

Studying MeV Emission from the Galaxy with the Compton Spectrometer and Imager

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UC Berkeley/Space Sciences Laboratory
July 21, 2022

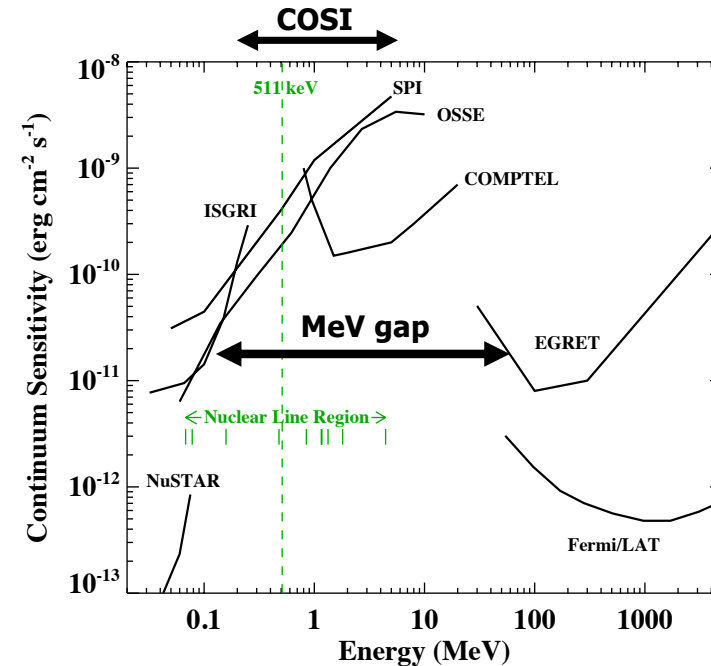


Science opportunities in the MeV bandpass

COSI
A Gamma-ray
Space Explorer



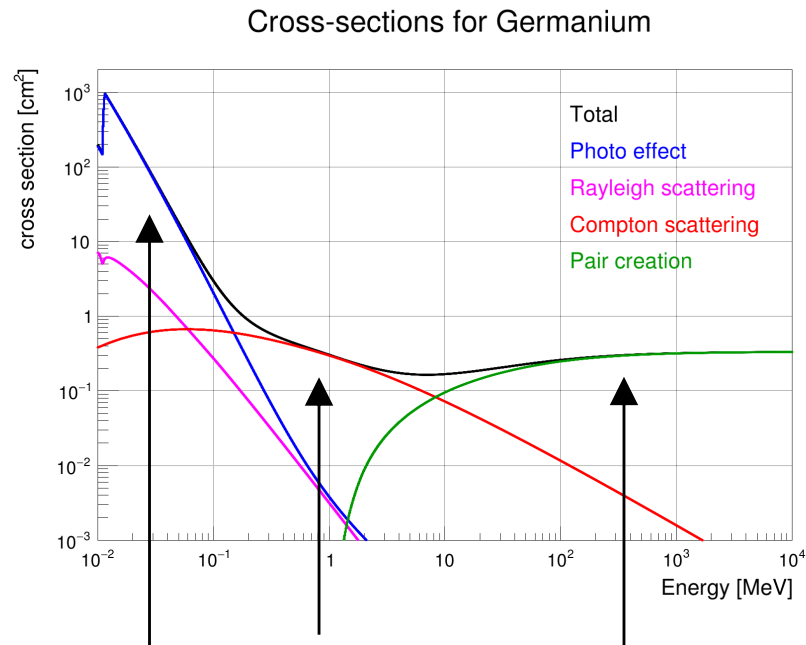
- ❑ Signals and sources in the COSI energy range (0.2-5 MeV)
 - e^-e^+ annihilation line at 511 keV
 - Gamma-ray lines that probe nucleosynthesis
 - Accreting black holes
 - Gamma-ray bursts (GRBs)
 - Multimessenger sources
 - Merging neutron stars
 - High-energy neutrino sources
- Galactic Diffuse Continuum Emission (GDCE)



The “MeV gap” is one of the least-well explored regions of the electromagnetic spectrum

Detecting photons at $\sim$ MeV energies

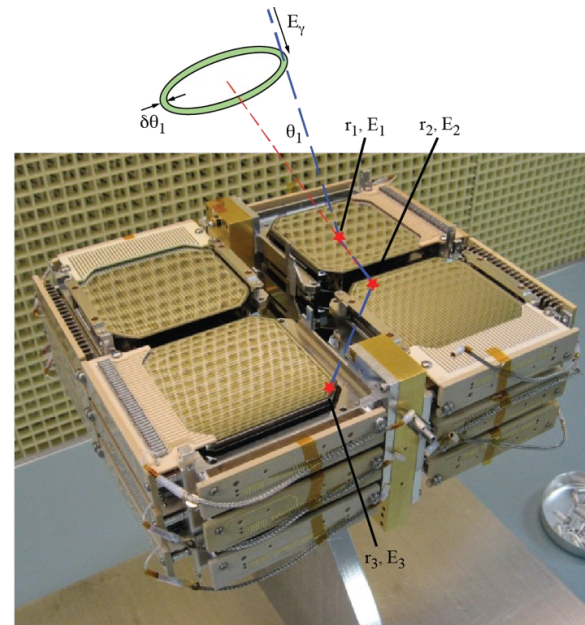
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Full photon
absorption
(NuSTAR,
etc.)

Compton
telescopes
(COMPTEL,
COSI)

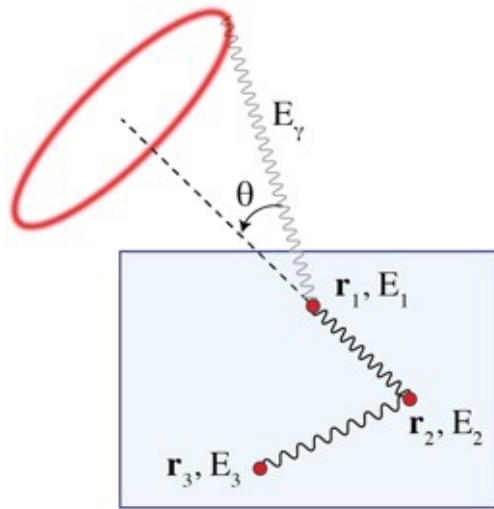
Pair creation
telescopes
(Fermi/LAT)



- COSI-balloon instrument
- Twelve 8x8 cm² germanium detectors
- Funded under NASA's Astrophysics Research and Analysis (APRA) program

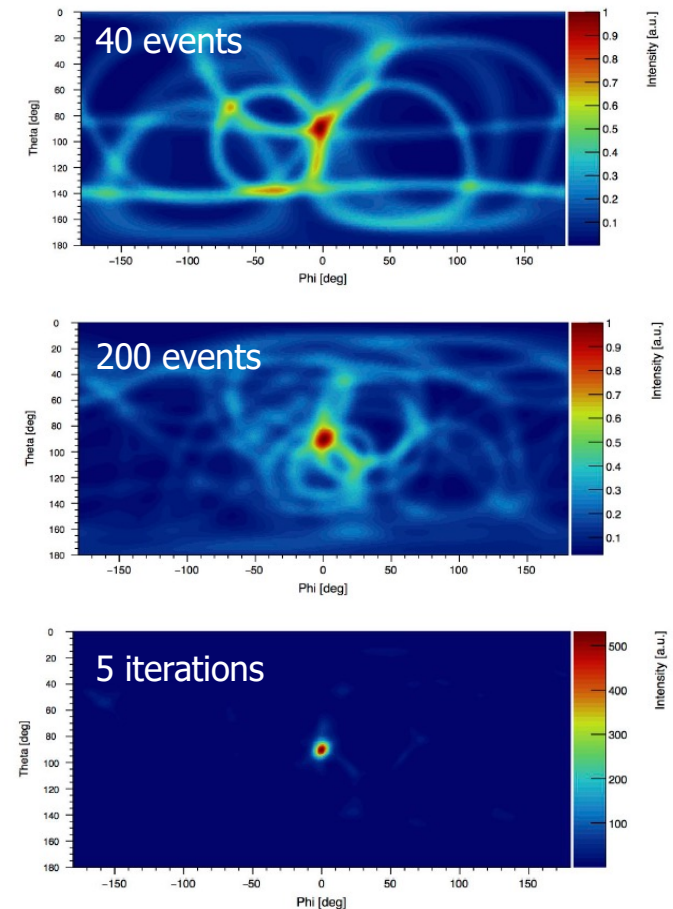
Compton telescope operating principle

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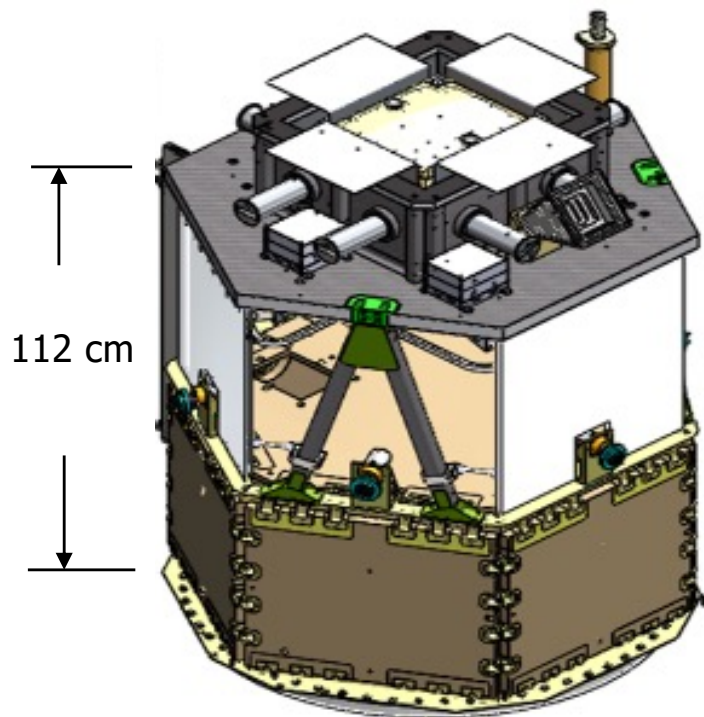
- Results of an imaging simulation of a point source with iterative deconvolution (Kierans+18)

- Multiple interactions in the detector
- $E_\gamma = E_1 + E_2 + E_3 + \dots$
- The photon may have come from any point on the “event circle”



Overview of COSI instrument and requirements

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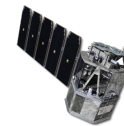


COSI instrument/payload and spacecraft

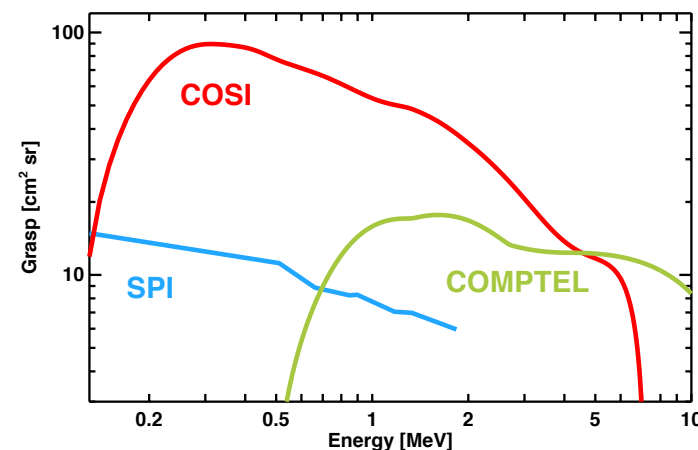
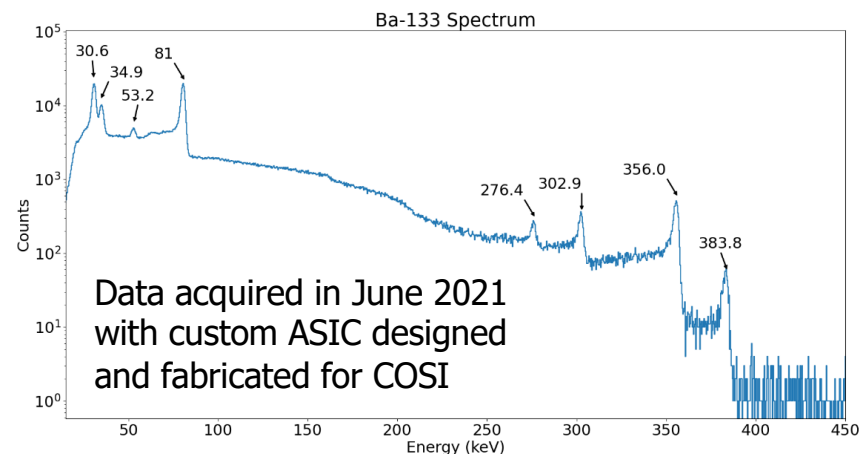
Parameter	Requirements
Energy range	0.2-5 MeV
Sky coverage	100%-sky each day
Energy resolution	0.2-1% FWHM
Angular resolution	2.1° FWHM @ 1.8 MeV (^{26}Al)
Localizations	<1.0° for GRBs
Polarization sensitivity	For GRBs, AGN, Galactic BHs

COSI has a unique combination of excellent energy resolution and large field of view

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- ❑ COSI uses germanium detectors for excellent energy resolution
 - $\Delta E/E$ more than an order of magnitude better than the previous Compton telescope (COMPTEL on CGRO)
- ❑ COSI's instantaneous FOV is $>25\%$ -sky:
 - Large improvement in grasp (= product of effective area and FOV) over INTEGRAL/SPI and COMPTEL

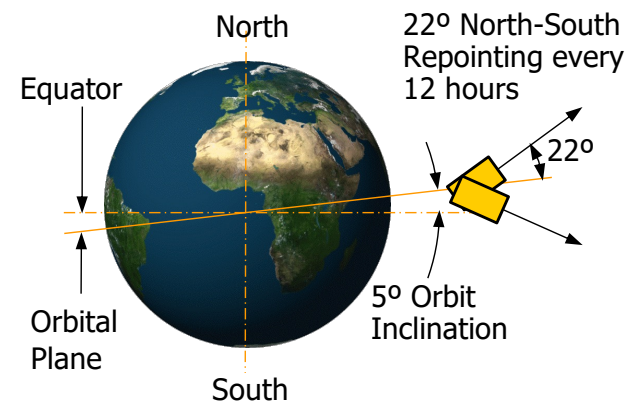
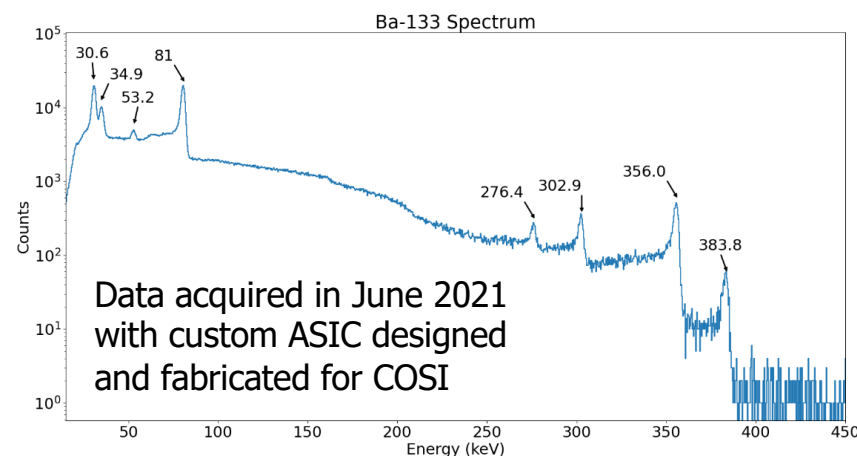


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 - $\Delta E/E$ more than an order of magnitude better than the previous Compton telescope (COMPTEL on CGRO)
- ❑ COSI's instantaneous FOV is >25%-sky:
 - Large improvement in grasp (= product of effective area and FOV) over INTEGRAL/SPI and COMPTEL
- ❑ COSI constantly points away from Earth and alternates between North and South to cover the whole sky in 24 hours



COSI science goals

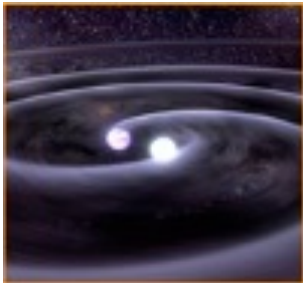
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Revolutionizing our understanding of creation and destruction of matter in our Galaxy and beyond

1. Uncover the origin of Galactic positrons
2. Reveal Galactic element formation
3. Gain insight into extreme environments with polarization
4. Probe the physics of multimessenger events

Goal 4: MMA

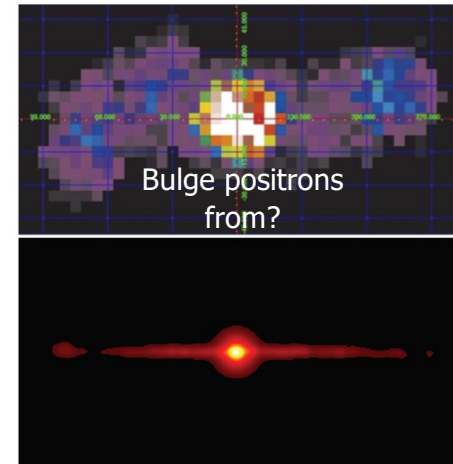


Goal 3: Polarization



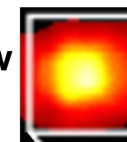
511 keV with
INTEGRAL
(Bouchet+10)

Goal 1: Positrons



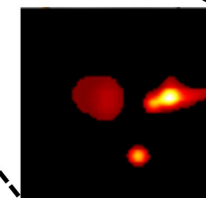
Cygnus region

Now



Goal 2:
Nucleosynthesis

^{26}Al 1.809 MeV



COSI

The COSI collaboration

University of California (Berkeley and San Diego)

- John Tomsick (Principal Investigator, UCB)
- Steven Boggs (Deputy PI, UCSD)
- Andreas Zoglauer (Project Scientist, UCB)
- Juan Carlos Martinez Oliveros (Student Collaboration Lead, UCB)
- Pascal Saint-Hilaire (Science Enhancement Option Lead, UCB)



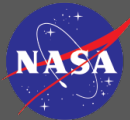
Naval Research Laboratory (Washington, DC)

- **Leads:** E. Wulf, C. Sleator, B. Philips



Goddard Space Flight Center (Greenbelt, Maryland)

- **Leads:** A. Shih, C. Kierans, A. Smale

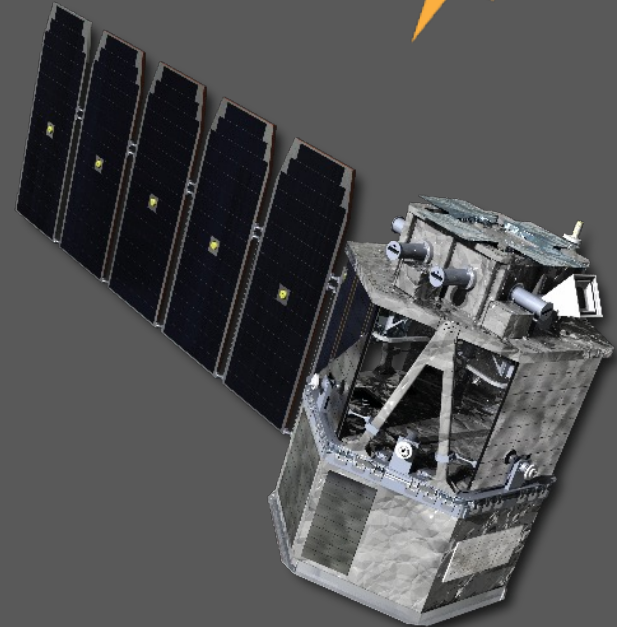


Northrop Grumman (Dulles, Virginia)



Institutions of Co-Is and Collaborators

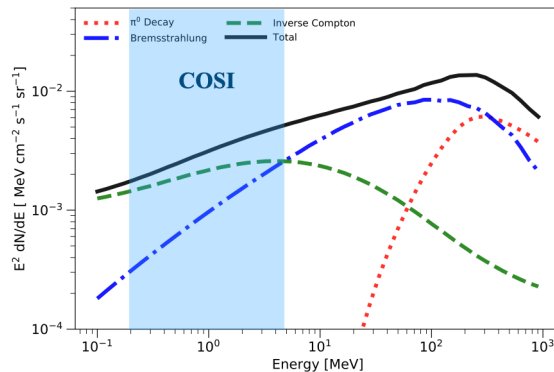
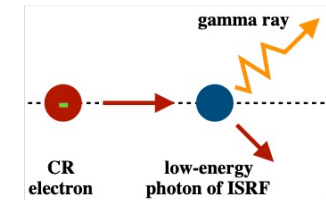
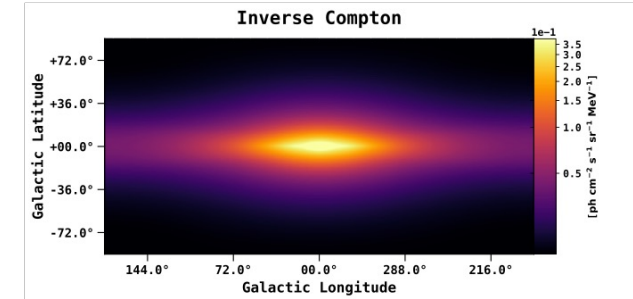
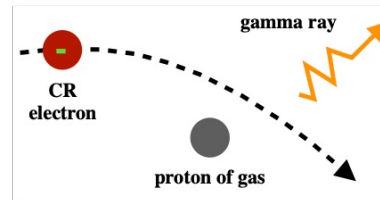
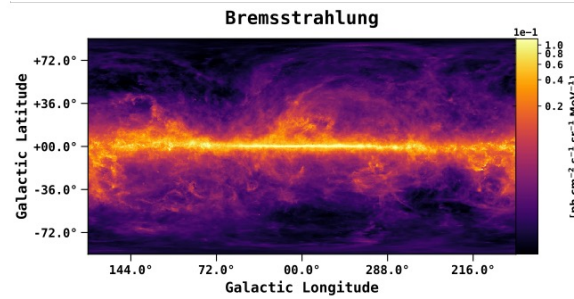
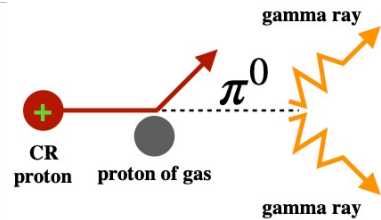
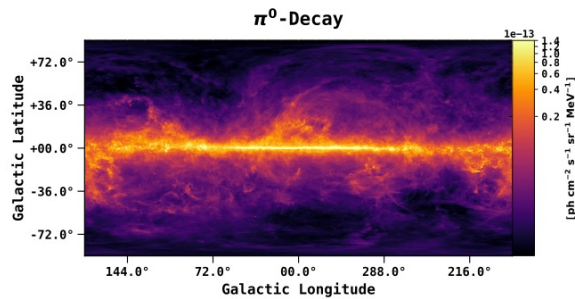
- Clemson University (**Leads:** D. Hartmann, M. Ajello, M. Leising)
- Los Alamos National Laboratory (C. Fryer)
- Louisiana State University (E. Burns)
- France, IRAP (P. Jean, P. von Ballmoos, J. Malzac, J. Knödseder)
- Italy, INAF (A. Bulgarelli, G. Ghirlanda, V. Fioretti, F. Tavecchio)
- Japan, Kavli IPMU and Nagoya University (**Leads:** T. Takahashi, K. Nakazawa)
- Germany, JMU (T. Siebert)
- Taiwan, NTHU (H.-K. Chang)



- ***COSI is a NASA Small Explorer (SMEX) planned for launch in 2026.***
- ***Tomsick et al., arXiv:2109.10403***

The Galactic Diffuse Continuum Emission

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- ❑ IC expected to dominate in COSI's bandpass
- ❑ Bremsstrahlung may also contribute at the $\sim 10\%$ level
- ❑ Studying the GDCE in the MeV provides a particularly good probe of cosmic ray (CR) electrons

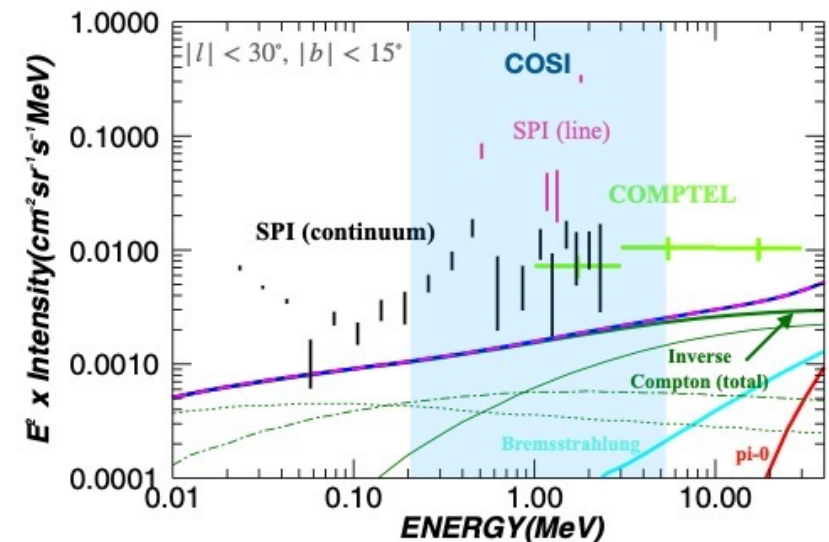
Slide credit:
Chris Karwin

Existing measurements

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- ❑ SPI and COMPTEL show an MeV excess by a factor of 2-3 above the GALPROP estimate in an extended region around the Galactic center
- ❑ Also, see Siegert+22 (arXiv:2202.04574) for a SPI update with more data and a detailed analysis



Bouchet+11: SPI and COMPTEL data compared to the GALPROP (Moskalenko & Strong 1998) model estimate

Possible reasons for the MeV excess

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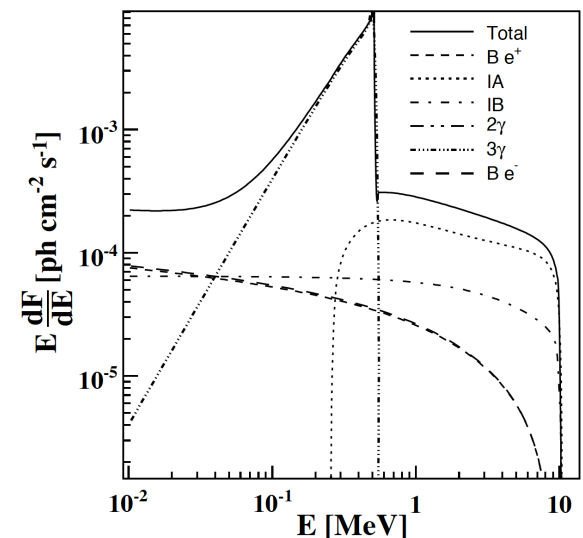
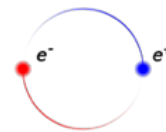


□ Within GALPROP

- Modification to the CR propagation (e.g., Siebert+22 consider adjusting the spatial diffusion coefficients, δ_i)
- Enhanced interstellar radiation field (ISRF)

□ Beyond GALPROP

- Presence of a sub-threshold MeV source population?
- Positron annihilation
 - In-flight annihilation would produce a continuum up to the injection energy (but see, e.g., Beacom & Yüksel 2006 for limits on E_{inj})
 - Orthopositronium 3γ continuum below 0.511 MeV
- Dark matter contribution?



Potential positron (e^+) contributions for $E_{inj} = 10$ MeV (Sizun+06)

COSI 2016 Wanaka Flight



46 days later, COSI
landed in Peru,
completing the longest
mid-latitude flight for a
large balloon

May 30, 2016: First
balloon to report a
GRB detection and
localization with
Gamma-ray
Coordination
Network (GCN):
GRB160530A

COSI
detects and
images the
Crab nebula

COSI detects and
images 511-keV
emission from
Galactic e^+e^-
annihilation

COSI measures 1.809
MeV emission from
Galactic Al-26



May 17, 2016:
COSI launch

Reports on flight
data:
Tomsick+16, GCN
Lowell+17ab
Lowell+17 (thesis)
Kierans+18 (thesis)
Sleator+19 (thesis)
Kierans+20
Siegert+20
Zoglauer+21
Beechert+22
(and still a couple
more in prep.)

COSI-balloon ^{26}Al study

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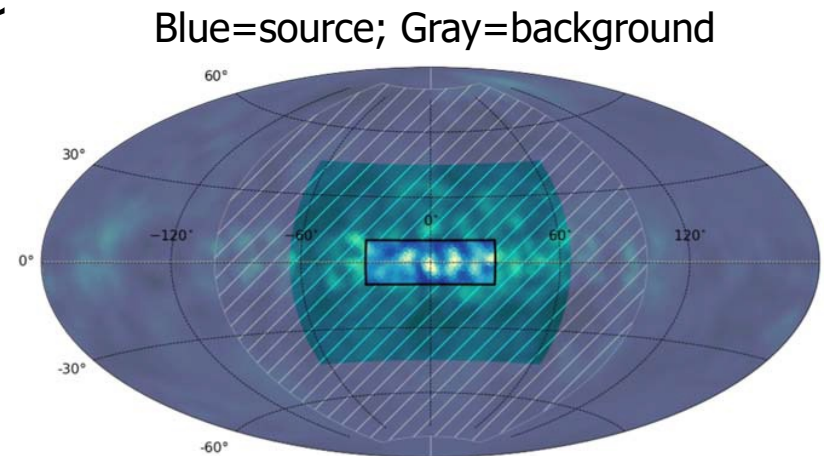


❑ Produced a broadband spectrum of the inner Galactic plane

- Source region ($60^\circ \times 20^\circ$) with exposure of 156 ks
- Background exposure = 1.4 Ms

❑ Source minus background spectrum (next slide) clearly shows:

- 511 keV emission line (also seen in earlier analyses: Kierans+18+20; Siegert+20)
- ^{26}Al 1.809 MeV emission line (Beechert+22)
- Continuum emission



Beechert+22

COSI-balloon continuum emission from the Galaxy

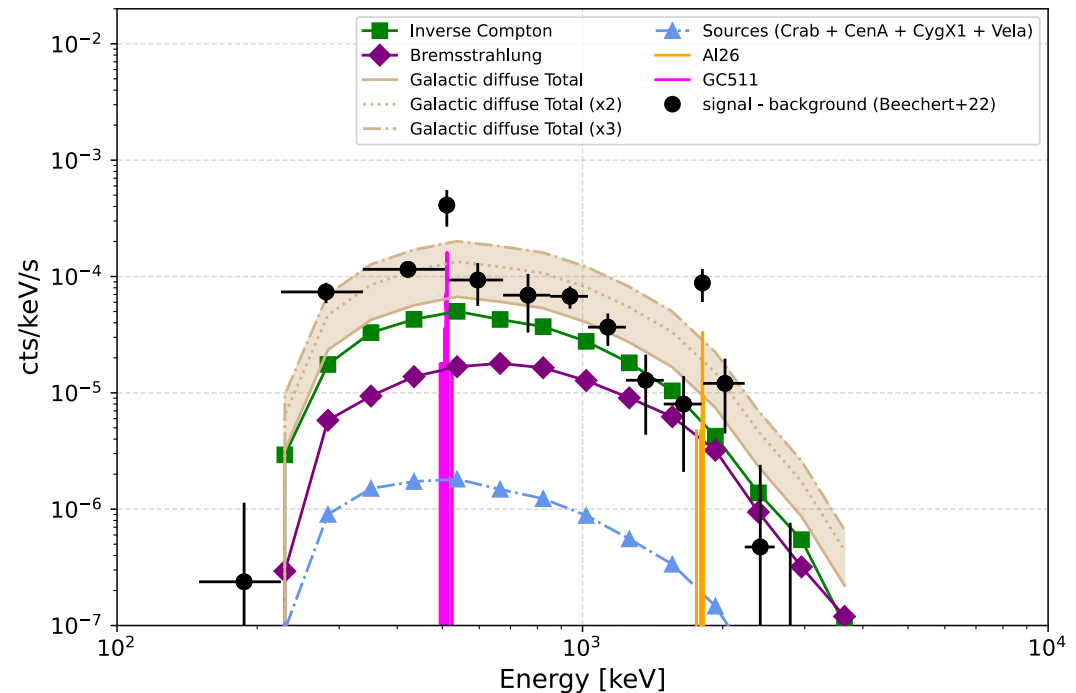
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□ Preliminary analysis shows that the continuum emission level is between 1x and 3x (depending on the energy) of the GALPROP prediction for GDCE

□ Spectrum below 0.511 MeV shows the largest excess

- Orthopositronium continuum?
- Unresolved point sources?



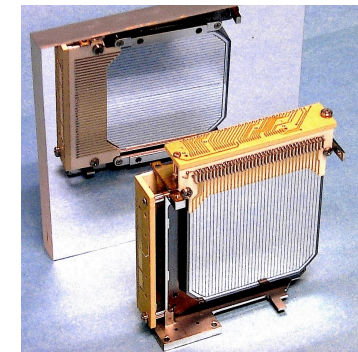
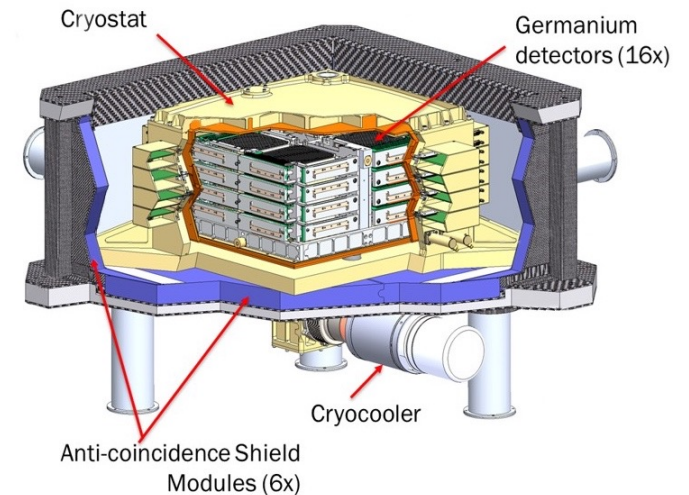
Spectrum from the source region
(Karwin et al., in prep.)

COSI advances vs. COSI-balloon

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- ❑ Change from 12 to 16 germanium detectors
- ❑ Detector x-y position resolution better by 1.7x
 - Better angular resolution ($\sim 2^\circ$ FWHM @ 2 MeV)
 - Better event reconstruction
- ❑ Longer exposure
 - COSI has a 2-year baseline mission
 - 16 Ms instead of 156 ks
- ❑ No atmosphere
 - No attenuation, lower and more stable background
- ❑ All-sky and (therefore) all-Galaxy coverage



From 37 to 64
strips/side

Summary and conclusions

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- ❑ We expect COSI to provide a greatly improved measurement of the GDCE in the MeV band to:
 - Constrain the excess emission vs. the GALPROP prediction
 - Improve constraints on the ISRF as well as CR electron propagation models
 - Potentially, detect the bremsstrahlung component in the MeV
- ❑ COSI is currently in Phase B formulation and is scheduled for launch in mid-2026
- ❑ If COSI's capabilities are interesting for your science, please ask me about how you can get involved
 - Also, see <http://cosi.ssl.berkeley.edu> and Tomsick et al., arXiv:2109.10403