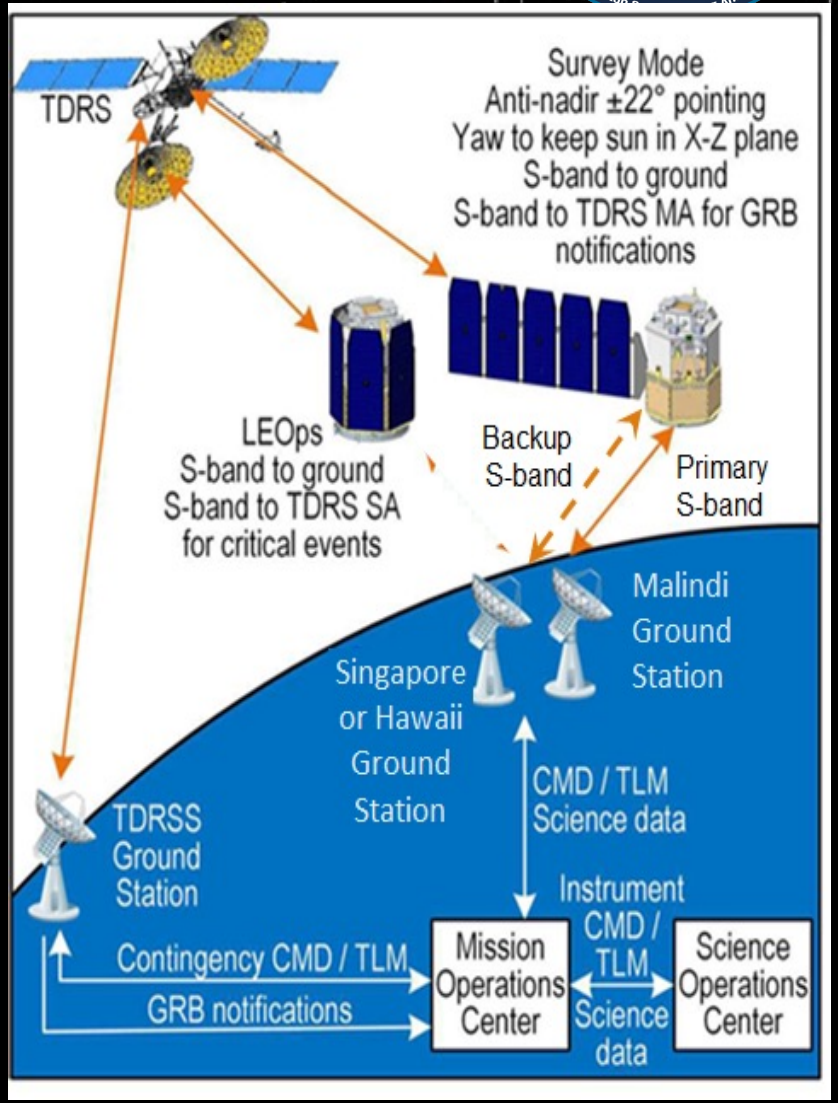
4x



Characteristic	Requirement
Energy Range	30 keV to 2 MeV
Energy Resolution	15—20% at 662 keV
Sky Coverage	>2π
Localizations	~30 degrees over 75% of the sky

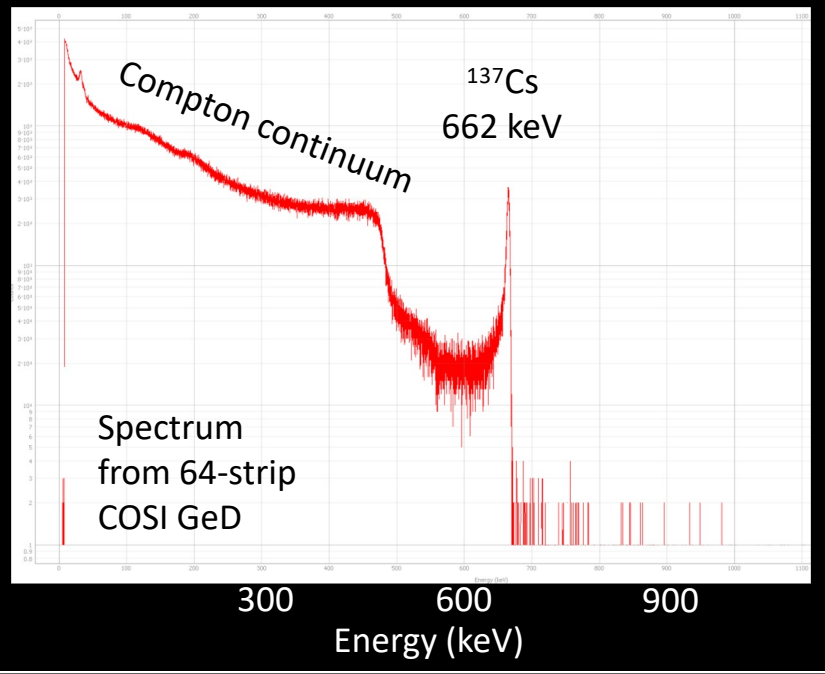
Ground Communications and Data Link

- MOC and SOC at UC Berkeley
- Ground stations to accommodate 6.3 Gbits/day (59 kbps science data)
  - Primary: Malindi ground station
  - Secondary: Singapore ground station
- Plan for transient alerts
  - Detection in at least 2 of 5 BGO shield segments
    - Time binning and threshold level TBD, but expect approximately one alert per day
  - Buffered germanium data selected and sent down via Tracking and Data Relay Satellite
  - Automatic ground processing for GCN notifications



Current Status & Schedule

- Payload
  - **GeDs:** Received 64-strip GeD at UC Berkeley
  - **ASIC:** Flight ASIC in fabrication; delivery expected Sep. 2023
  - **Cryostat:** Detector holder vibe-tested; other design upgrades
  - **Anticoincidence shields:** Order placed for BGO for one side wall (EM)
  - **Cryocooler:** Order placed for FM (10-month lead time)
- Spacecraft: Few changes from previous mission



Activity	2022	2023	2024	2025	2026	2027	2028
	A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Key-Decision Points			3/25 KDP-C		10/5 KDP-D	4/30 KDP-E	
Mission Milestones		1/17 SRR	2/26 PDR	12/3 CDR	9/4 10/16 SIRPER	PSR 3/24	LRD 8/27 10/1 PLAR
COSI Instrument Milestones			2/9 IPDR	11/8 ICDR			

Currently in Phase B and passed Systems Requirements Review (SRR)

PDR in 2024 February

CDR in 2024 December

Payload I&T

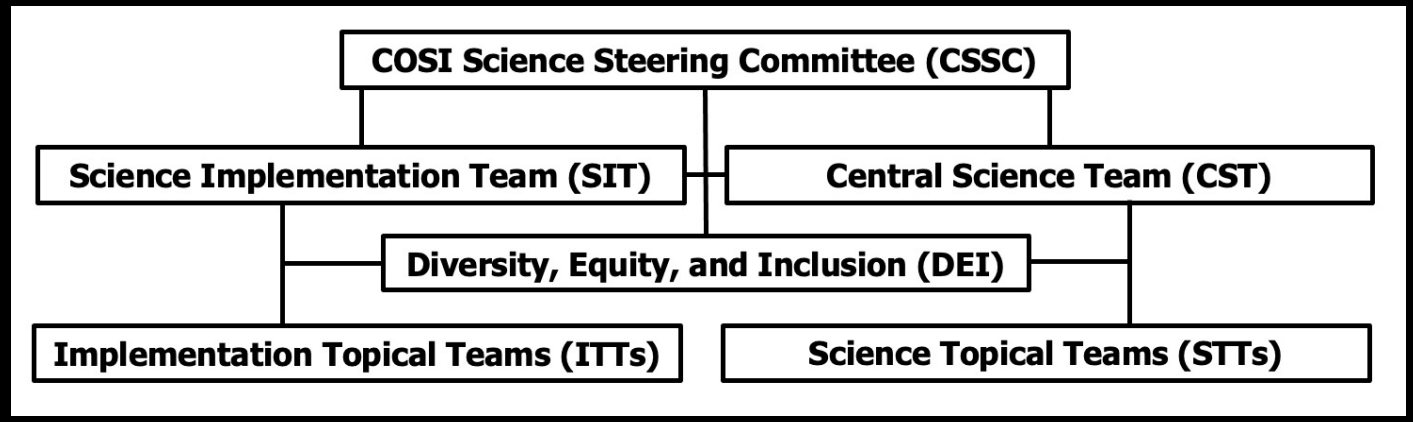
System Integration Review in 2026 Sept

Launch!

Science Team

Subgroup	Lead	Co-Leads	Technical Expert
Positrons	Carolyn Kierans (GSFC)	Thomas Siegert (JMU, Germany)	Thomas Siegert (JMU, Germany)
Nucleosynthesis	Thomas Siegert (JMU, Germany)	Chris Fryer (LANL)	TBD (UCB)
GRBs	Eric Burns (LSU)	Steve Boggs (UCSD), Dieter Hartmann (Clemson)	Alyson Joens (UCB) Eliza Neights (GSFC)
Galactic	Julien Malzac (IRAP, France)	Chris Karwin (GSFC)	Chris Karwin (GSFC)
Extragalactic	Marco Ajello (Clemson)	Fabrizio Tavecchio (INAF, Italy)	Jarred Roberts (UCSD)
Dark Matter	Tad Takahashi (IPMU, Japan)	Fabrizio Tavecchio (INAF, Italy), Shigeki Mastumoto (IPMU, Japan), Tom Melia (IPMU, Japan)	Thomas Siegert (JMU, Germany)

- CSSC:
  - John Tomsick
  - Andreas Zoglauer
  - Dieter Hartmann



Conclusions

- Spectrometer, imager, and polarimeter sensitive to gamma-rays in the 0.2-5 MeV bandpass launching in 2027
- Will revolutionize our understanding of the creation and destruction of matter in our Galaxy and beyond
  - Reveal Galactic element formation
  - Uncover the origin of Galactic positrons
  - Gain insight into extreme environments with polarization
  - Probe the physics of multimessenger events
- Lab work ramping up as we approach PDR in Feb. 2024
- Yearly data challenges are an opportunity for community involvement and DC1 has been released
  - https://github.com/cositools/cosi-data-challenge-1

Gamma Ray Science Interest Group

- Goal: Advise NASA regarding current and future needs of the hard X-ray and gamma-ray astrophysics community

Join GR SIG!!!

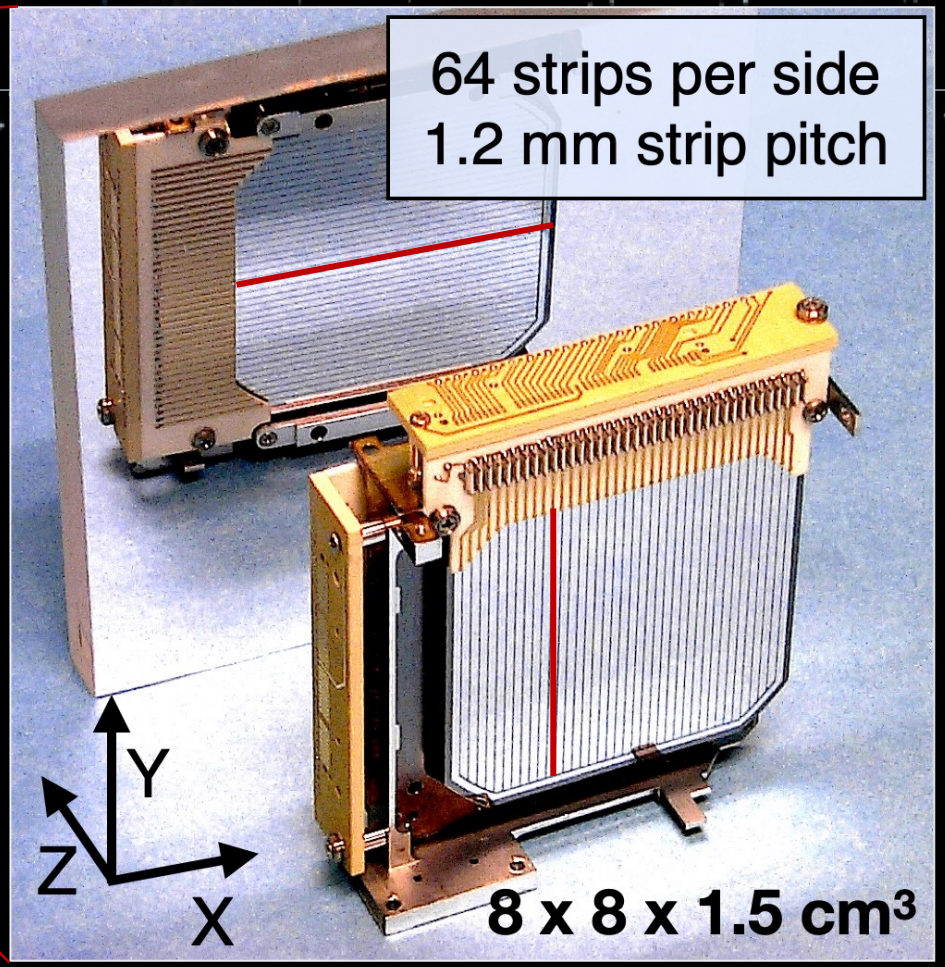
Thank you!


COSI
Gamma-ray Space Explorer
The Compton Spectrometer And Imager
UCB - UCSD - LSU - Clemson - NASA - NRL - NGSP
MTHU - JMU - Nagoya - IPMU - Kavli - INAF - IMAP - LANL

Backup


COSI
Gamma-ray Space Explorer
The Compton Spectrometer And Imager
UCB - UCSD - LSU - Clemson - NASA - NRL - NIGSN
MTHU - JMU - Nagoya - IPMU - Kavli - INAF - IMAP - LANL

COSI Instrument



- Germanium detectors (GeDs)
  - Large field-of-view
    - instantaneous: >25% of the sky
  - Excellent energy resolution
  - Inherent sensitivity to polarization