



# Nucleosynthesis Science with COSI

Aravind Valluvan UC San Diego

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#### Gamma-Ray Telescopes of the 2010s and 2020s





28 February 2025

SCIENCE & EXPLORATION

# Mission accomplished for Integral, ESA's gamma-ray telescope

### **Compton Spectrometer and Imager**

- NASA Small Explorer launching in August 2027
- Fills the MeV gap: 200 keV 5 MeV range
- High-resolution spectroscopy: 0.2–1% FWHM
- Wide field of view: 100% daily sky coverage
- γ-ray lines from nuclear decays act as fingerprints of radioactive isotopes



#### **COSI Science Goals**





 Gain insights into extreme environments with polarization





Uncover the origin of Galactic positrons



Probe the physics of multi-messenger events



## Tracing the last 1 Myr with <sup>26</sup>Al and <sup>60</sup>Fe



### The Case of Missing Galactic SNRs



#### 44Ti probas Aastpeletedispécilian





### The Positron Connection



- INT/SPI: Large-scale, smooth emission, peaking at Galactic Bulge (~  $5 \ge 10^{43} \text{ e}^+/\text{s})^1$
- Individual production sites are unknown
- Theory: e<sup>+</sup> from nuclear line decay

<sup>26</sup>Al: 0.4 x 10<sup>43</sup> e<sup>+</sup>/s <sup>44</sup>Ti: 0.3 x 10<sup>43</sup> e<sup>+</sup>/s

COSI will resolve substructure and potentially identify point-like sources

<sup>26</sup> Al from massive stars and CCSNe		
<sup>56</sup> Ni from type Ia SNe	<sup>44</sup> Ti from SNe	
Novae	Pulsars	
Low-mass X-ray binaries	Microquasars	
Cosmic-rays	Dark matter interactions	

Table 1: Potential 511 keV progenitors

### **Extended Science Portfolio**

Siegert+ 2021

<u>Katayose+ 2021</u>, <u>Caputo+ 2023</u>



C. C. Caller



X-ray emissions

Milky Way

— 50,000 light-years

Roberts+ 2025

Sun .

### COSI Data Analysis

- COSIpy library will perform all high-level science analysis tasks
- Poisson likelihood-based forward folding analysis

$$\mathscr{L}(\mathbf{s}_{j} | n_{i}) = \prod_{i} P\left(n_{i} | \lambda_{i}(\mathbf{s}_{j})\right) \longrightarrow$$

- Beta versions released each year along with mock data
  - 2025 public release on <u>April 1</u>

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### In Summary, COSI will

- Fill the MeV gap, probe nuclear line emissions, and map Milky Way nucleosynthesis
- Reveal ~1 Myr galactic SN activity and flow of material with <sup>60</sup>Fe and <sup>26</sup>Al
- Disentangle the individual contributors to <sup>26</sup>Al and positron production
- Uncover hidden SNRs with <sup>44</sup>Ti and constrain SN explosion mechanisms



#### The COSI collaboration

#### University of California

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

#### **Naval Research Laboratory**

Eric Wulf (Electronics and BGO shield lead)

#### Goddard Space Flight Center

- Albert Shih (Cryostat Heat Removal Subsystem lead)
- Carolyn Kierans (Data pipeline co-lead)

#### Space Dynamics Laboratory

Northrop Grumman





#### Institutions of Co-Investigators and Collaborators

- Clemson University
- Louisiana State University
- Los Alamos National Laboratory
- Lawrence Berkeley National Laboratory
- IRAP, France
- INAF and ASI, Italy
- Kavli IPMU and Nagoya University, Japan
- JMU/Wuerzburg and JGU/Mainz, Germany

- NTHU, Taiwan
- University of Hertfordshire, UK
- Centre for Space Research, North-West University, South Africa
- Deutsches Elektronen Synchrotron (DESY), Germany
- LAPTh-CNRS, France
- Yale University
- Michigan Tech (Tiffany Lewis)
- Washington University, St. Louis

- Marshall Space Flight Center
- Boston University
- IAA-CSIC, Spain
- Stanford University