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Julius-Maximilians-UNIVERSITÄT WÜRZBURG

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The Compton Spectrometer and Imager (COSI)

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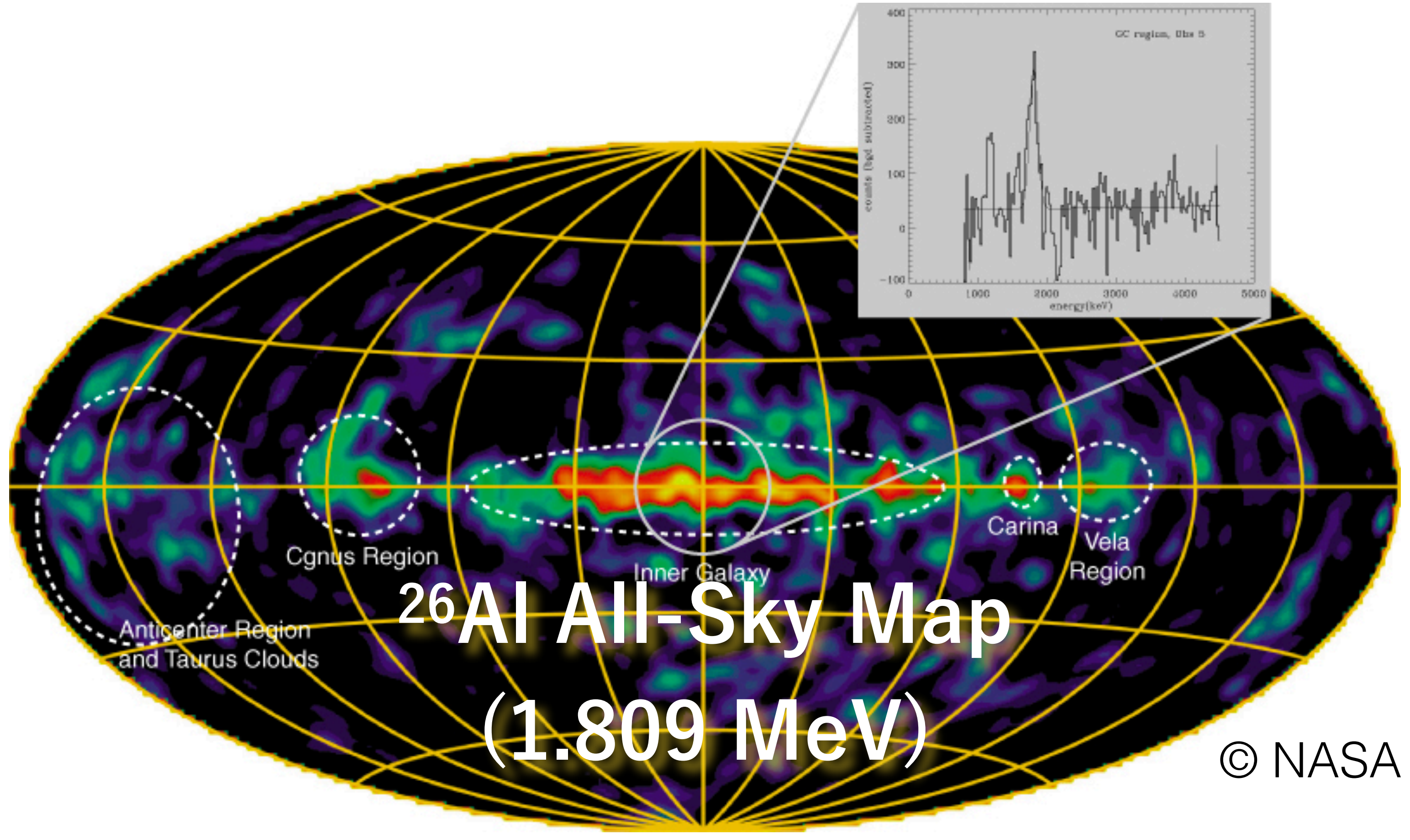
On behalf of the COSI Team

MeV gamma-ray astrophysics and its sensitivity gap

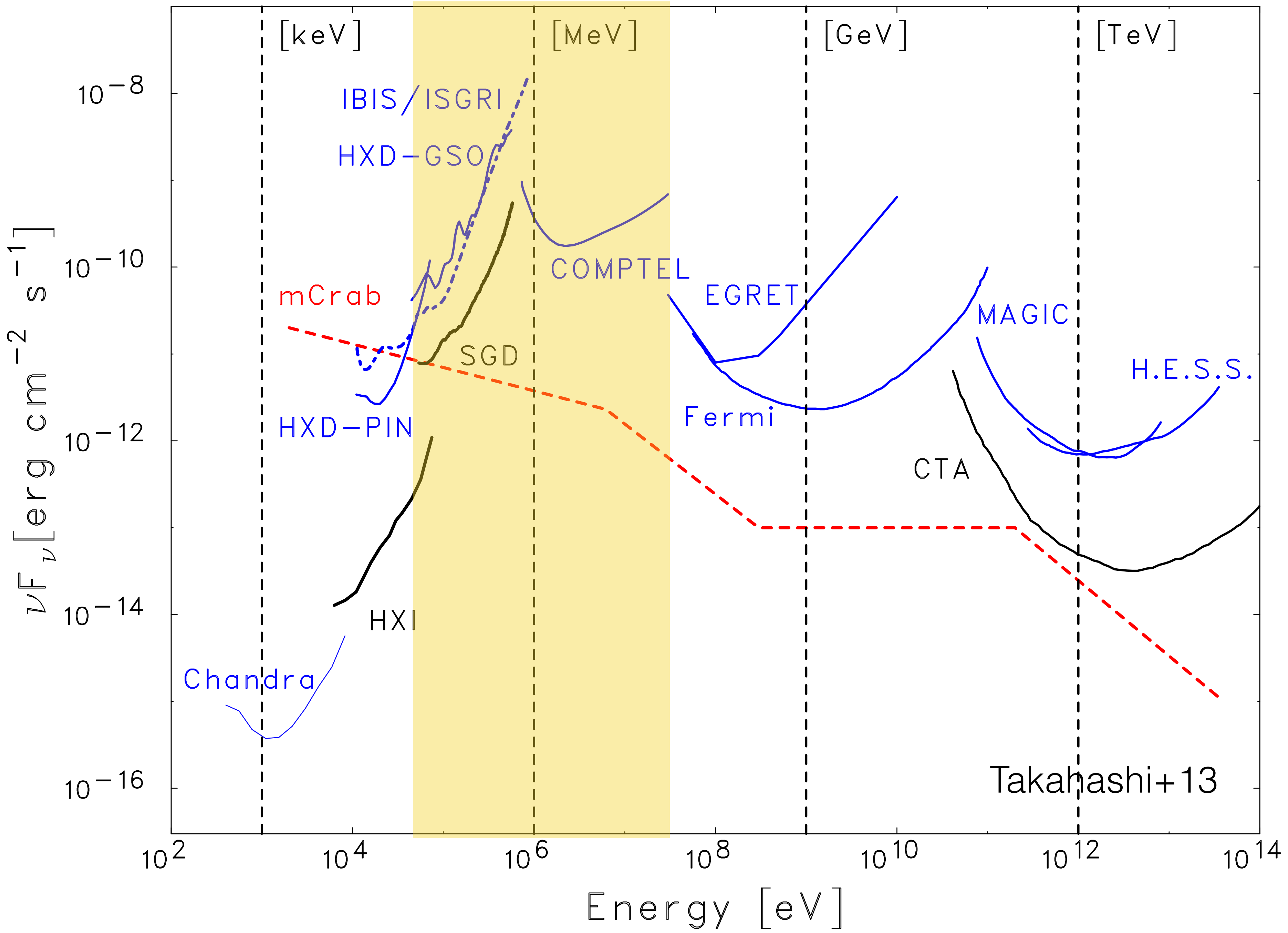
The origin of matter in the Universe

- Nucleosynthesis through nuclear gamma-ray line observations
- Anti-matter universe from e^+e^- annihilation line
- MeV-scale DM matter indirect search



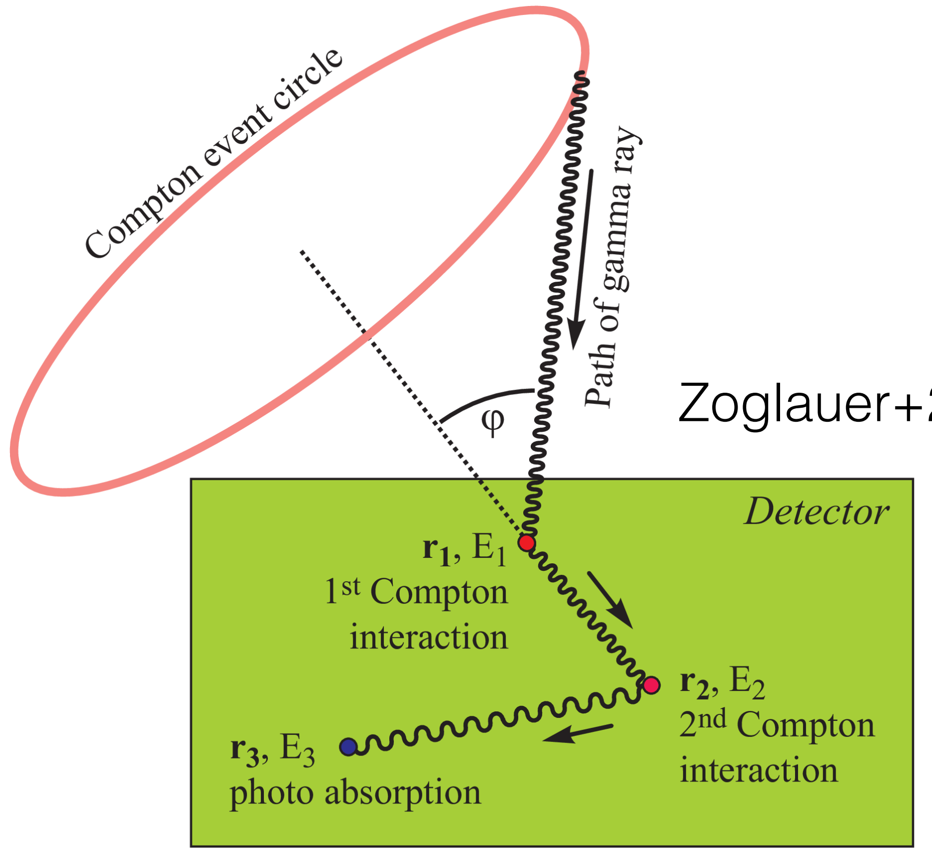
Extreme astrophysical environments

- Gamma-ray bursts
- Cosmic particle accelerators (BH, pulsar, binary etc)
- Low-energy cosmic-rays (IC, Bremsstrahlung, de-excitation gamma-ray lines)

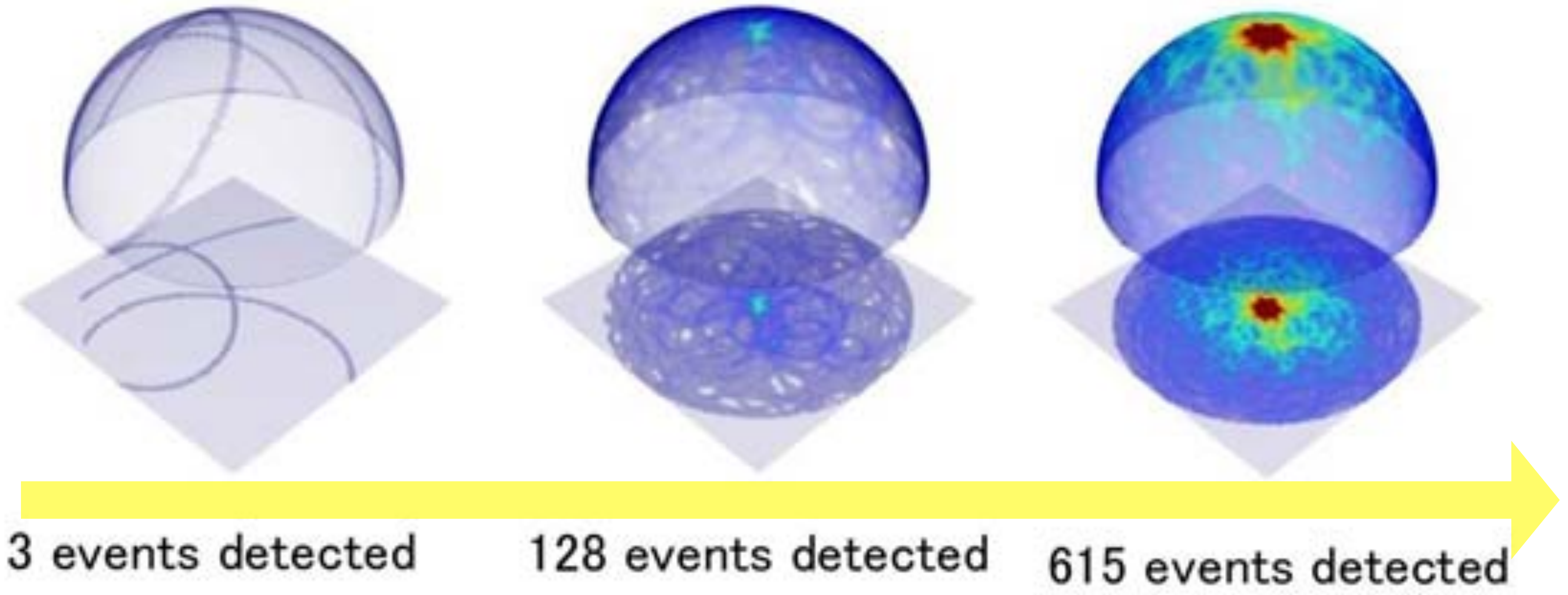


The Compton Spectrometer and Imager (COSI)

- ✦ was selected as a NASA SMEX satellite to be launched in 2027
- ✦ a Compton telescope observing gamma-rays in 0.2 - 5.0 MeV



Zoglauer+21

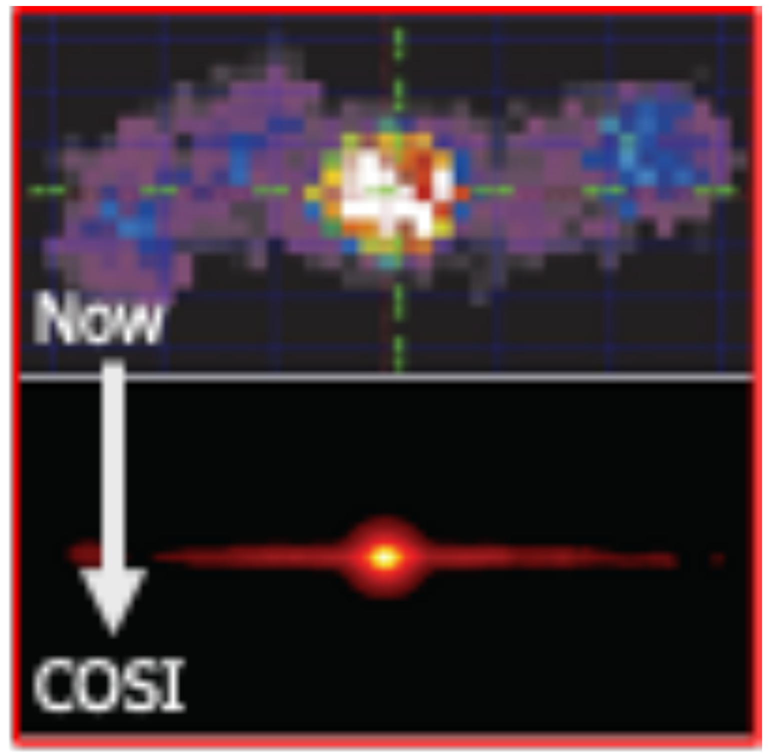


Matuura+14

Key capabilities

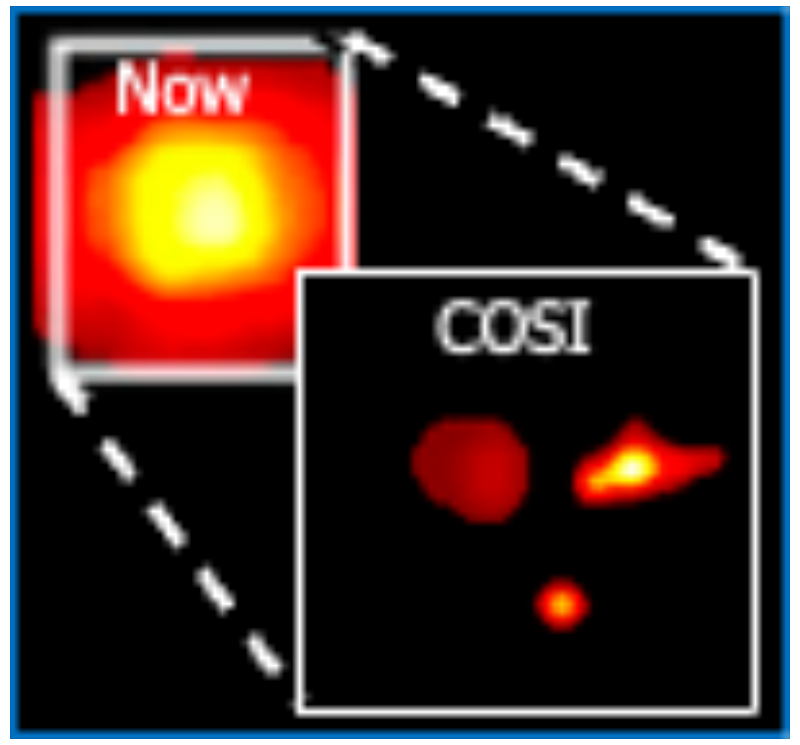
- ✦ Cryogenically-cooled germanium detectors
  ➔ line gamma-ray imaging with excellent energy resolution
- ✦ Instantaneous field-of-view is ~25% of the sky
  ➔ all-sky monitoring (whole sky observation in a day)

Primary Science Goals of COSI



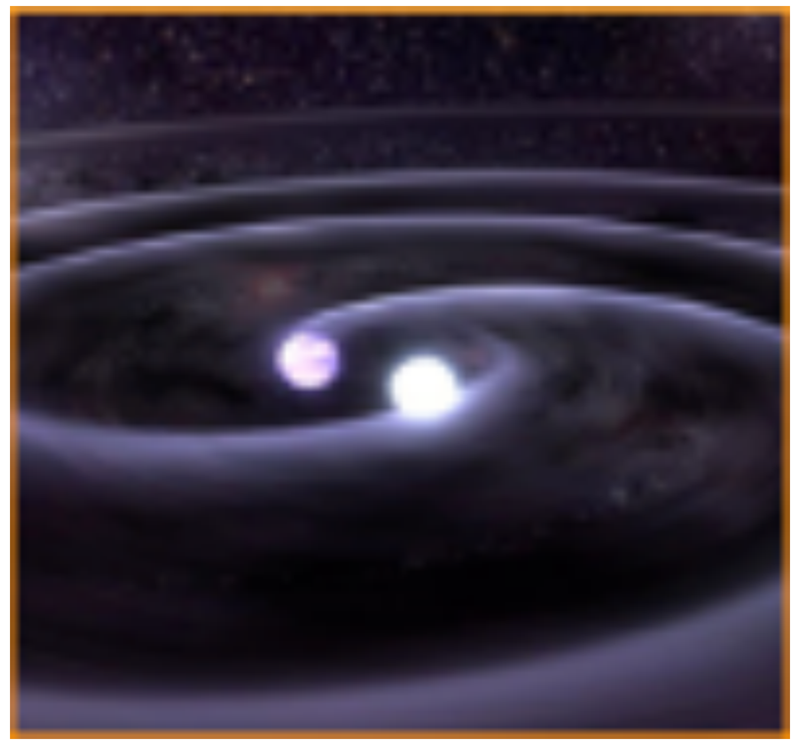
A. Uncover the origin of Galactic positrons

B. Reveal Galactic element formation

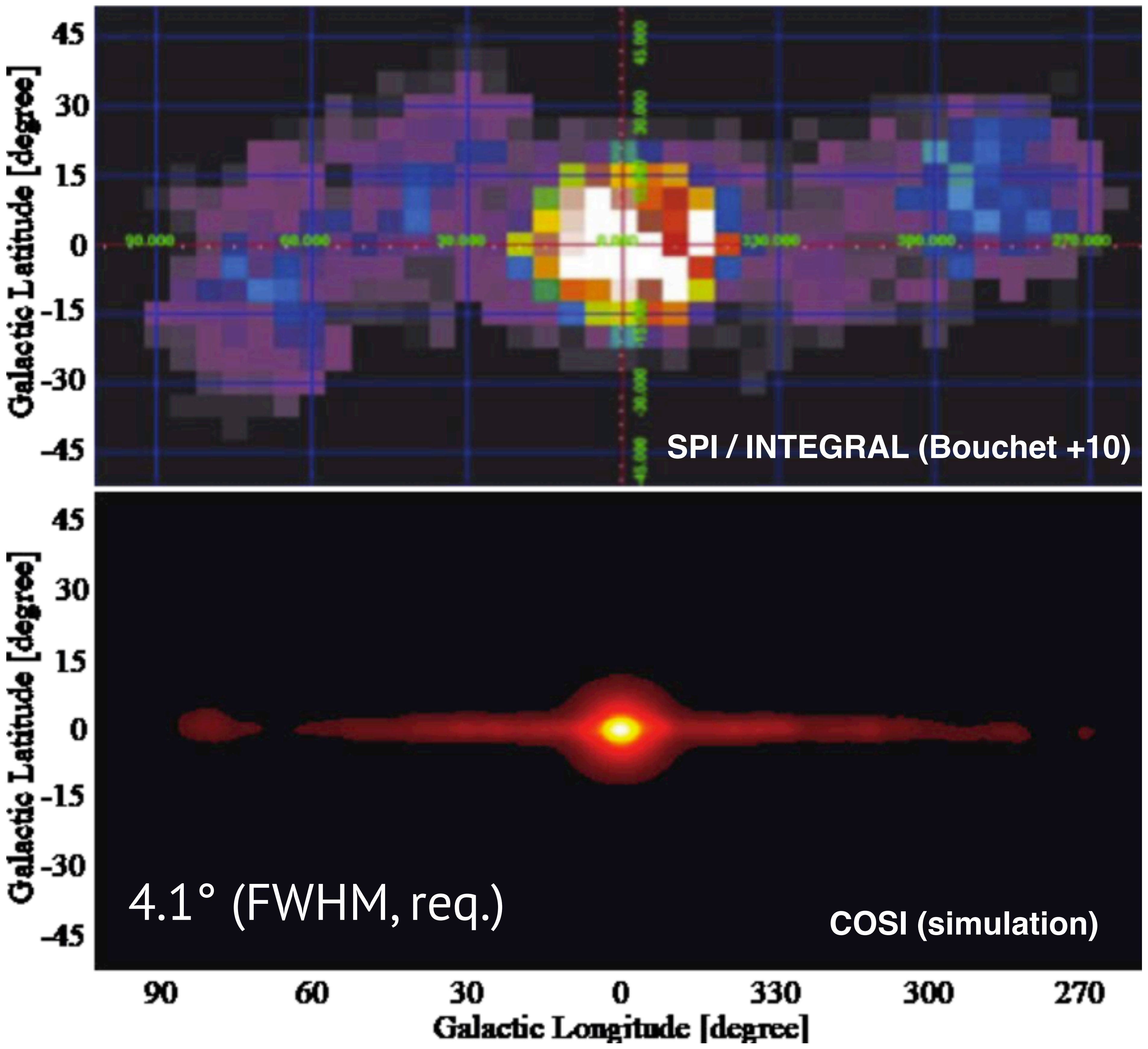


C. Gain insight into extreme environments with polarization

D. Probe the physics of multimessenger events



A. Uncover the origin of Galactic positrons



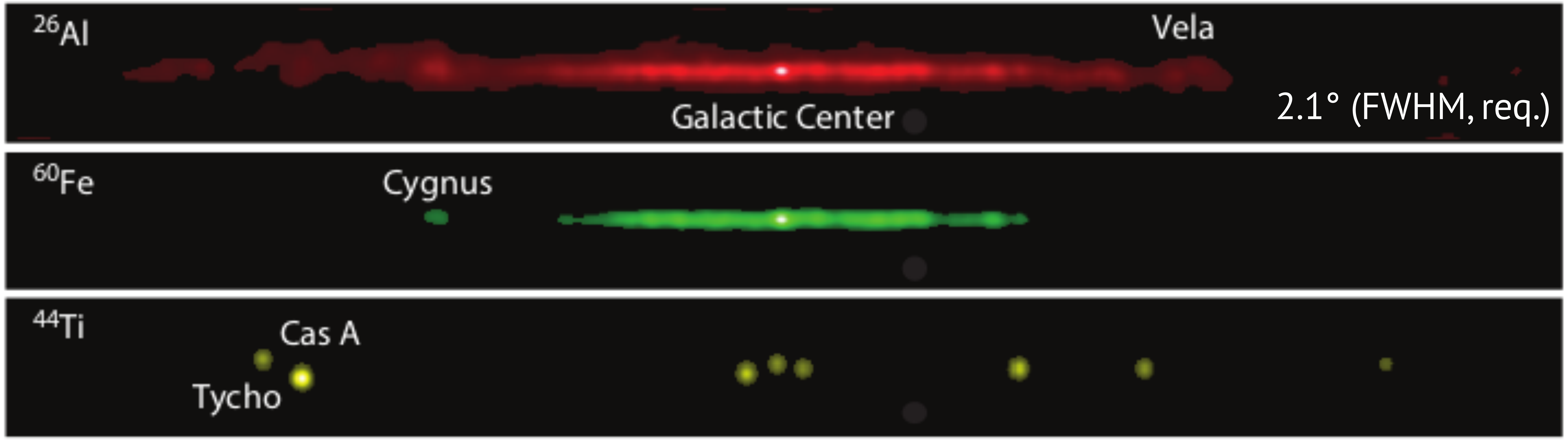
What is the origin of positrons?

- How many positron sources?
  - β+ nucleosynthesis, individual sources, DM?
- Why is the bulge so bright?
- What is the nature of the disk emission?

Observations with COSI

- 511 keV image of the bulge and disk
- The disk-scale height measurement
- Search for individual point sources
- Line/continuum spectroscopy, e.g., red/blue shift, o-Ps continuum emission

B. Reveal Galactic element formation



The tracer of the nucleosynthesis in the universe

Fe-60 (1.173&1.333 MeV, $\tau = 2.6 \times 10^{6}$ yr)

- Core-collapsed supernovae (CCSNe)

Al-26 (1.809 MeV, $\tau = 7.2 \times 10^{5}$ yr)

- massive star wind & CCSNe

Ti-44 (1.157 MeV, $\tau = 60$ yr)

- Young SNe

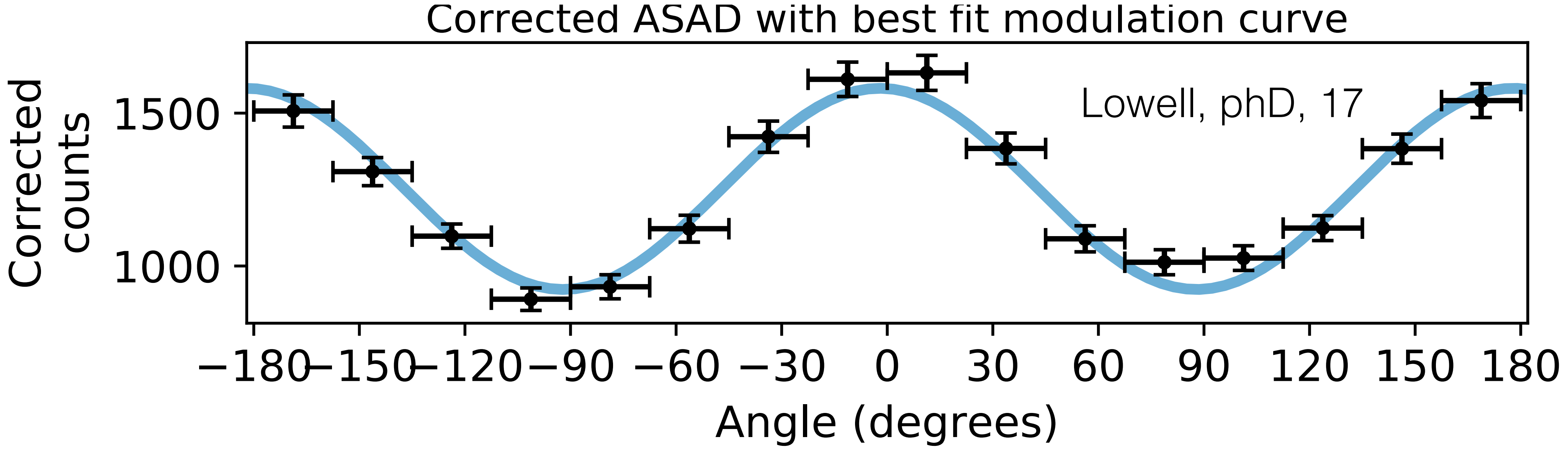
Line gamma-ray imaging with COSI

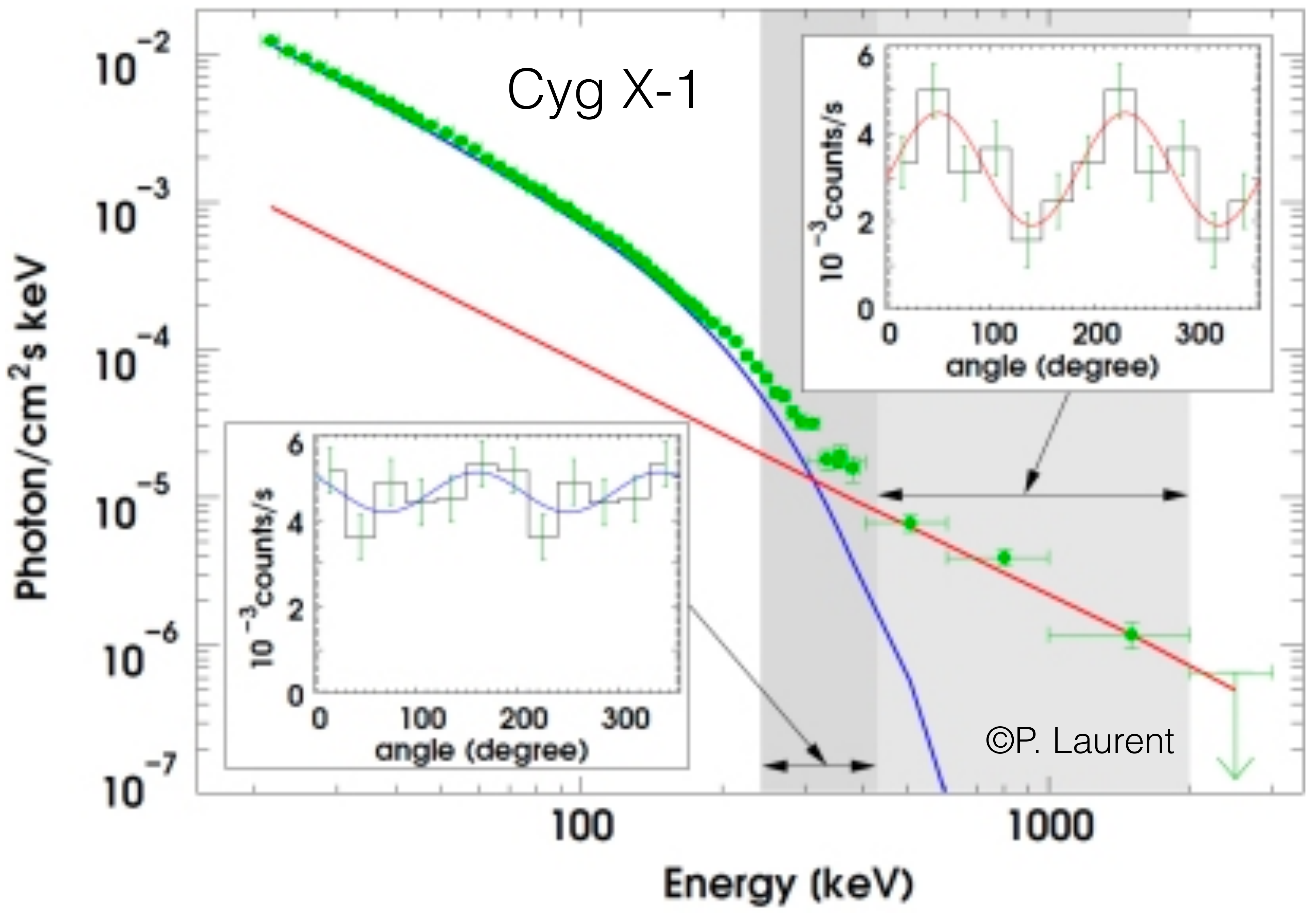
- First all-sky image of Fe-60
- Improved Al-26 image, and correlation with Fe-60
- Search for Ti-44 sources (Cas A, Tycho, SN1897A, etc.)

C. Polarization & D. Multi-messenger events

Polarization measurements with COSI

Azimuthal angle distribution of scattered gamma rays provides the polarization degree/angle





- Measure the polarization of galactic black holes and AGNs with ~20 mCrab, and constrain the emission models (e.g., corona, jet)

Multi-messenger events

- With a large field-of-view, COSI will measure short transient events (+polarization).
- For a short GRB, its localization <2.5 deg will be reported within 1 hour.

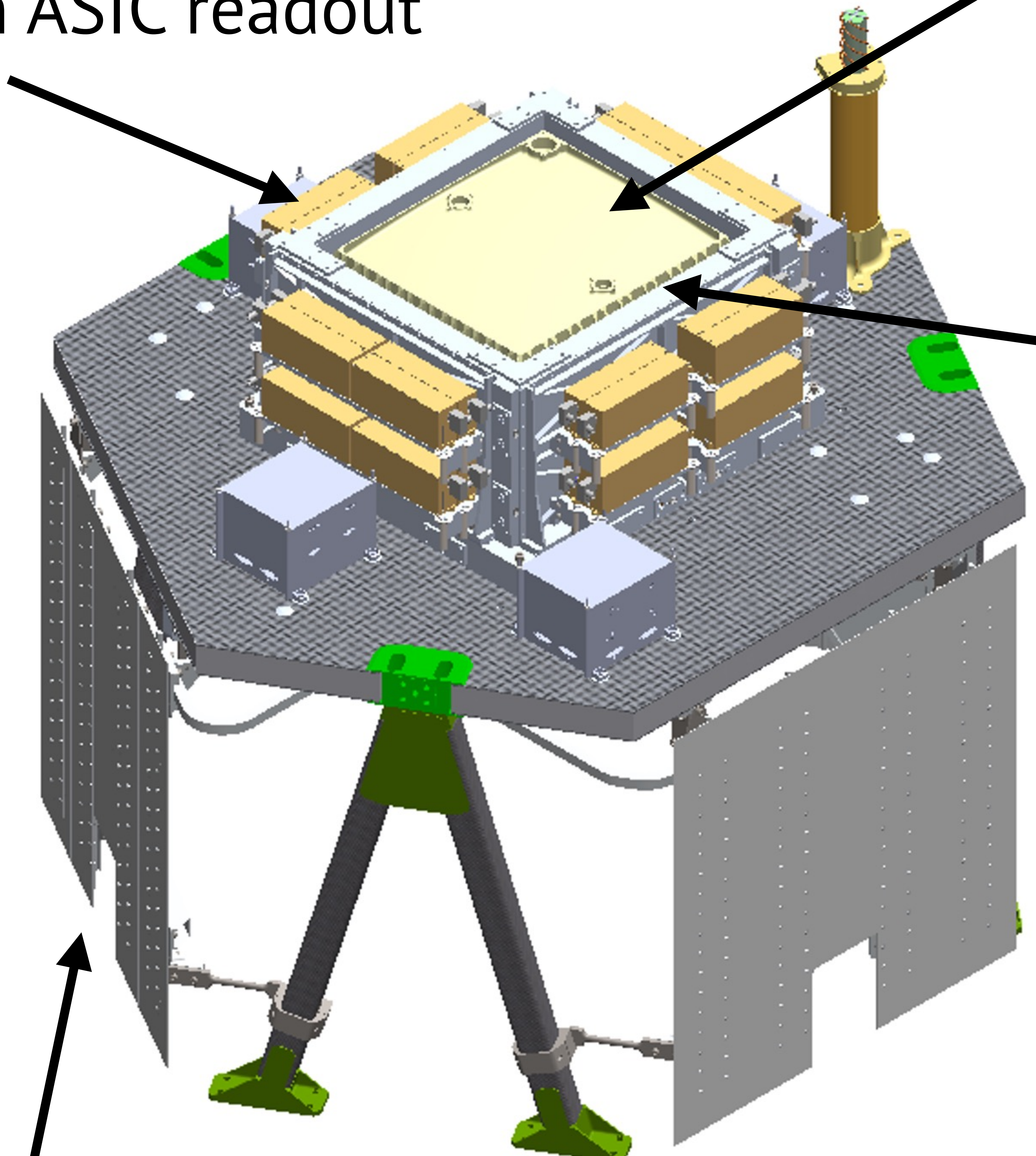
Instrumental Design and Sensitivity

Front-end electronics with ASIC readout

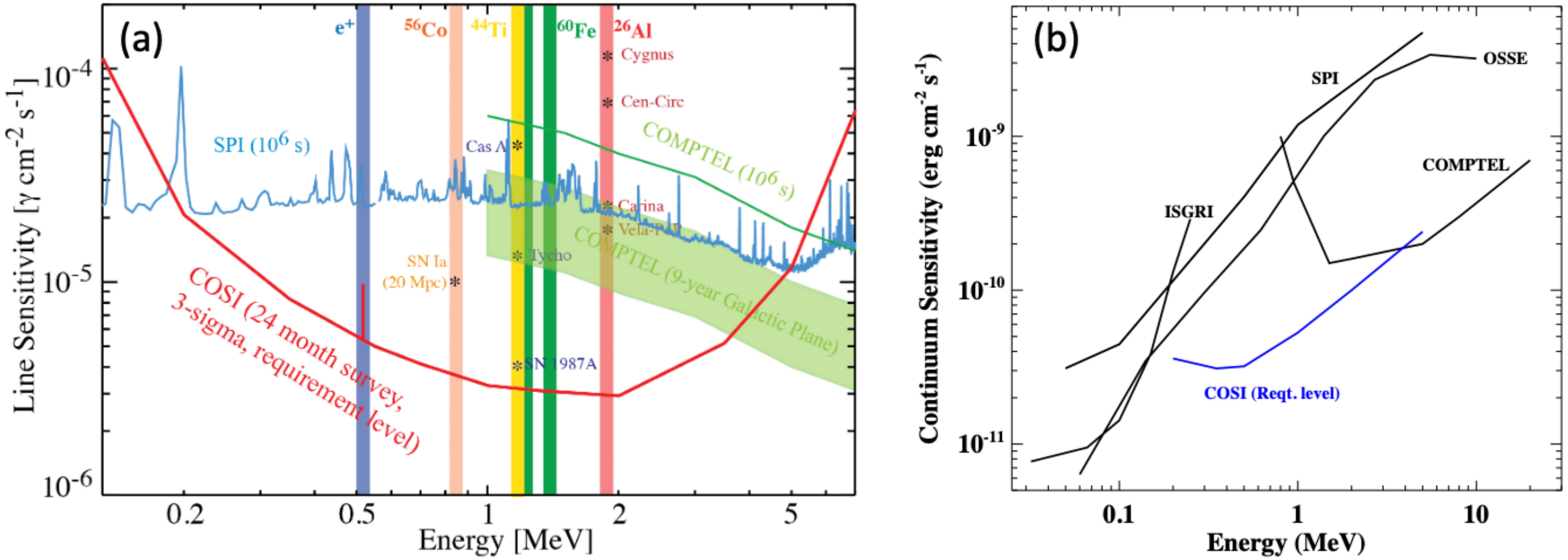
Cryogenically cooled germanium detectors in a vacuum cryostat

- consisting of 16 modules
- The size of each is 8x8x1.5 cm³
- Cooled to < 90K with a mechanical cryocooler

BGO shields for background reduction

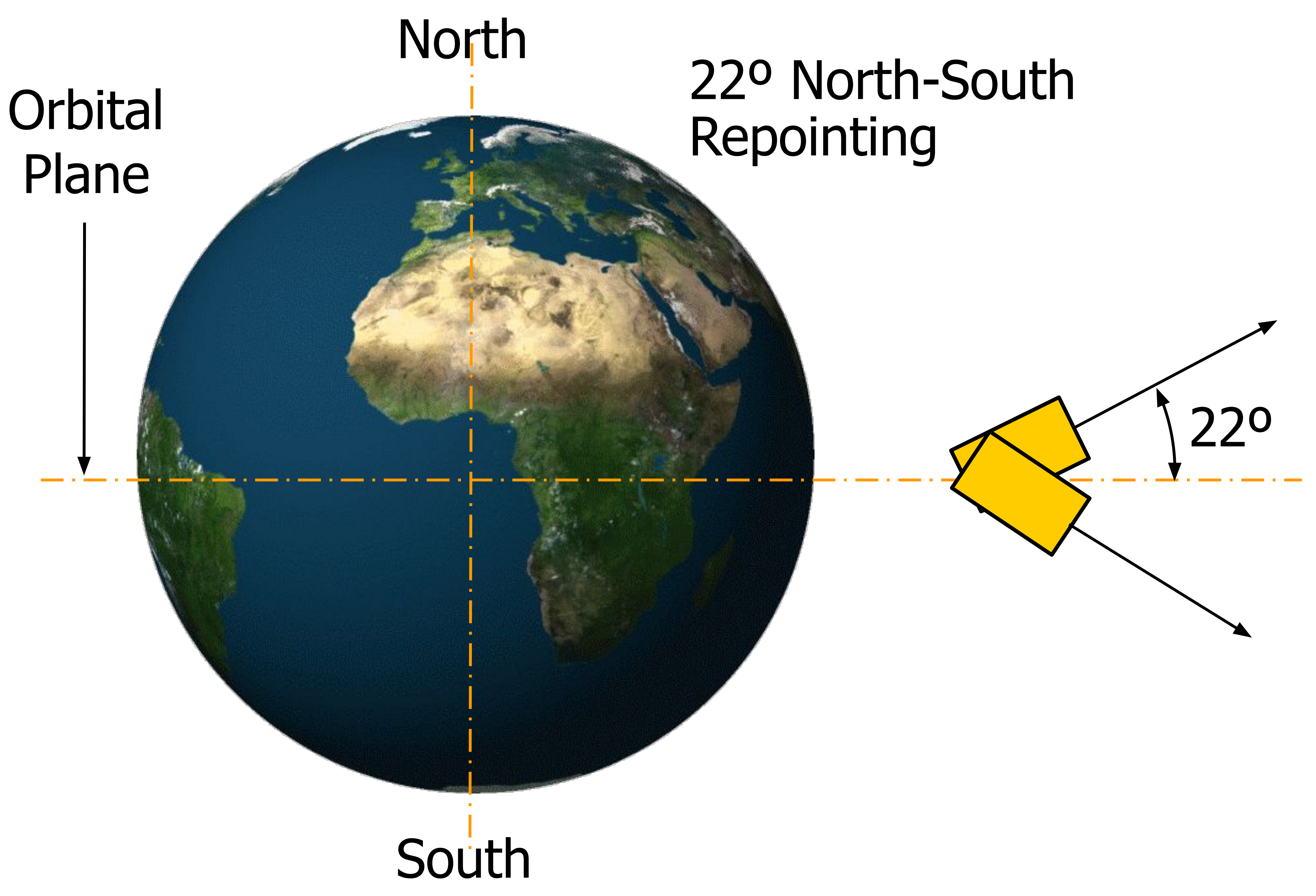


Heat removed by system of heat pipes and radiators



Narrow-line and continuum sensitivity for a point source during 2 years

Operation and sky coverage

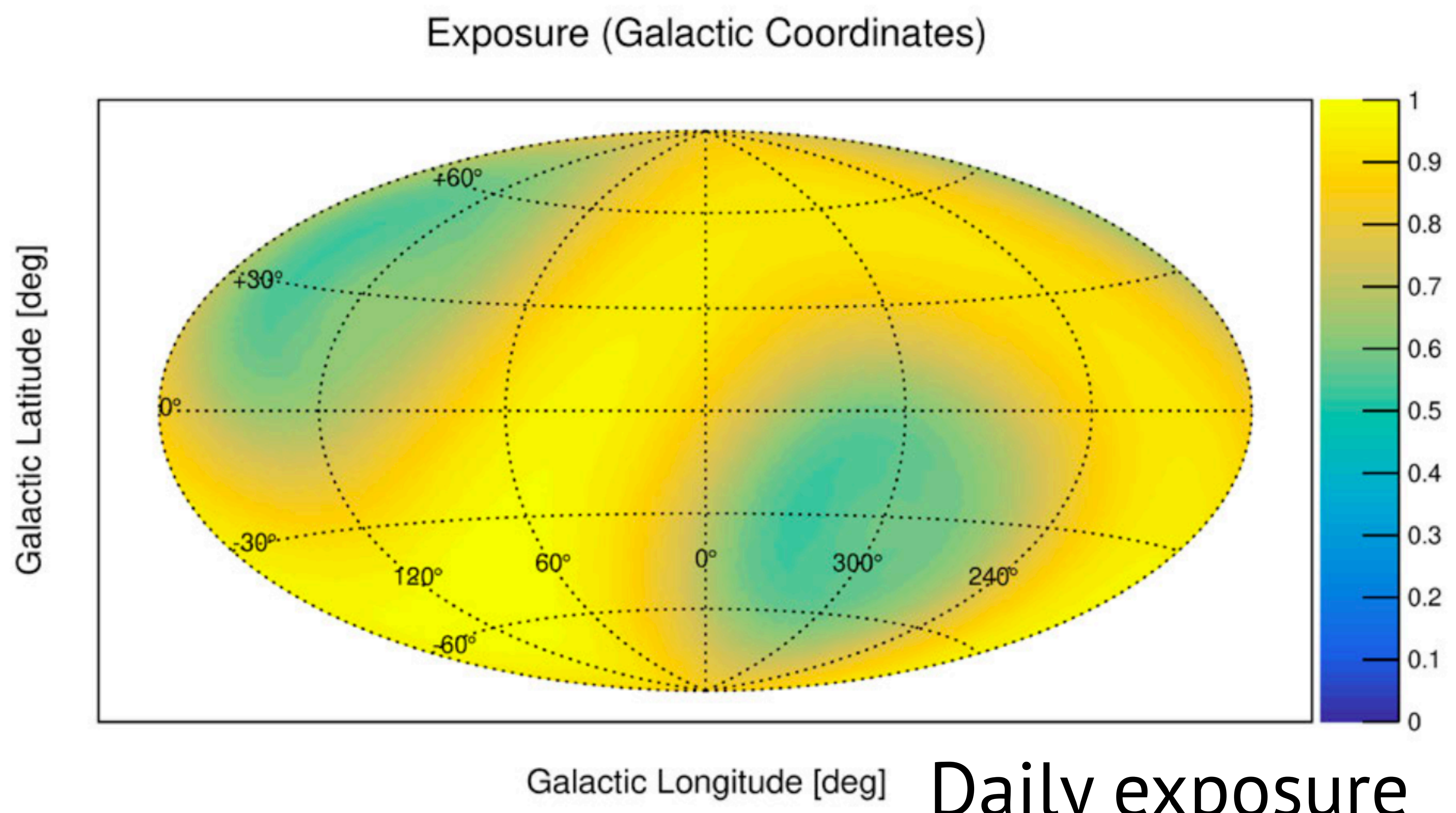


A low-earth orbit

A near-equatorial orbit (to minimize SAA passages)

25% sky coverage in a single shot

The satellite changes its pointing from 22 deg. North to 22 deg. South with 12-hour cycle



Daily exposure

The whole sky is covered in a single day

Ideal for transient event monitor (GRBs), all-sky imaging (511 keV, Al-26)

Current Status

Currently in Phase B

- ✦ passed Systems Requirements Review
- ✦ Preliminary Design Review, Feb. 2024

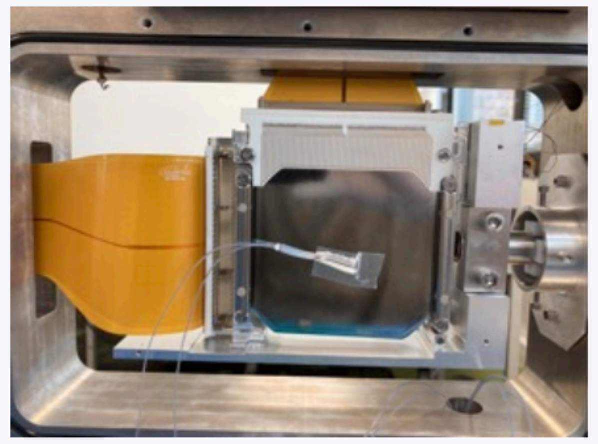
Payload

- ✦ GeDs: Received 3 64-strip GeD at UC Berkeley
- ✦ ASIC: Flight ASIC in fabrication
- ✦ Background Transient Observatory (student-lead project): finalizing the design

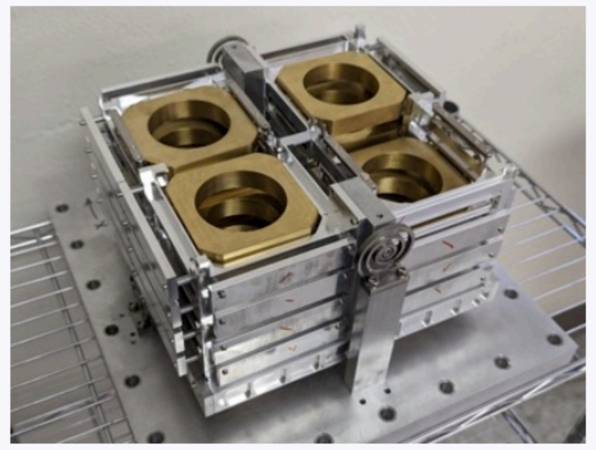
Spacecraft: based on previous missions (ICON)

Pipeline/Analysis tools: yearly released with the simulation dataset (COSI data challenge)

At UC Berkeley/SSL

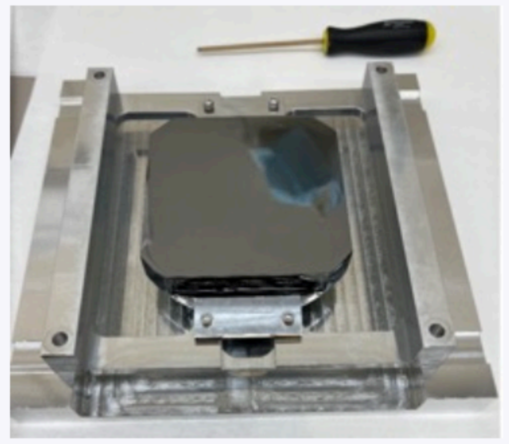


Test cryostats for GeDs



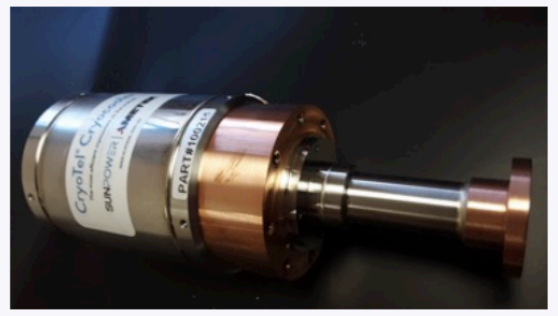
GeD holder assembly

At Ortec (Oak Ridge)



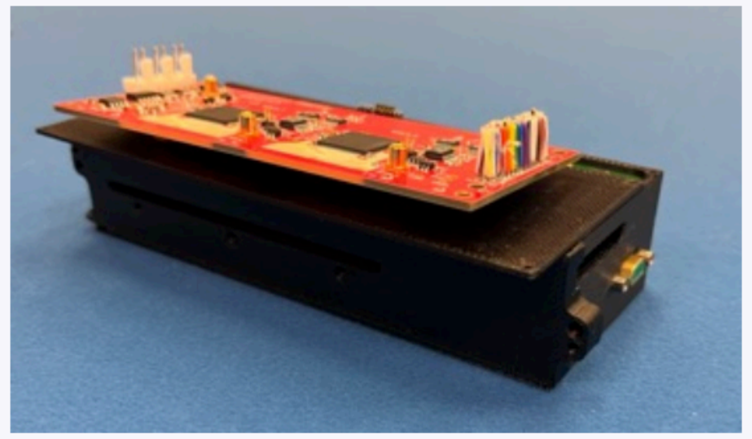
Germanium procurement and processing 64 strip GeDs

At NASA/GSFC

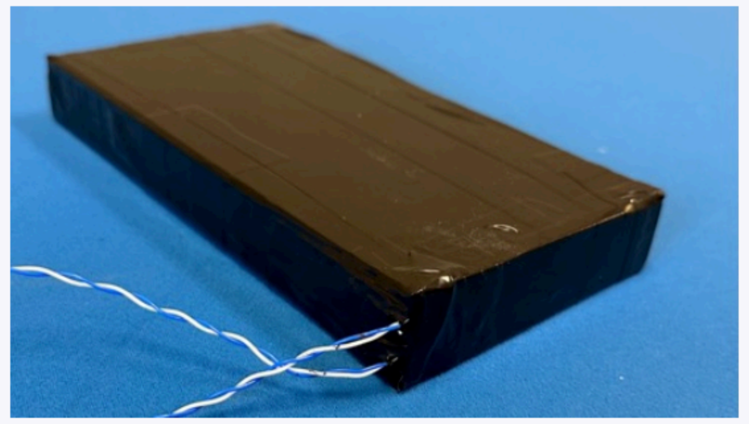


Cryocooler

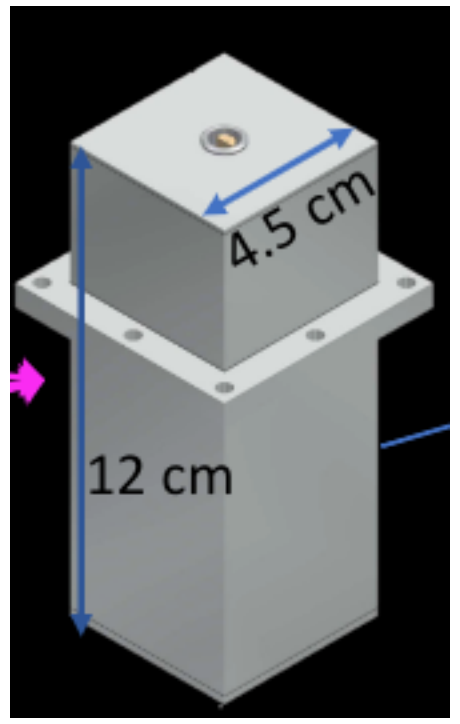
At Naval Research Lab

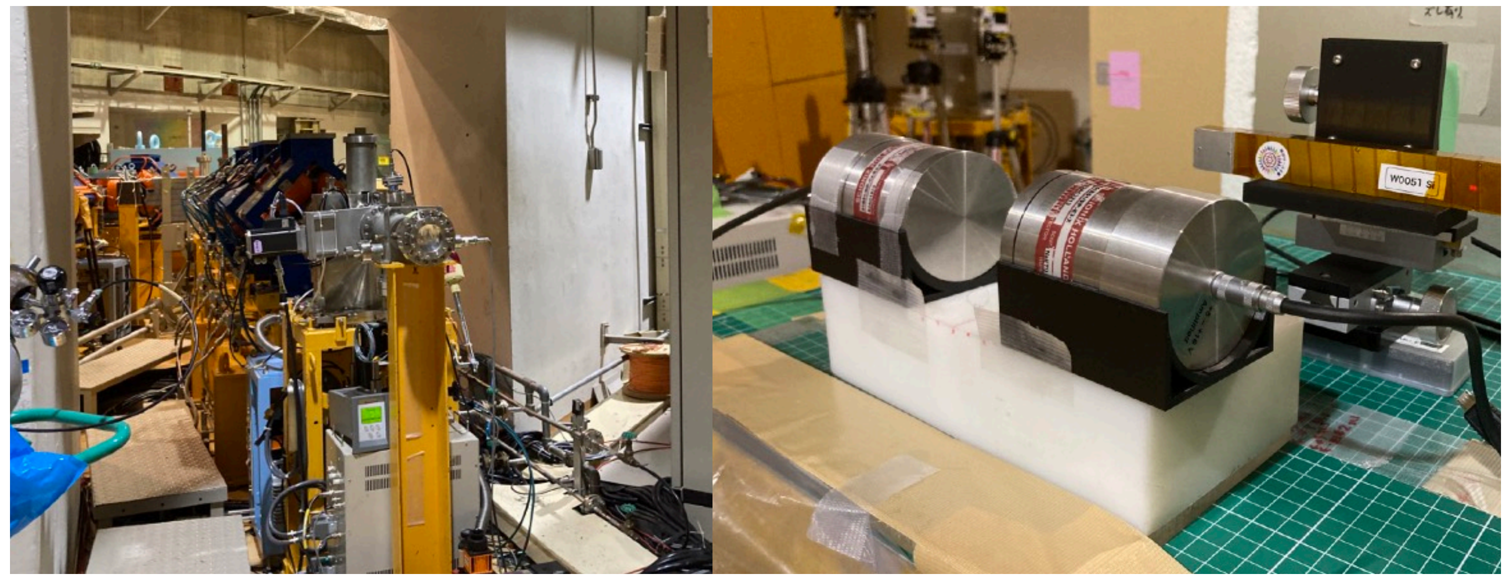


Detector interface board (DIB) with two 32-channel ASICs



BGO scintillators with SiPM readout





BTO detector design & heavy-ion beam test at Japan

COSI tools and yearly data challenges

Two softwares for data analysis and simulation

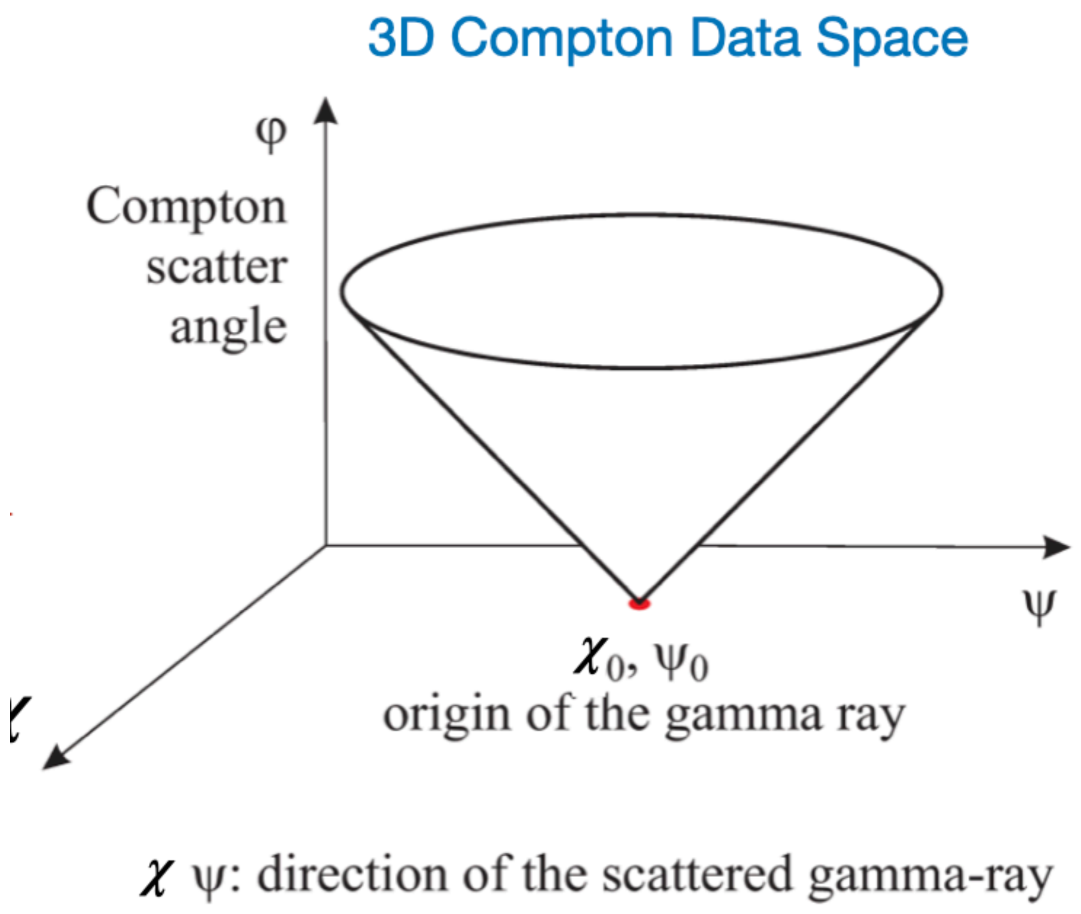
- MEGAlib: raw-level data analysis and simulation
- COSIpy: high-level data analysis (spectrum/image/polarization)

Every year, we perform data challenges, the data analysis of COSI based on simulation data

- 5 data challenges are planned until 2026 before the launch
- Data Challenge 1 (balloon data): https://github.com/cositools/cosi-data-challenge-1
- Data Challenge 2 (late-2023): 3-6 months of simulated satellite observations

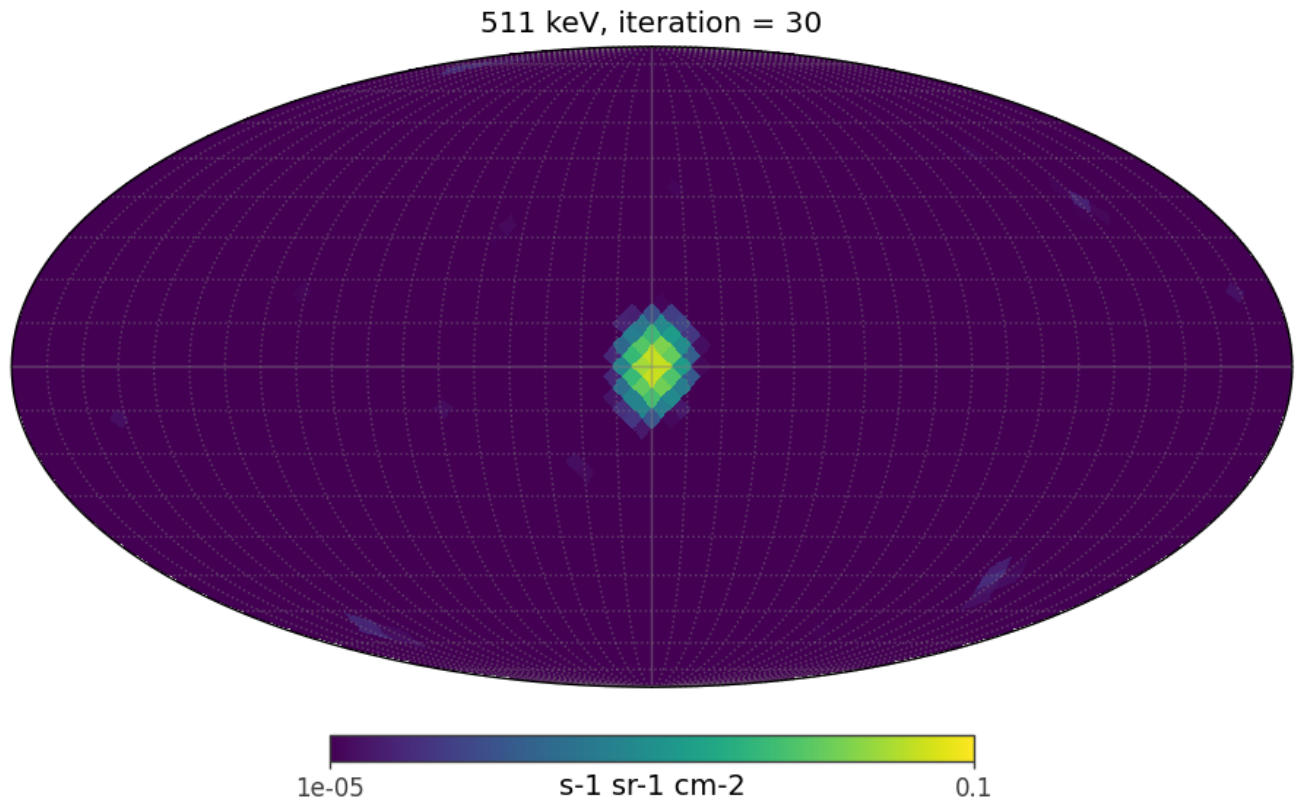
DC2 Example

Image deconvolution of 511 keV line

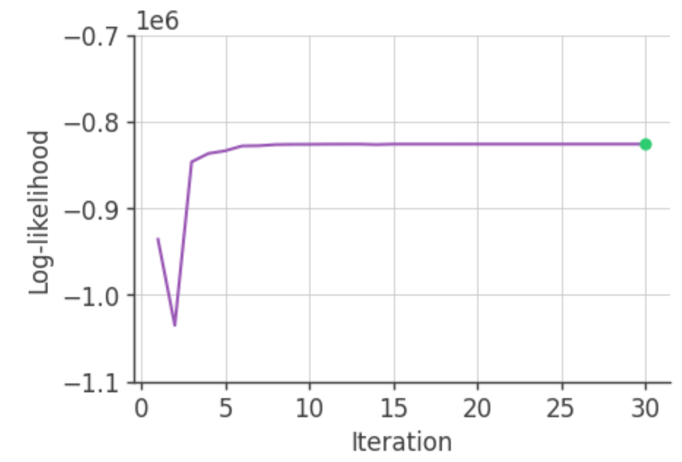


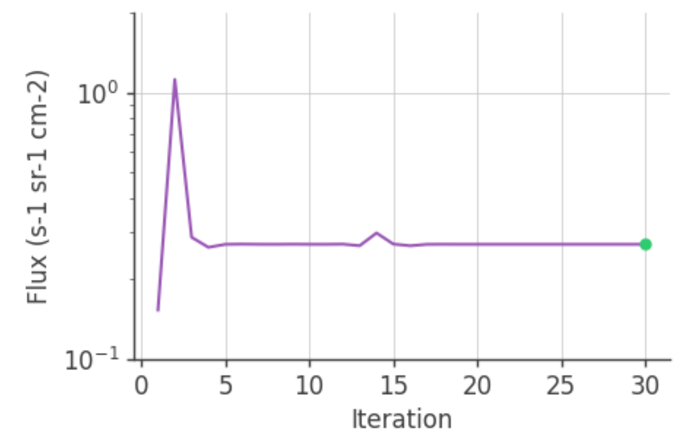
Data $(E_m, \phi, \chi\psi)$

- detector response
- coordinate conversion
- iterative image reconstruction method (e.g. RL)



Model (E_i, lb)





COSI collaboration and science team

University of California

- John Tomsick (Principal Investigator, UCB)
- Steven Boggs (Deputy PI, UCSD)
- Andreas Zoglauer (Project Scientist, UCB)

Naval Research Laboratory

- Eric Wulf (Electronics/BGO shield lead)

Goddard Space Flight Center

- Albert Shih (CHRS lead)
- Carolyn Kierans (Data pipeline co-lead)
- Alan Smale (HEASARC/archiving lead)

Northrop Grumman

Institutions of Co-Investigators and Collaborators

- JMU/Wurzburg and JGU/Mainz, Germany
- Clemson University
- Los Alamos National Laboratory
- Louisiana State University
- Yale University
- IRAP, France
- INAF, Italy
- Kavli IPMU and Nagoya University, Japan
- NTHU, Taiwan
- University of Hertfordshire, UK
- Centre for Space Research, North-West University, South Africa

Science Team	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)	Hiroki Yoneda (JMU, Germany)
GRBs	Eric Burns (LSU)	Steve Boggs (UCSD), Dieter Hartmann (Clemson)	Alyson Joens (UCB)
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)