

The Compton Spectrometer and Imager (COSI)

F. Tavecchio (INAF - OABrera)
on behalf of the INAF-COSI team



COSI in a nutshell



A NASA/SMEX satellite with a Compton Telescope (0.5-2 MeV)

Selected in 2020, originally planned for launch in 2025

Launch: August 2027 (pending NASA budget)

Duration: >2 years

PI John Tomsick (UCB)

<https://cosi.ssl.berkeley.edu>

Institutions involved:

NASA

U. C. Berkeley

Naval Research Laboratory

Clemson Univ.

GSFC

ASI (Italy)

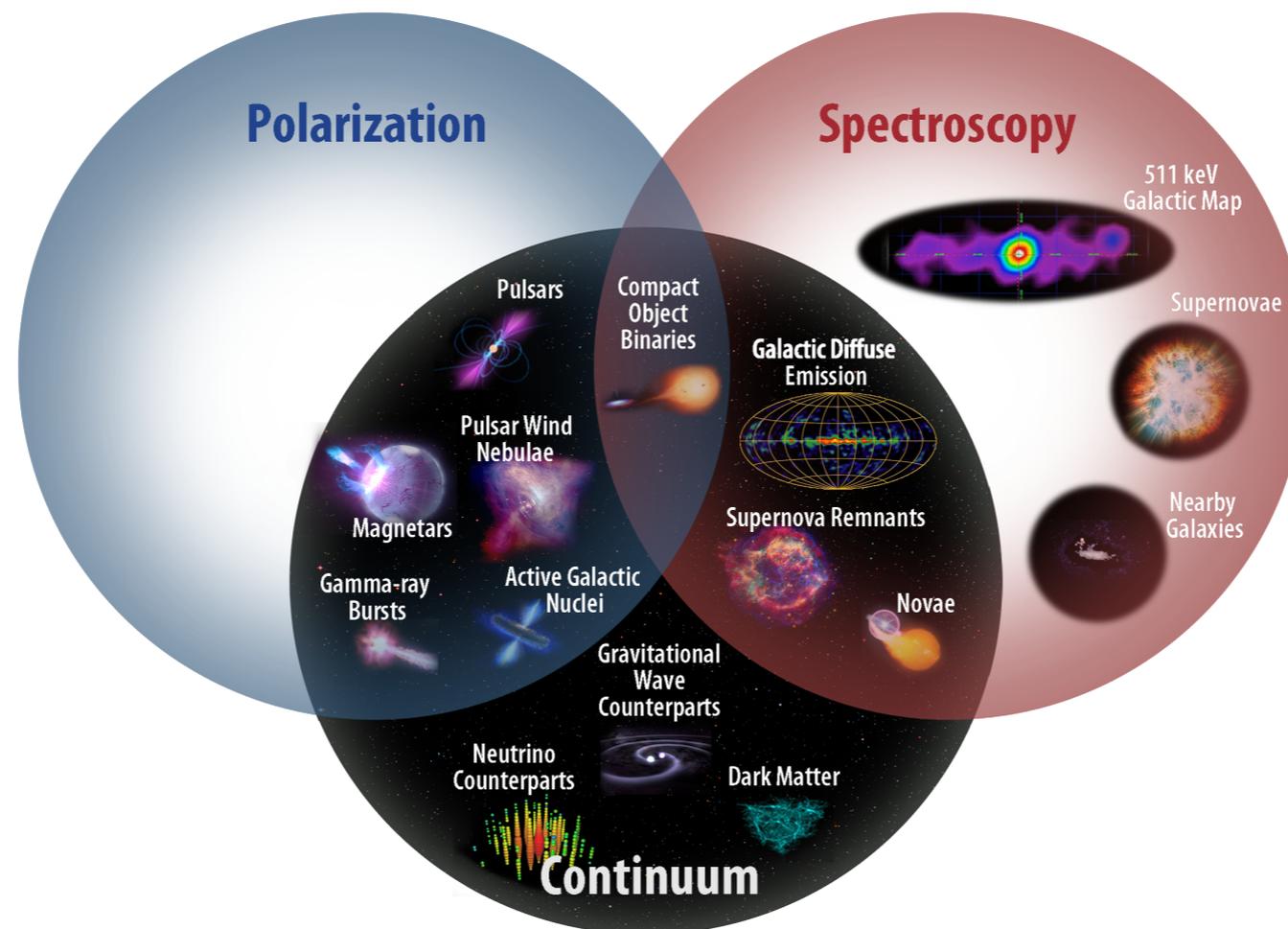
INAF (Italy)

IRAP (France)

Tokio and Nagoya Univ.

Why the MeV band?

- The MeV band: a bridge between the thermal and non-thermal Universe
- Nuclear processes only accessible in this band (lines). Positron annihilation
- The output of several compact sources peaks in this band (e.g. GRB, blazars)



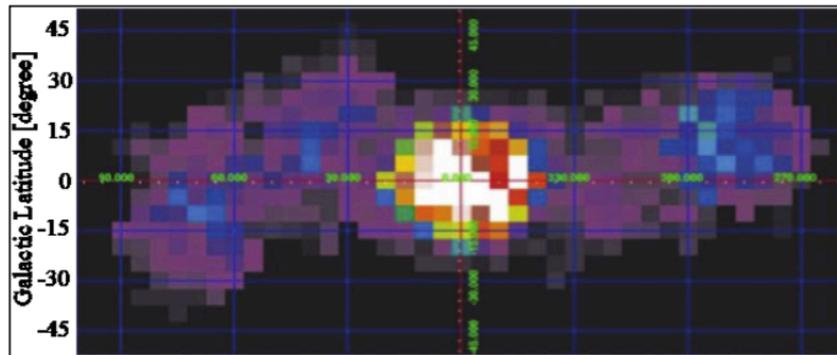
A nice example

The e^\pm galactic annihilation line

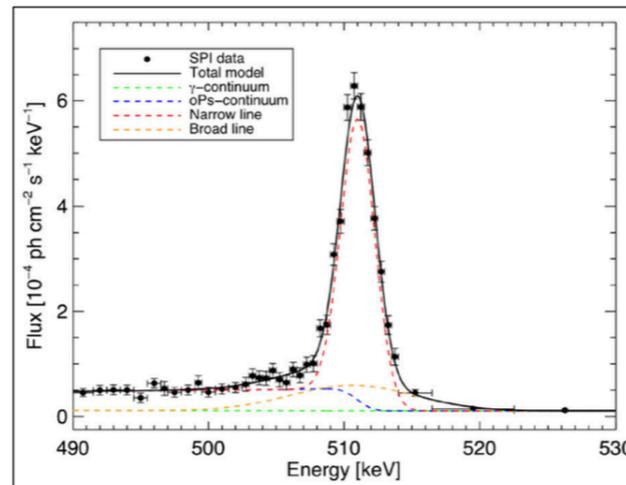
Potential sources

Discovered in the '70, origin of e^+ still a puzzle
 The strongest persistent gamma-ray line in the sky
 Strong excess from the GC, spatial distribution poorly known
 A tool to study low-energy CR propagation in the Galaxy

SPI map (Bouchet et al. 2010)



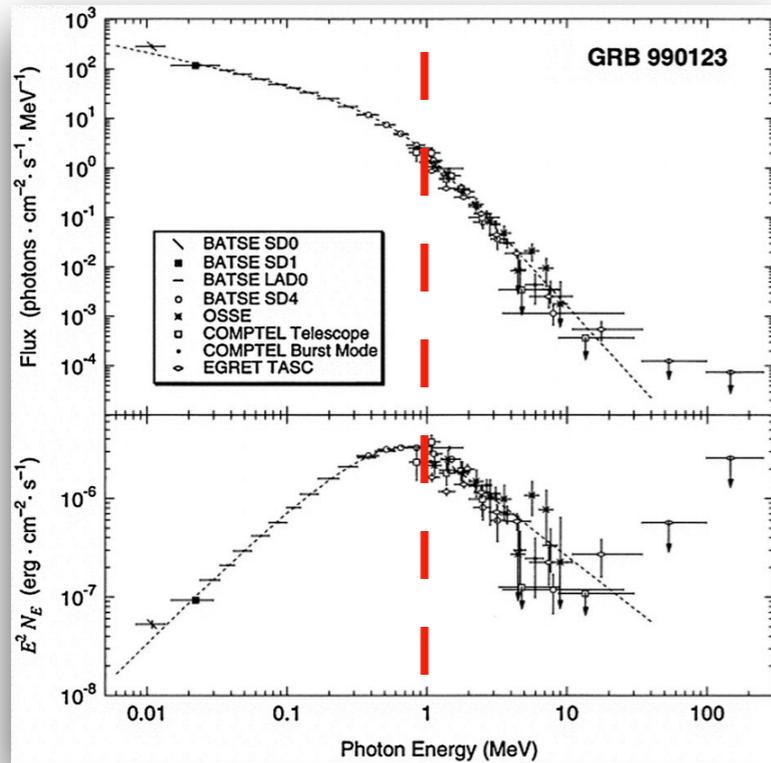
SPI spectrum (Siegert et al. 2019)



Type of source	Source and references
Nucleosynthesis products	^{26}Al from stellar winds [Diehl et al., 2006; Limongi and Chieffi, 2018; Siegert, 2017]
	^{26}Al & ^{44}Ti from CCSNe [Diehl et al., 2006; Lyudin et al., 1994]
	^{56}Co from Type Ia SNe [Clayton, 1973; Leventhal et al., 1978; Milne and Leising, 1999]
	^{13}N , ^{18}F , ^{22}Na from Novae [Leising & Clayton 1987; Hernanz et al. 1999]
Individual sources	Low-mass X-ray binaries [Weidenspointner et al., 2008]
	Hypernovae/GRBs [Cassé et al., 2004]
	Pulsar winds [Wang, 2006]
	Microquasars [Guessoum et al., 2006]
	Stellar flares [Bisnovatyi-Kogan and Pozanenko, 2017]
	Neutron star mergers [Fuller et al., 2019]
	Sgr A* [Cheng et al., 2006; Totani, 2006] but also see [Panther et al., 2018]
Dark matter (DM)	Annihilating MeV dark matter [Boehm et al., 2004; Ema et al., 2020]
	Excitations of heavy DM [Finkbeiner and Weiner, 2007; Pospelov and Ritz, 2007]
	Primordial black holes [Laha, 2019]

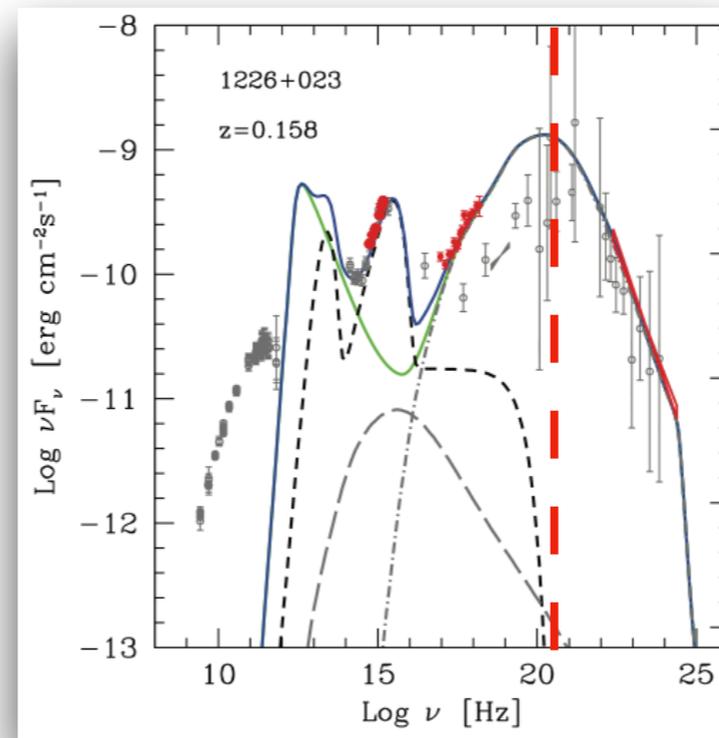
Compact objects and transients

Peak of the prompt around 1 MeV
 Clues for prompt emission mechanisms,
 Jet structure...
 GRB-GW connection...

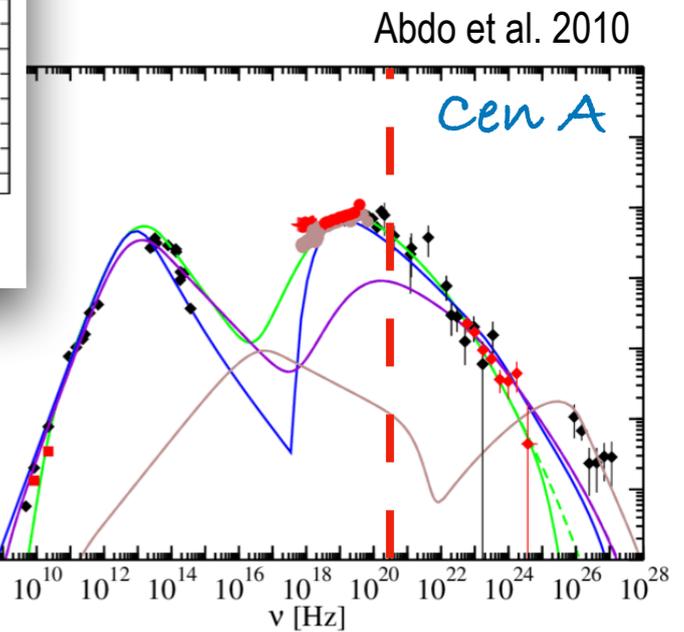


Peak of the high-energy bump around 1 MeV

Clues for emission mechanisms, jet composition
 (hadronic/leptonic)...

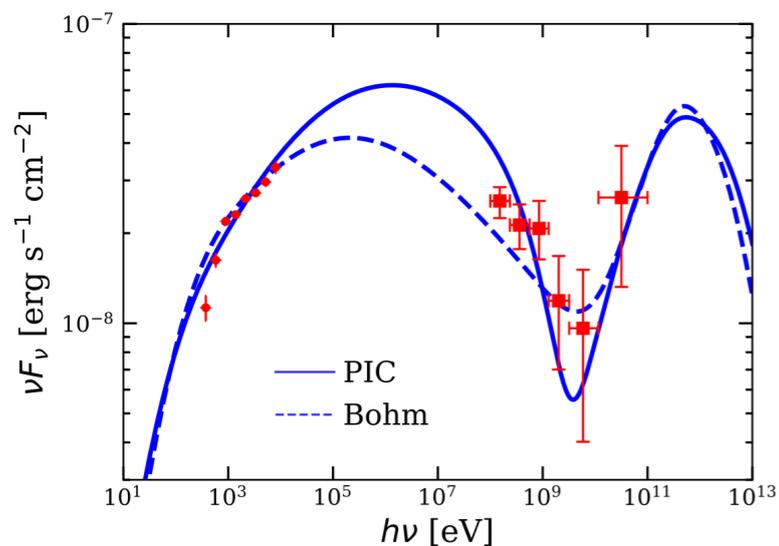


Ghisellini et al. 2009



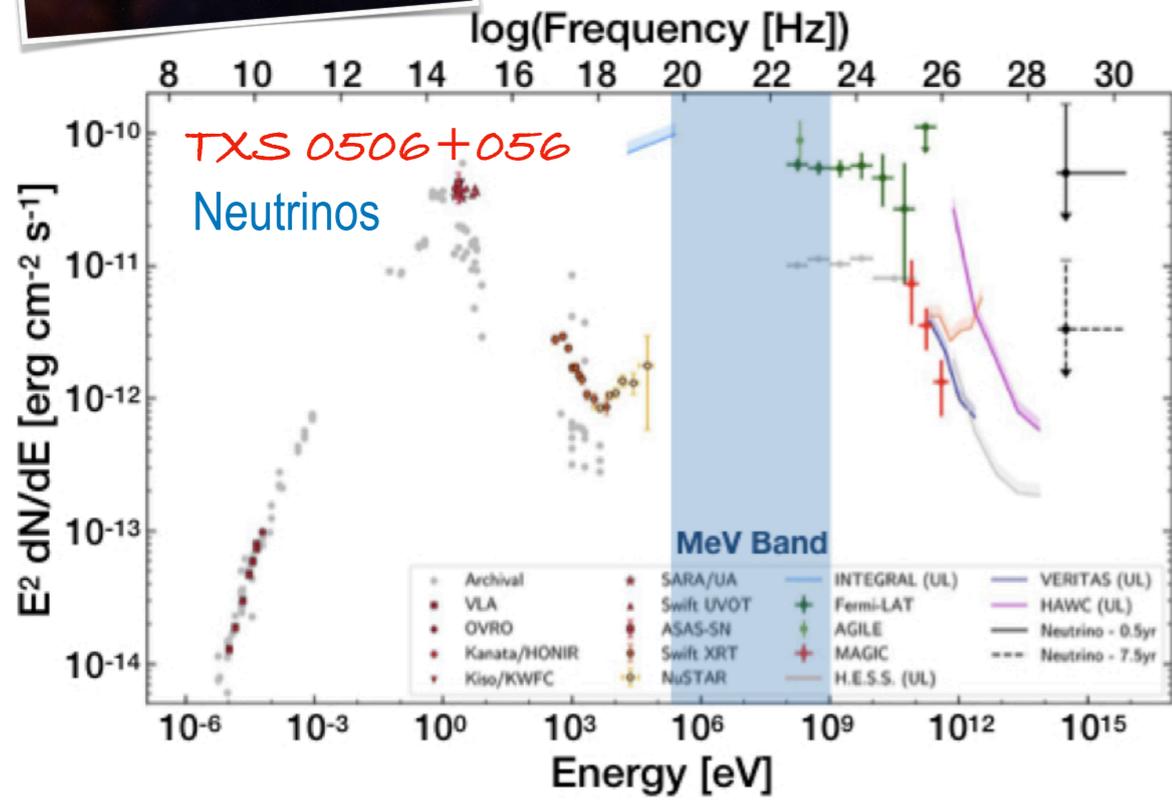
Powerful blazars, radiogalaxies

Gamma ray bursts

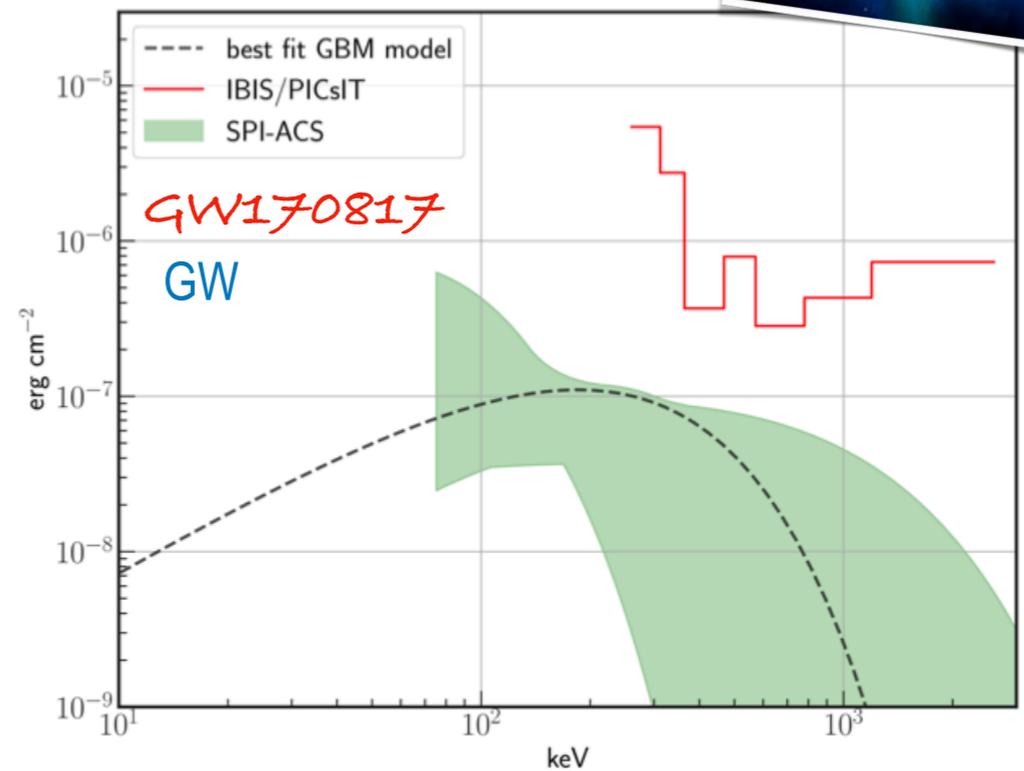


Wu et al. 2026

Multimessenger

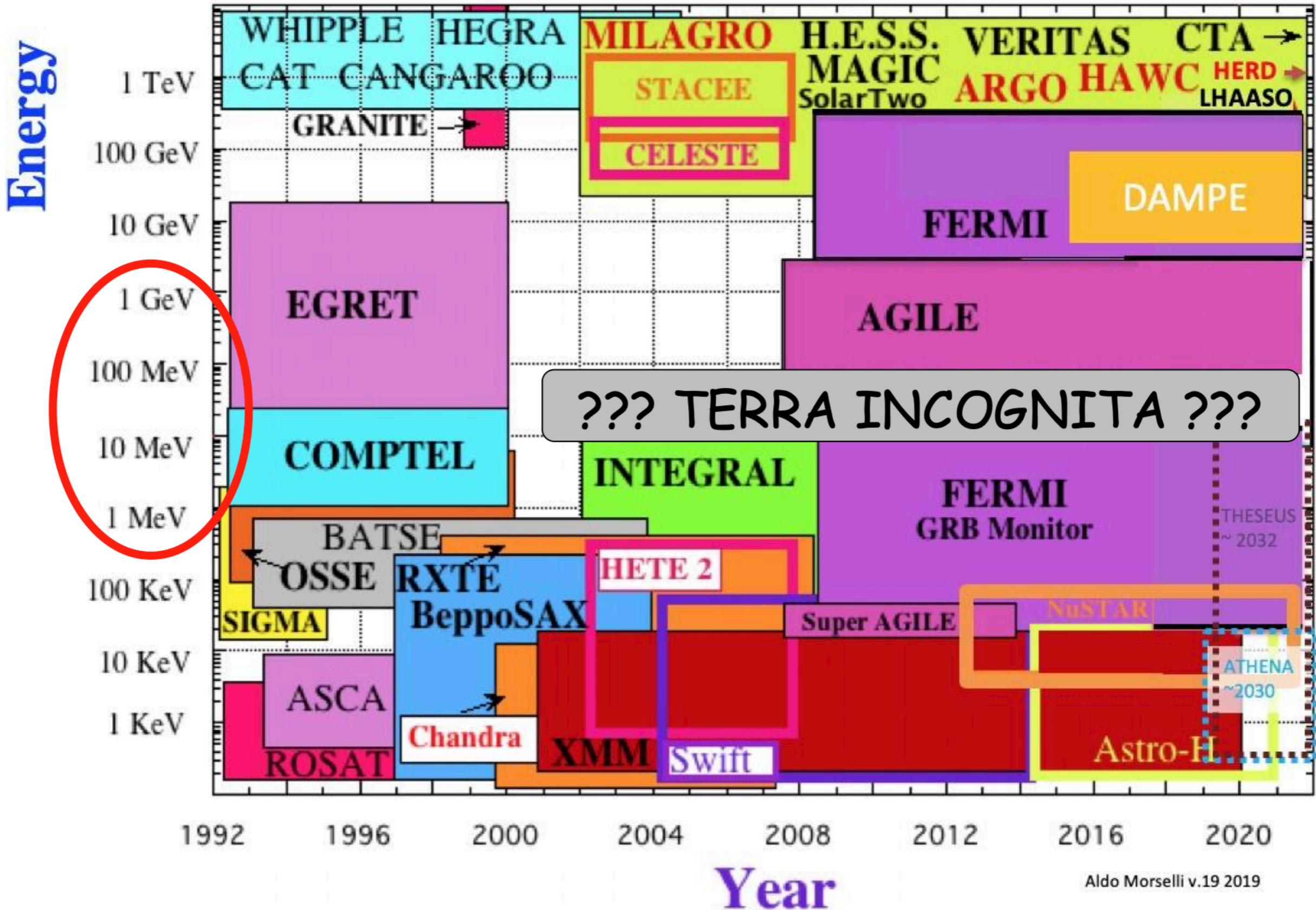


Venters et al. 2019

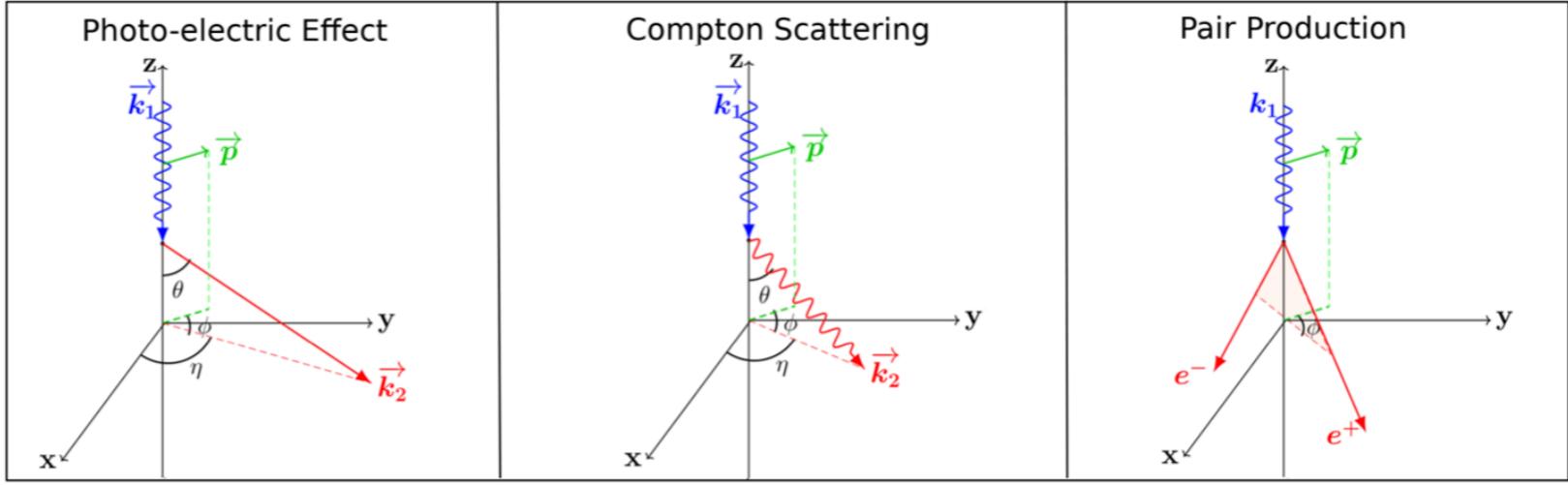
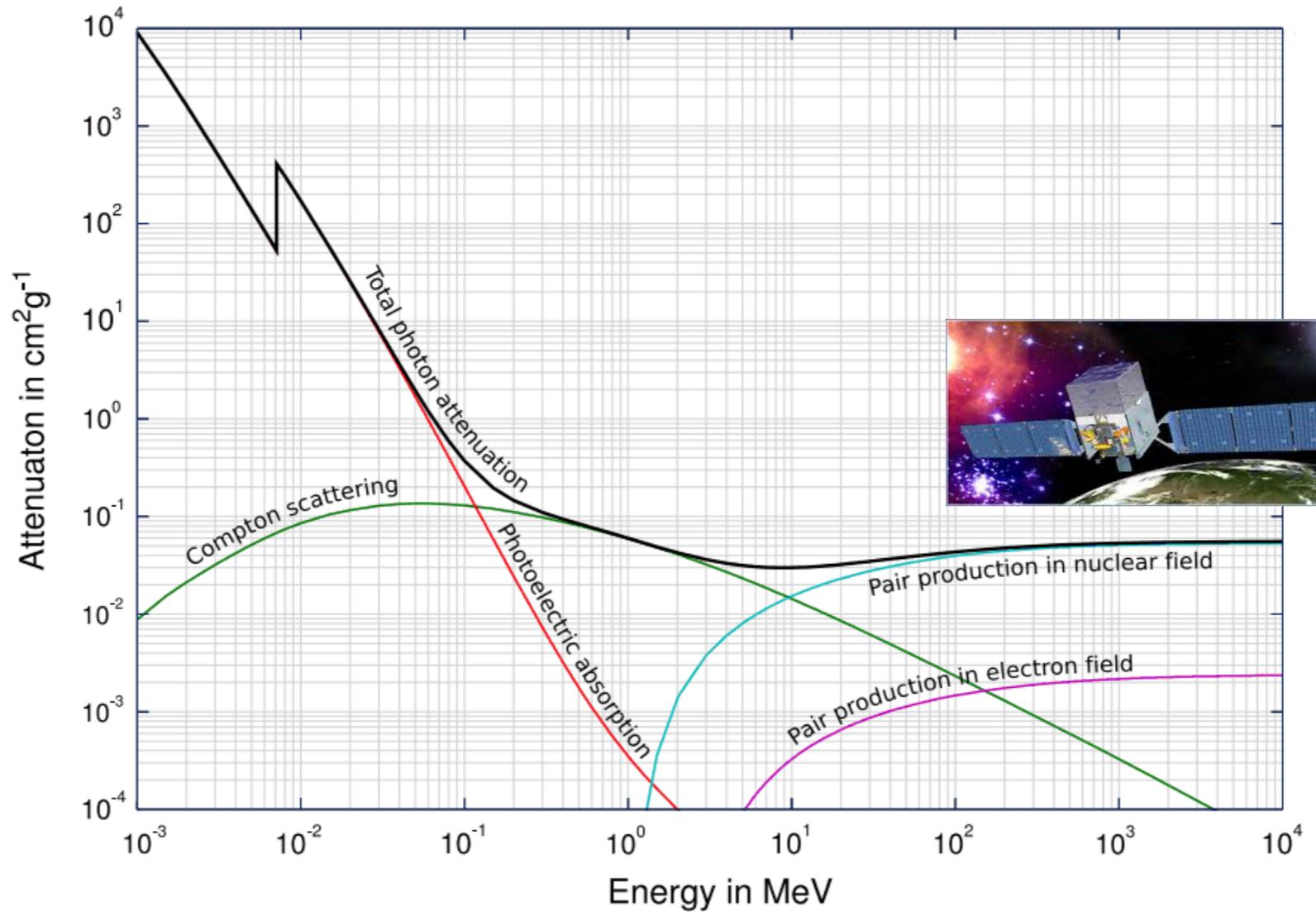


Savchenko et al. 2017

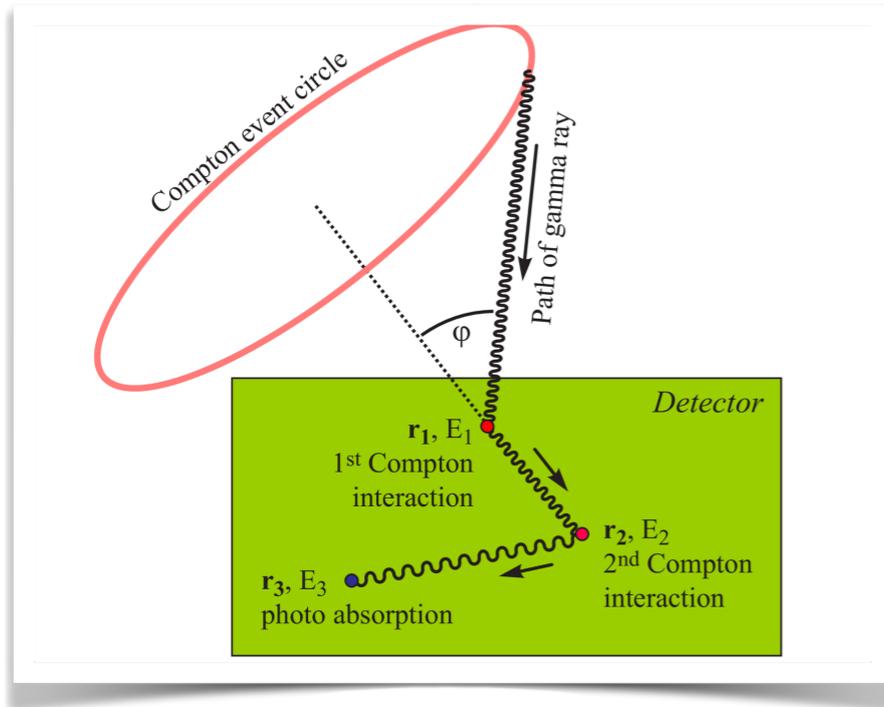
The temporal and spectral gap



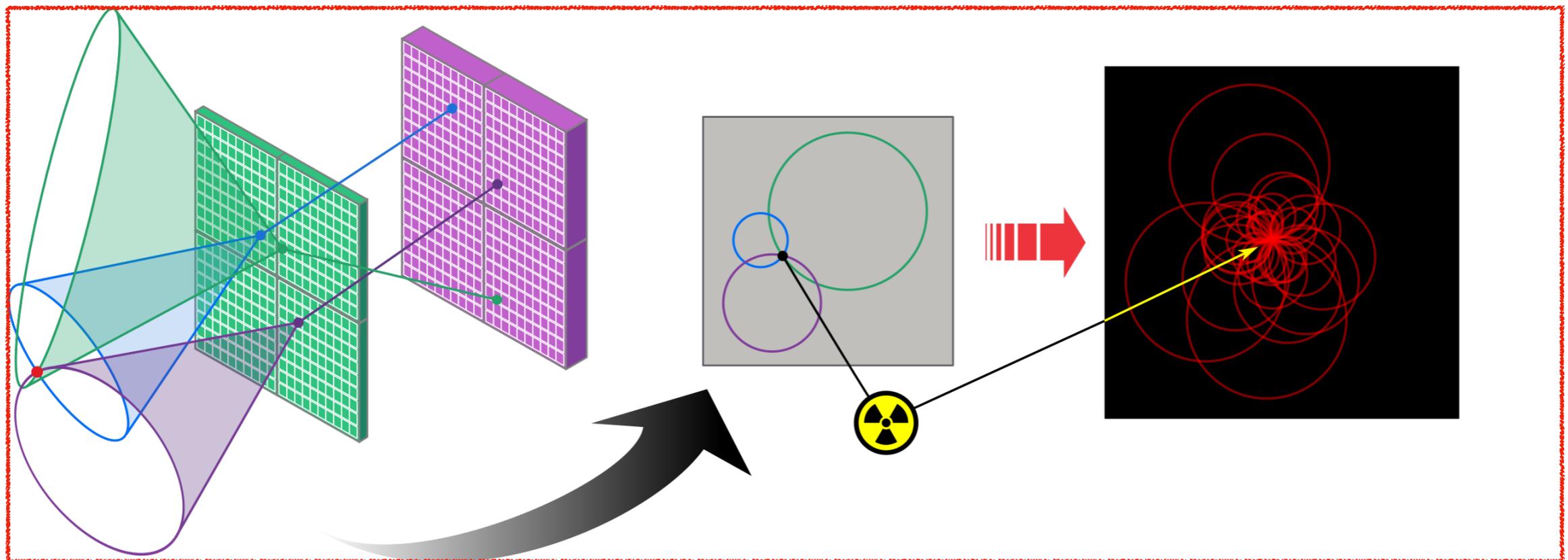
Detecting MeV photons



Compton Telescopes

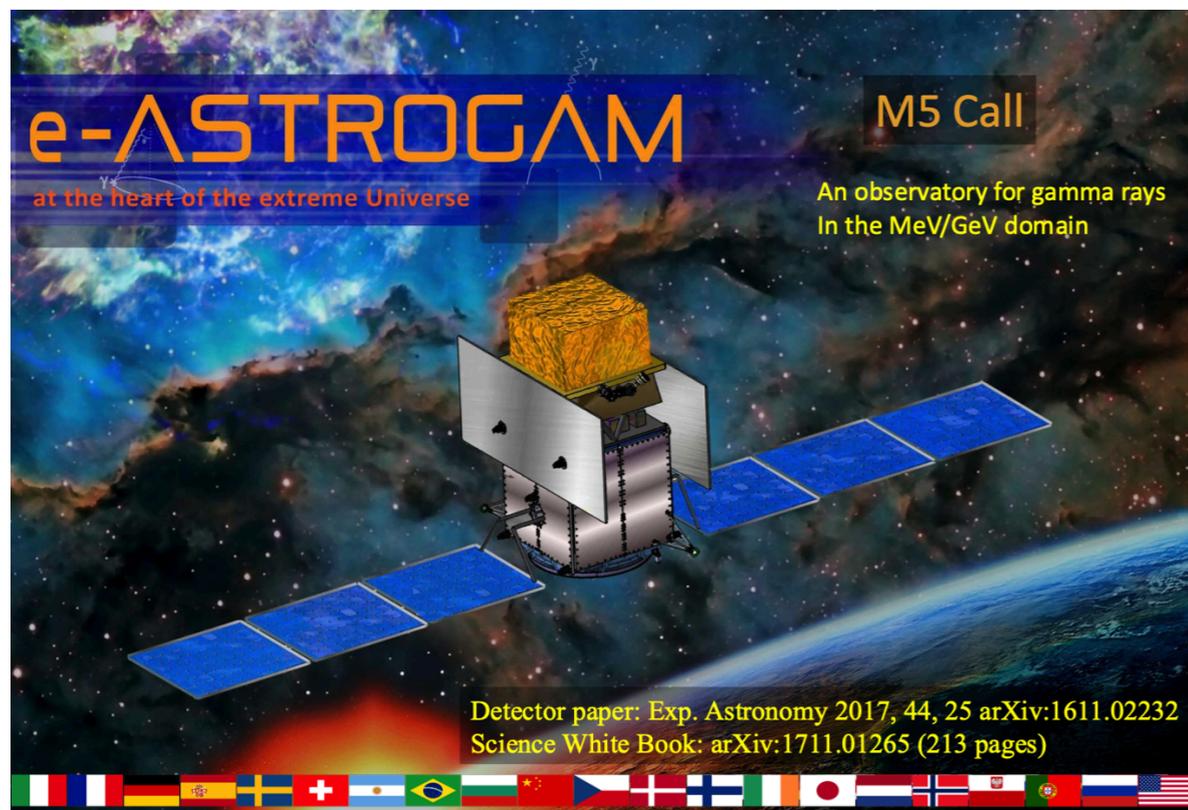


- The detector records two successive scatterings
- An "event circle" is determined
- The intersection of several circles provides the detection



The European initiative

Not approved for ESA M5



Not approved for ESA M8

newASTROGAM
Closing the MeV gap



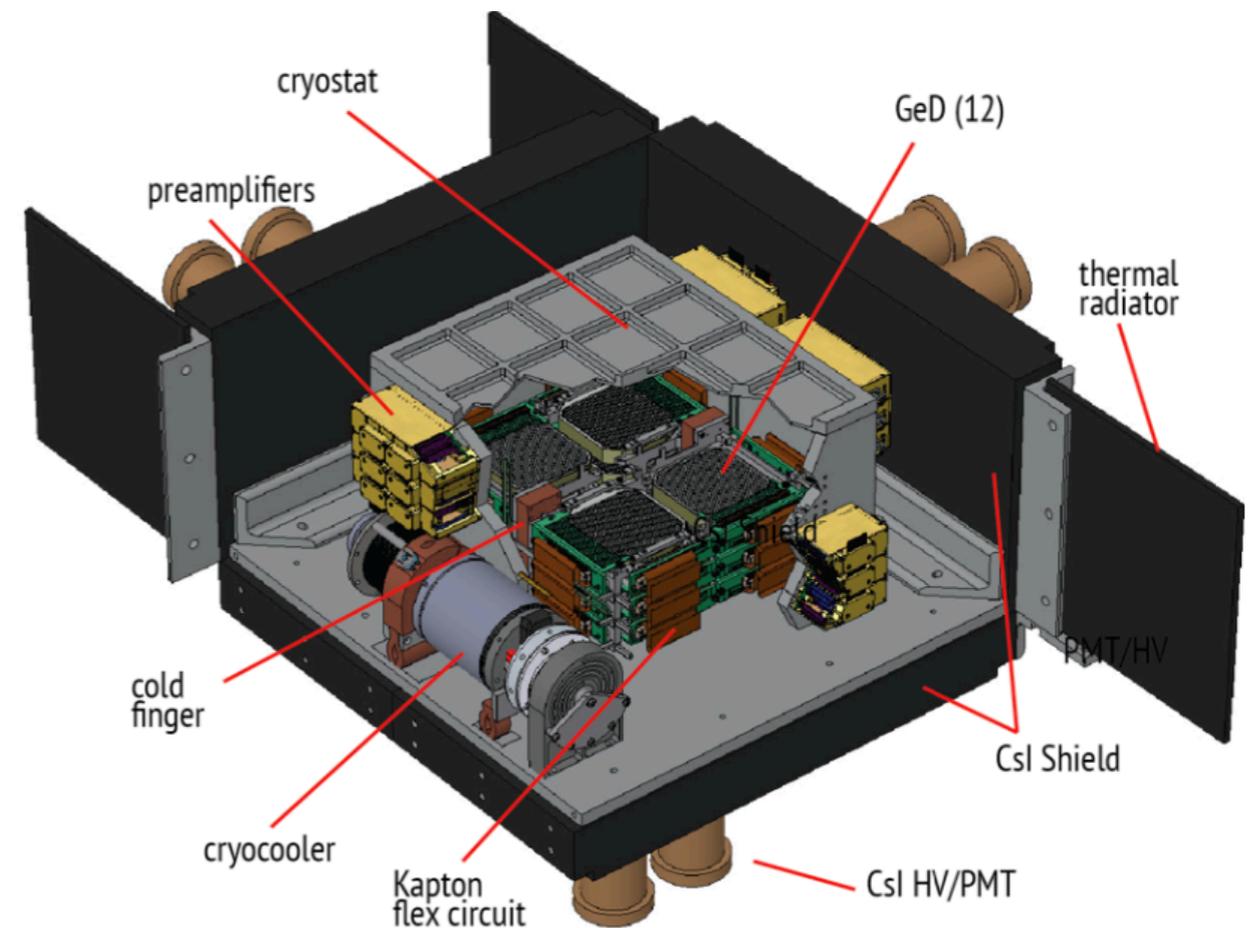
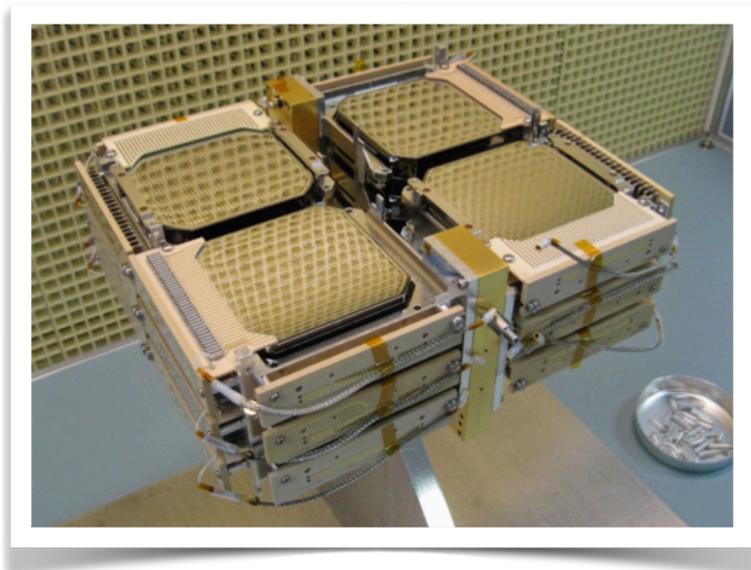
The Compton Spectrometer and Imager (COSI)

Balloon-borne Compton telescope

Evolution of Nuclear Compton Telescope

Solid-state (Ge) detectors (12 — 8x8x1.5 cm)

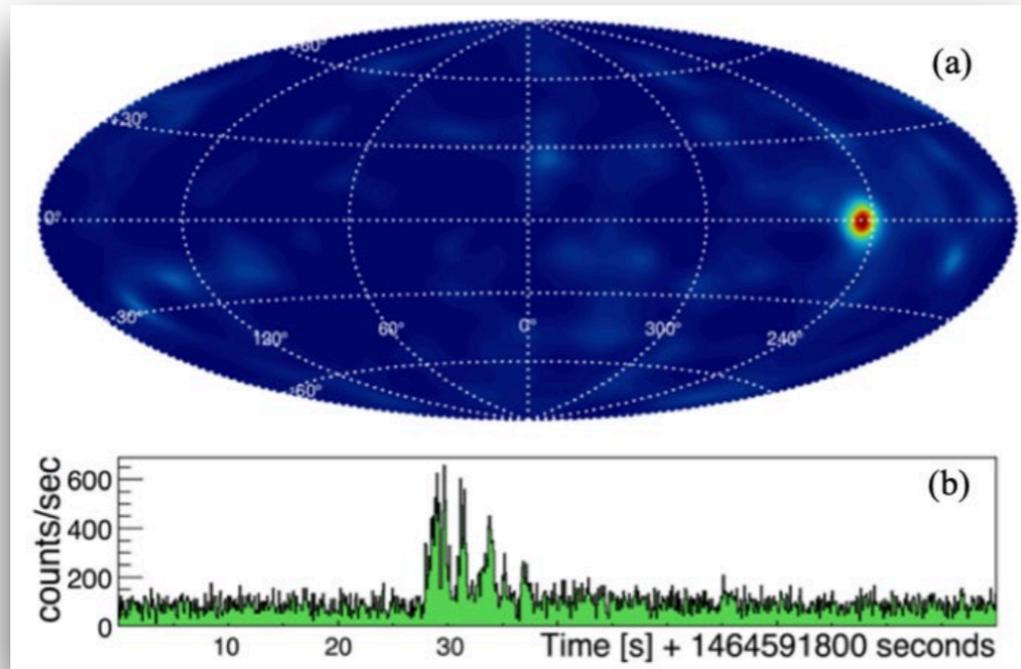
Ballon flights in 2014 and 2016



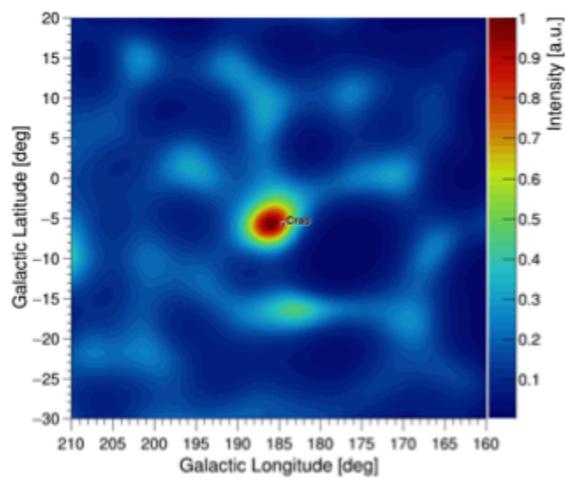
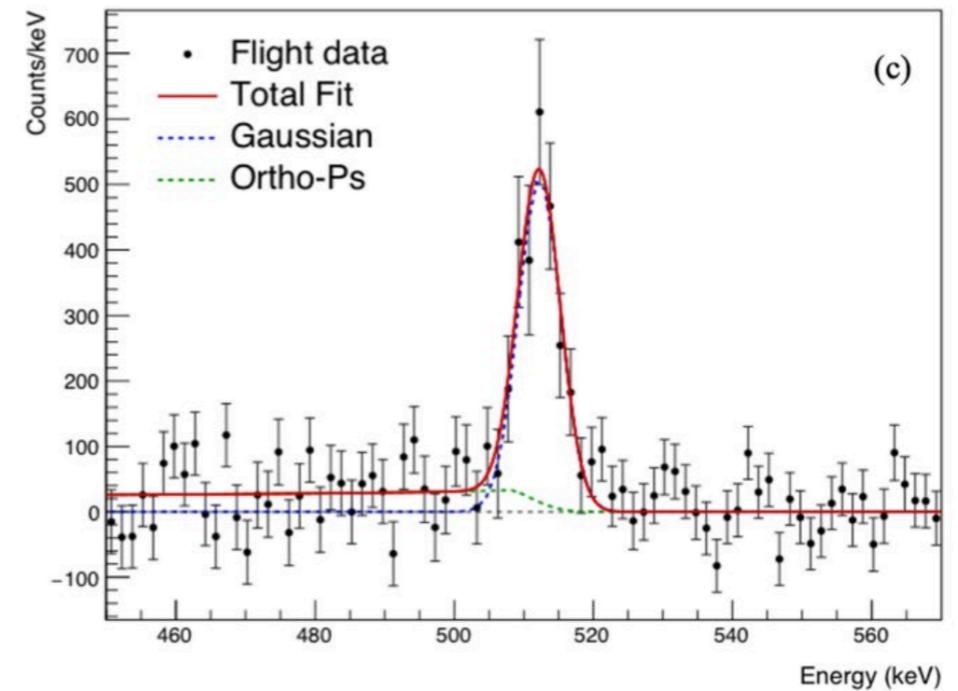
2016 balloon flight: results

46 days (May 16-July 2)

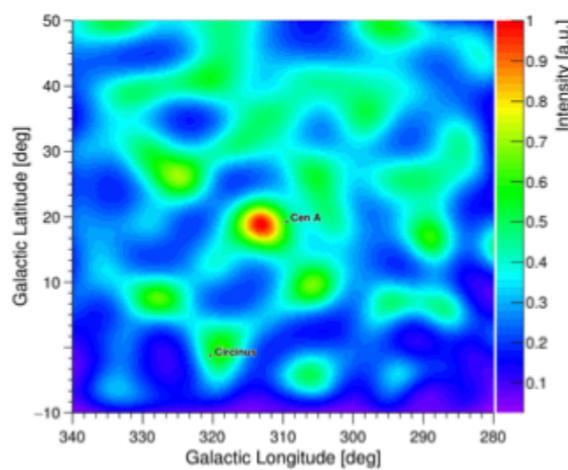
A gamma-ray burst, GRB 160530A



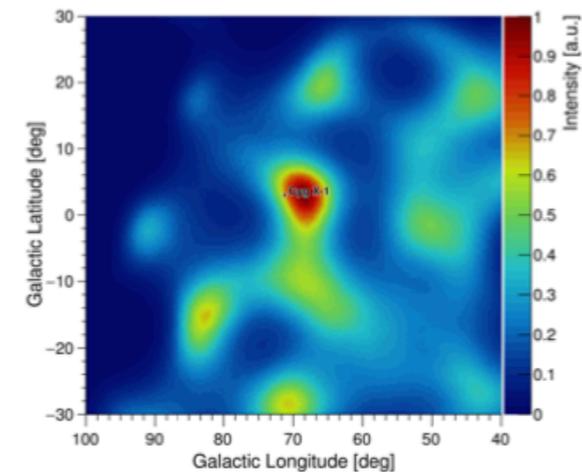
The 511 keV annihilation line



(a) Crab Nebula



(b) Centaurus A



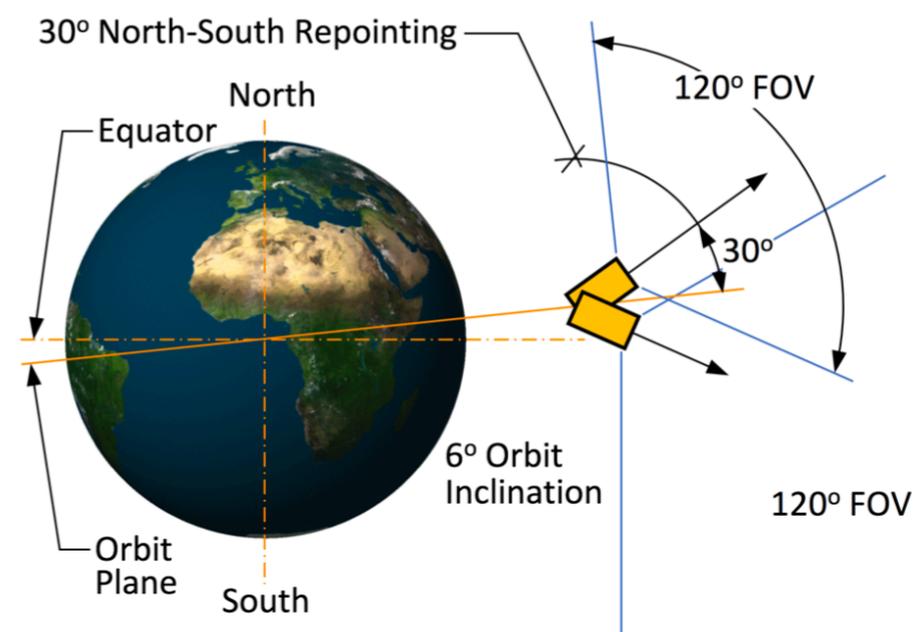
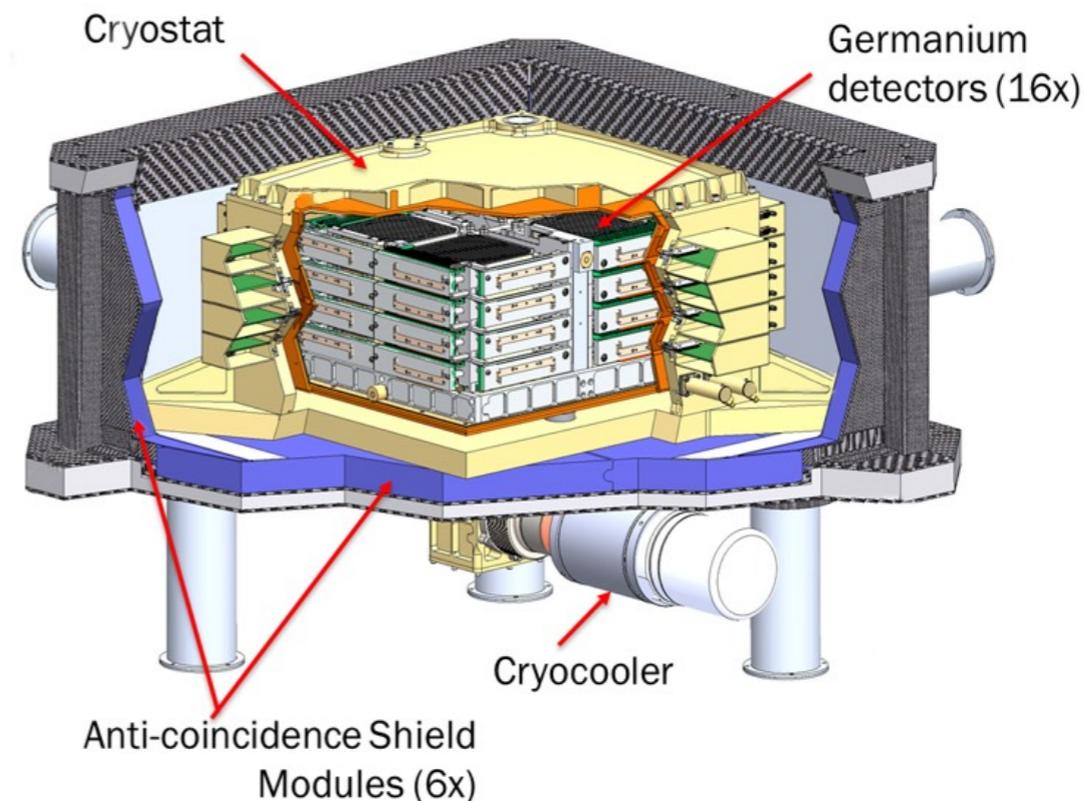
(c) Cygnus X-1

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

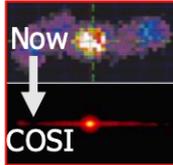


- ❑ COSI uses germanium detectors for excellent energy resolution
 - $\Delta E/E$ more than an order of magnitude better than the previous Compton telescope (COMPTEL on CGRO)

- ❑ COSI constantly points away from Earth and alternates between North and South to **cover the whole sky in 24 hours**
 - COSI's instantaneous FOV is:
 - >4x larger than COMPTEL
 - >12x larger than INTEGRAL/SPI

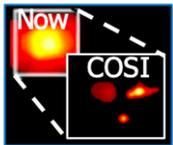


COSI Fact Sheet



Uncover the Origin of Galactic Positrons

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



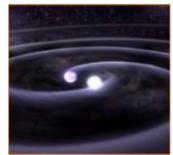
Reveal Galactic Element Formation

- 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



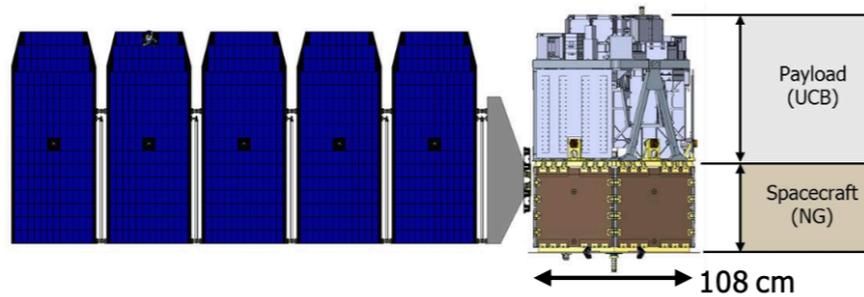
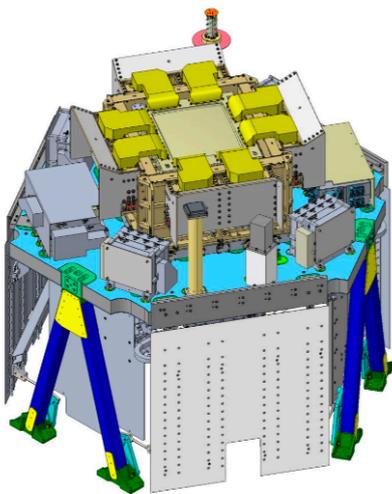
Probe the Physics of Multimessenger Events

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

Characteristic	Requirement
Sky Coverage	<ul style="list-style-type: none"> >25%-sky instantaneous FOV 100%-sky each day
Energy Resolution (FWHM)	<ul style="list-style-type: none"> <1.2% @ 0.511 MeV <0.8% at 1.157 MeV (^{44}Ti)
Narrow Line Sensitivity (2 yr, 3σ)	[photons/cm ² /s] <ul style="list-style-type: none"> 1.2×10^{-5} @ 0.511 MeV 3.0×10^{-6} @ ^{26}Al, ^{60}Fe, and ^{44}Ti
Angular Resolution (FWHM)	<ul style="list-style-type: none"> <4.1° @ 0.511 MeV <2.1° @ 1.8 MeV (^{26}Al)
Polarization	<ul style="list-style-type: none"> >1.4×10^{-10} erg/cm²/s
GRB alerts	<ul style="list-style-type: none"> 6×10^{-7} erg/cm² (<20° off-axis)

- Timing requirements
- 5 ms relative
 - Photon arrival times to UT to better than 100 ms
 - Goal <500 μs arrival times

- Data
- Malindi primary ground station
 - 4 kbps S-band return link to TDRSS for <1 hr reporting of GRB alerts
 - Mission Ops at SSL

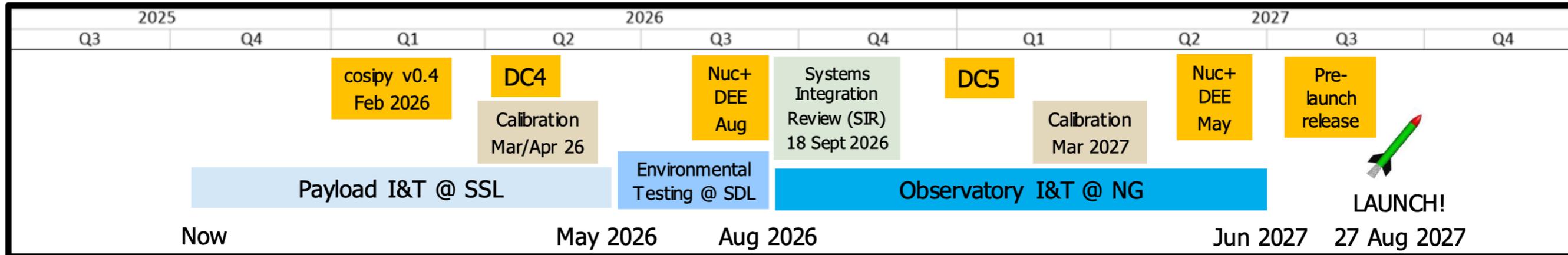


- Northrop Grumman: spacecraft (Dulles); structure (Magna)
- UCB/SSL: payload systems, cryostat, electronics, BTO
- Naval Research Lab: ASIC readout electronics and bismuth germanium oxide (BGO) shields
- Lawrence Berkeley National Lab and Mirion Technologies: germanium detectors
- GSFC: Cryostat Heat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

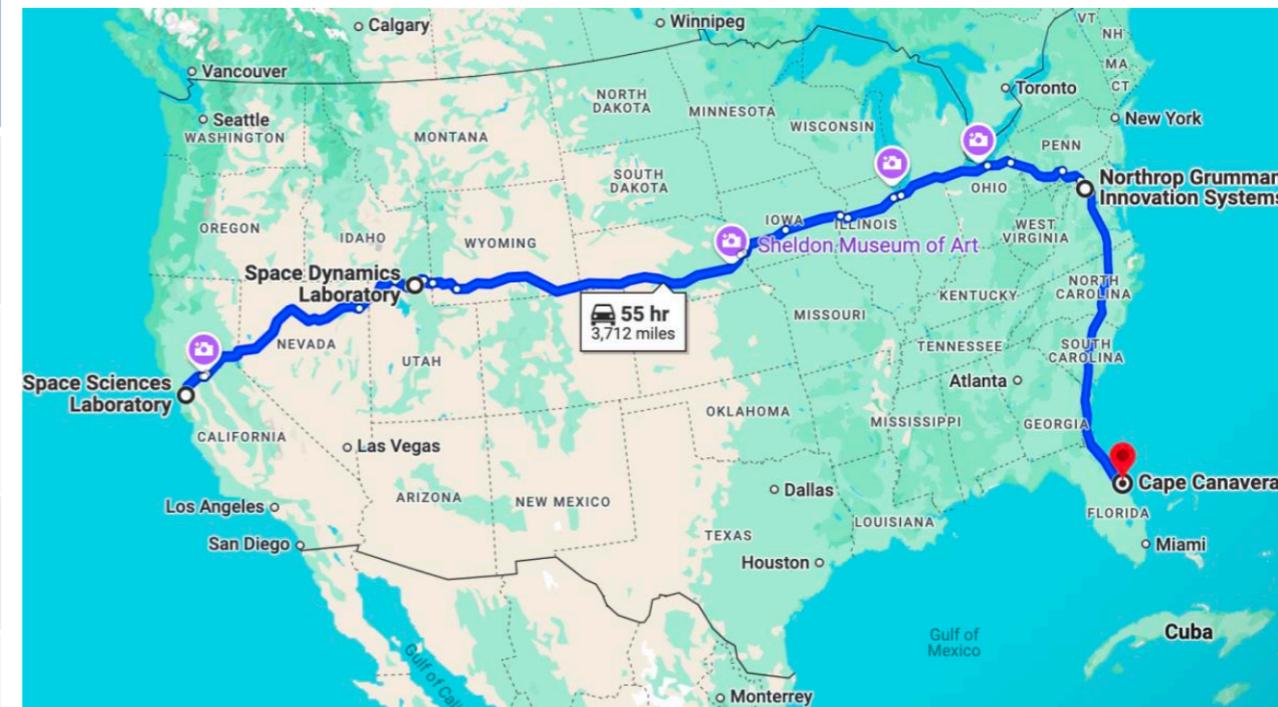
COSI Mass, Power, and Data	
Mass (372 kg Not to Exceed)	338 kg (Current Best Estimate, CBE)
Power (732 W generated by Solar Array w/ battery storage)	646 W CBE (including battery recharge)
Data (through Malindi Ground Station, provided by ASI)	~1 GB/day S-band
Data (through Tracking and Data Relay Satellite 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 $0.25^\circ \pm 0.15^\circ$ inclination
 - >2-year mission

Path forward for COSI



What activity?	Where?	When?
Payload Integration & Testing (I&T)	SSL (Berkeley)	Now to May 2026
Payload I&T - environmental testing	SDL (Utah)	May 2026 to Aug 2026
Observatory I&T	NG (DC area)	Aug 2026 to Jun 2027
Launch (SpaceX Falcon 9)	Cape Canaveral	Aug 2027



INAF involvement

INAF members of the COSI Team: (with HW, SW and scientific expertise)

V. Fioretti
A. Bulgarelli
G. Ghirlanda
F. Tavecchio
N. Parmiggiani TD
R. Falco AdR
A. Sciaccaluga AdR
M. Ghulam PhD
M. Maniscalco, PhD

Financed by ASI-INAF contract
Started in June 2024
Duration: 36 months

Scientific Working Groups

FT: Co-lead of extragalactic and DM SWGs

Developer team

VF and AB: leads of two sub-WPs

Extended INAF team (from the last round of “schede”):

In total 18 INAF researchers (building on the experience gained with AGILE, eASTROGAM proposal) are involved for a total of 1.2 FTE/yr (2024-2026)

INAF contribution

Work in Progress

- COSI analysis pipeline (OAS):

- Coordination and development of **cosiflow**, based on airflow, for the management and deployment of the COSI mission analysis pipeline (A. Bulgarelli, R. Falco, N. Parmiggiani)
- Coordination and development of the **Fast Transient Pipeline** for science alarm generation (A. Bulgarelli, N. Parmiggiani, V. Fioretti, G. Panebianco, M. Maniscalco)
- Development of algorithms for **transient localization and blind search analysis** using classical and machine learning techniques (N. Parmiggiani, M. Ghulam)

- COSI calibration (OAS):

- calibration and detector effects for the anticoincidence system (V. Fioretti)

- Data Challenges models and exploration of scientific cases (OA Brera):

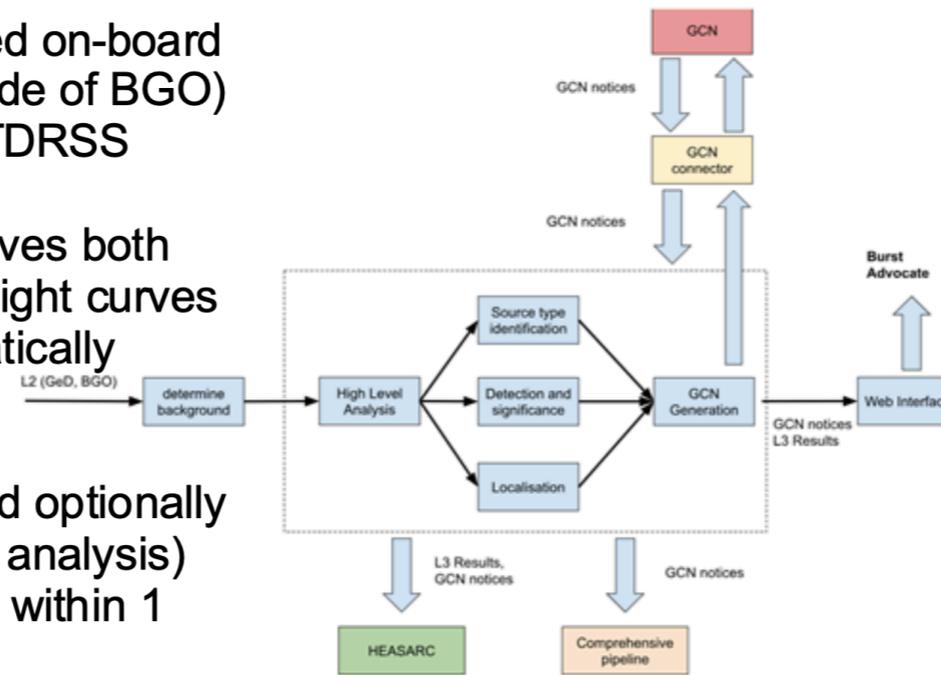
- input models for DC (GRB, AGNs, polarization), study of scientific cases (G. Ghirlanda, A. Sciacaluga, F. Tavecchio)

INAF contribution

Work in Progress

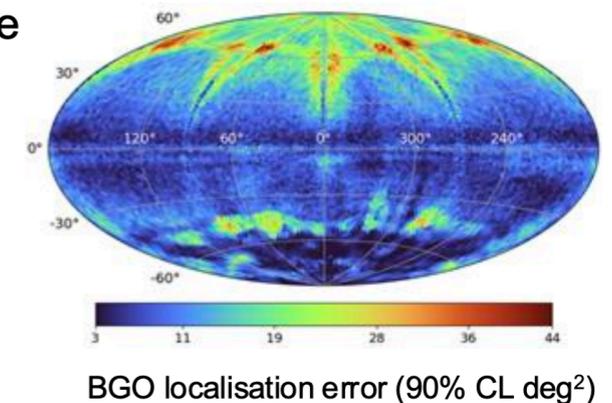
Fast Transient Pipeline for alert generation

- Transients (e.g. GRBs) are detected on-board by the anticoincidence system (made of BGO) and transmitted to the ground via TDRSS
- The **Fast Transient Pipeline** receives both the Compton events and the ACS light curves of the on-board trigger and automatically analyzes the data
- A report on the source location (and optionally the results of the time and spectral analysis) are transmitted to GCN/HEASARC within 1 hour



Activities on the Anticoincidence System (ACS)

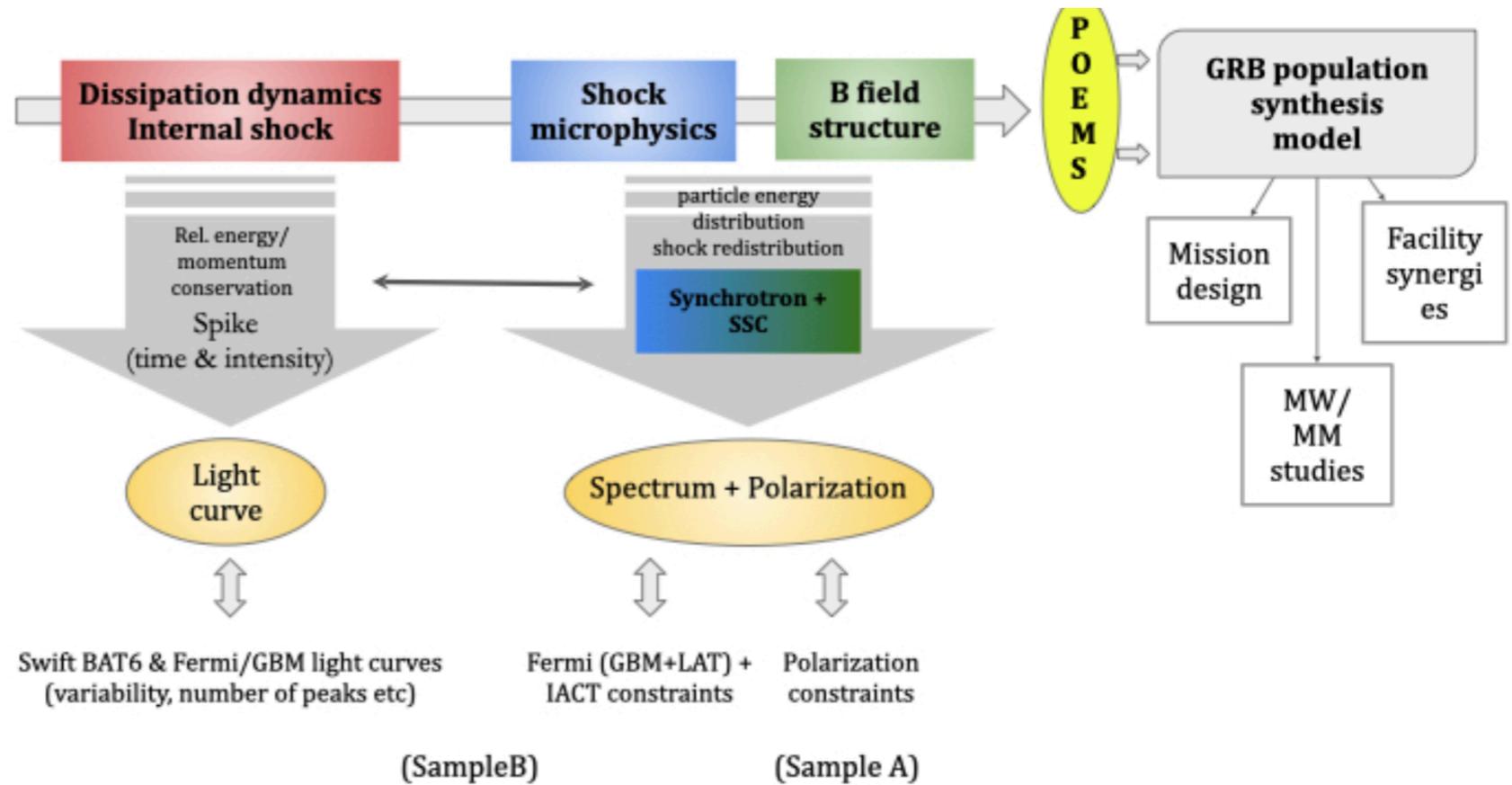
- Classical and machine learning methods to localize short GRBs using the BGO shield.
 - Published paper: [N. Parmiggiani et al. ApJ 2026](#)
- Deep learning (DL) models to estimate the ACS background using as input the orbital and attitude parameters of the satellite with the aims to detect GRBs as anomalies in the expected counts.
- Quantum Machine Learning model to evaluate Quantum Computers capabilities in the detection of Gamma-ray Bursts
 - Paper under review for Astronomy and Computing
- Geant4 benchmarking of the ACS simulation to include real detector effects to the COSI simulation
 - Published paper: [A. Ciabattoni et al. Exp Astr. 2025](#)



INAF contribution

Work in Progress

We plan to implement the model for emission and polarization developed in this task in an already available population synthesis model of GRB and use the output to derive a realistic estimate of the detection rate of COSI and the properties of the detected population.



INAF contribution



Fine-tuning and modeling of FSRQ with state-of-the-art knowledge.

(A. Sciaccaluga, F. Tavecchio)

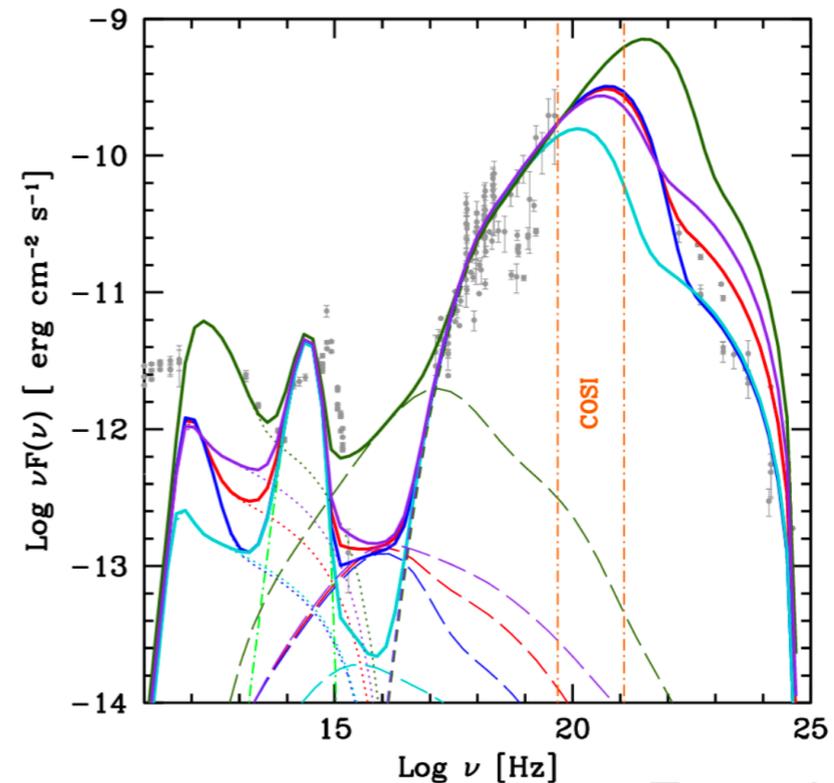
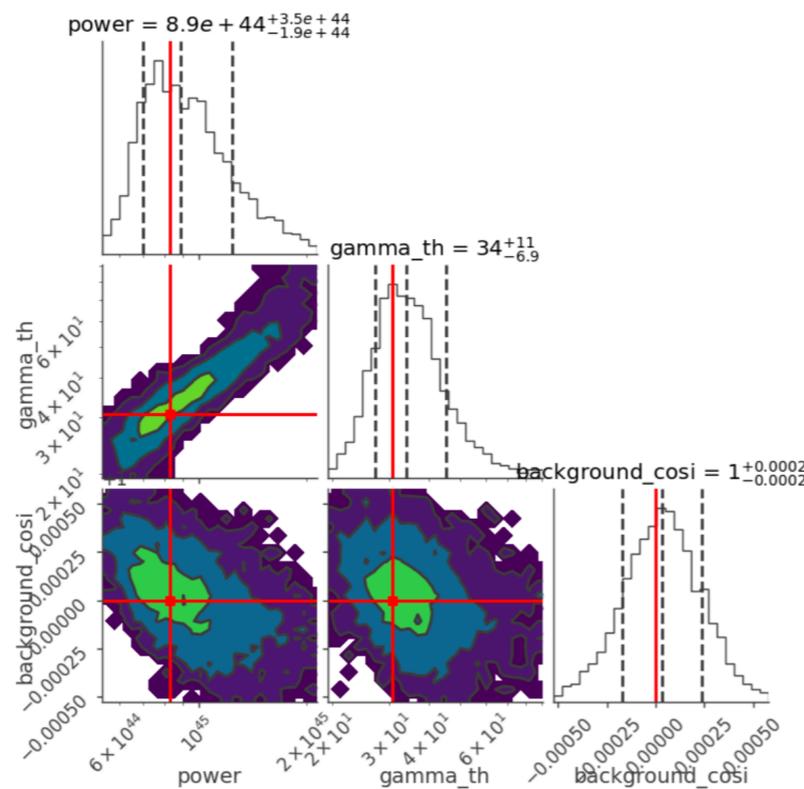
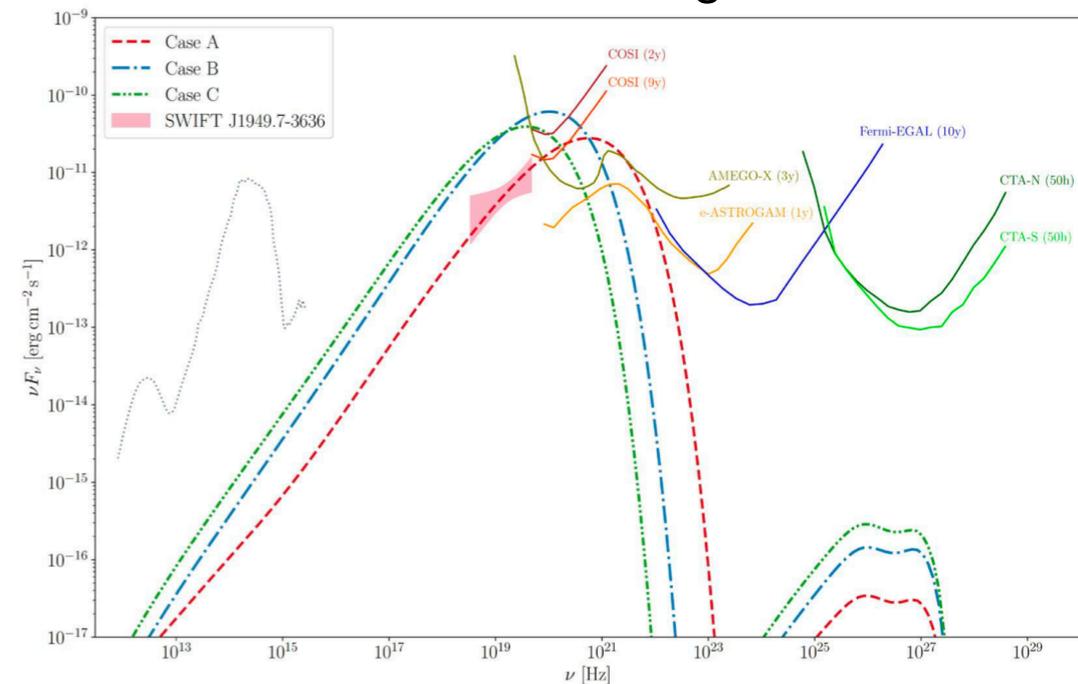
Modeling of potential new MeV population of MeV synchrotron blazars

(A. Sciaccaluga, F. Tavecchio)

Feasibility studies for COSI.

(A. Sciaccaluga, F. Tavecchio)

Sciaccaluga et al. 2026



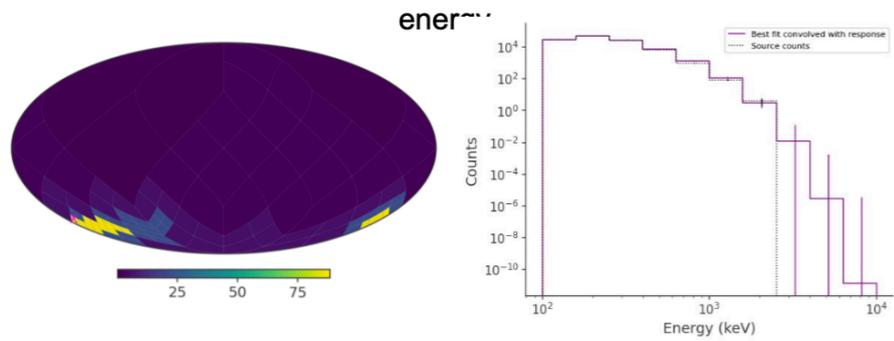
Tavecchio et al. 2025

COSI Data Challenges

Interactions

NGC 1068

Goal: determine the flux in the COSI band and the coronal cut-off

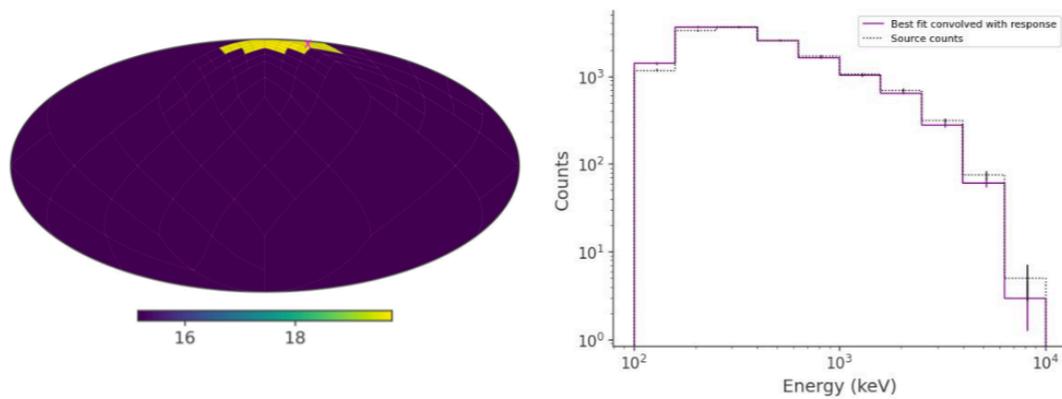


$$\Gamma = 1.92 \quad E_{\text{cut}} = 225^{+86}_{-64} \text{ keV} \quad F_{\text{COSI}} = 2.47^{+0.81}_{-0.67} \times 10^{-3} \frac{\text{photons}}{\text{cm}^2\text{s}}$$

4C+21.35

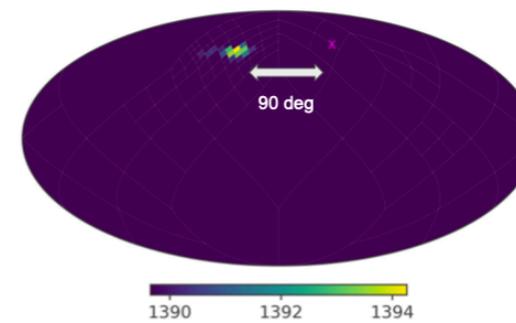
Goal: fit the 4C+21.35 spectrum in the flaring and non-flaring state

Non-flaring state

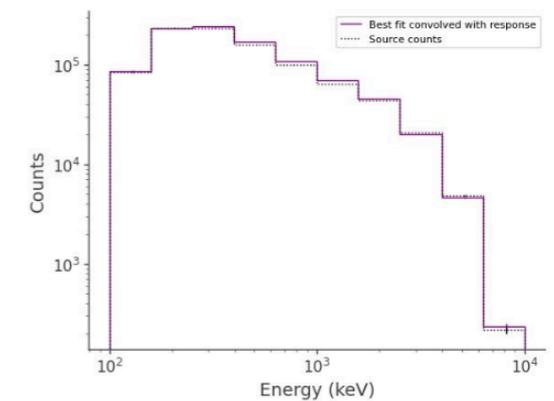


3C 279

Goal: spectral fit and polarization properties



Localization issues, already reported on slack



Spectral model: power law

COSI Data Challenges

<https://github.com/cositools/cosi-data-challenges>

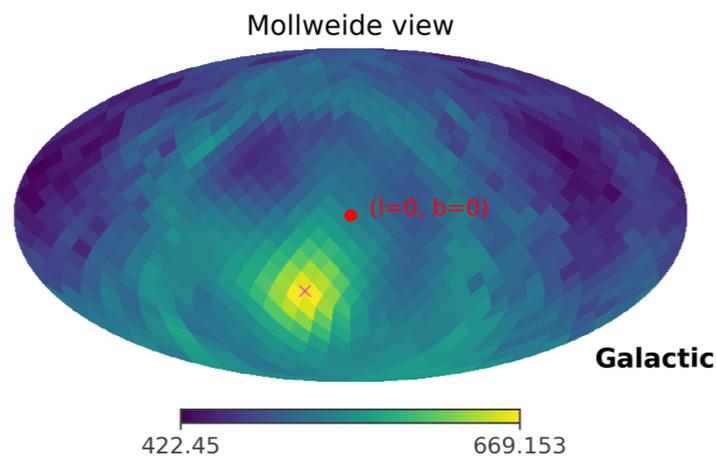
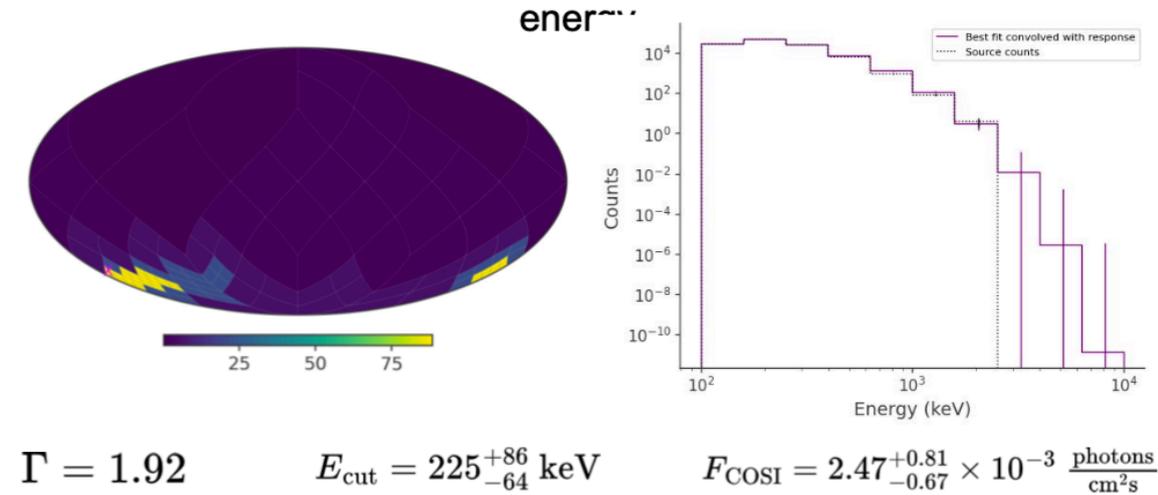
<https://github.com/cositools/cosipy>

DC3 is public!

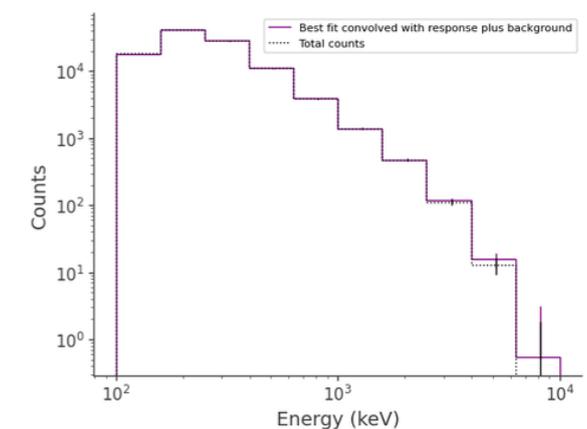
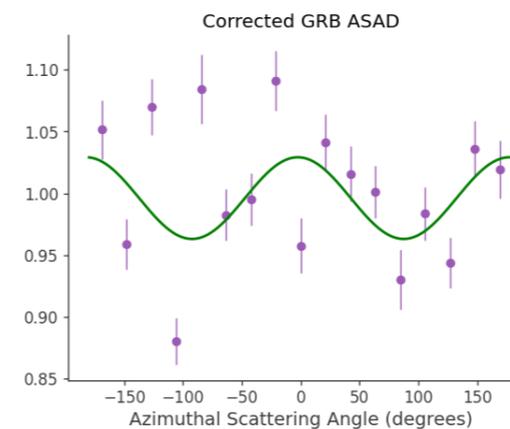
DC4 will be public in august-september!

NGC 1068

Goal: determine the flux in the COSI band and the coronal cut-off energy



Sky map and spectrum of GRB180504



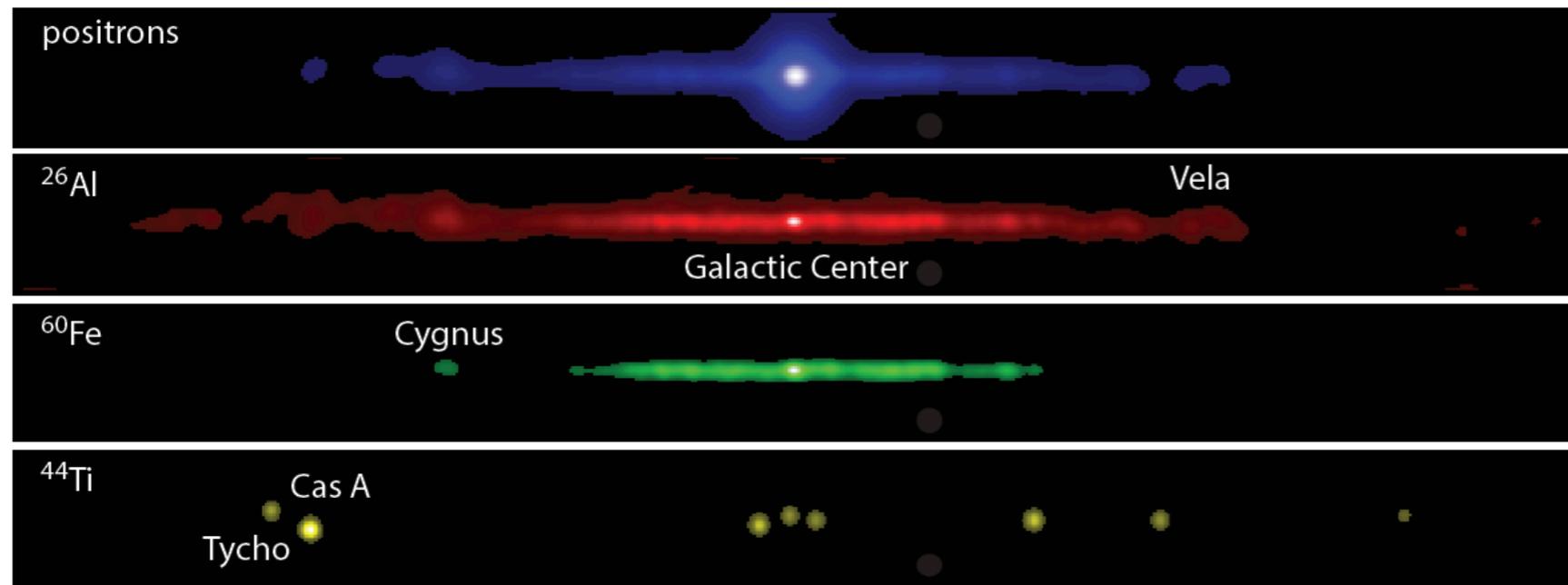
Thank you for your attention!



Backup

Anticipated COSI measurements

Emission line science



Additional wide-field mapping:

- Ortho-positronium
- Galactic continuum (related to positrons and cosmic rays)
- **All-sky survey**

Transient source science

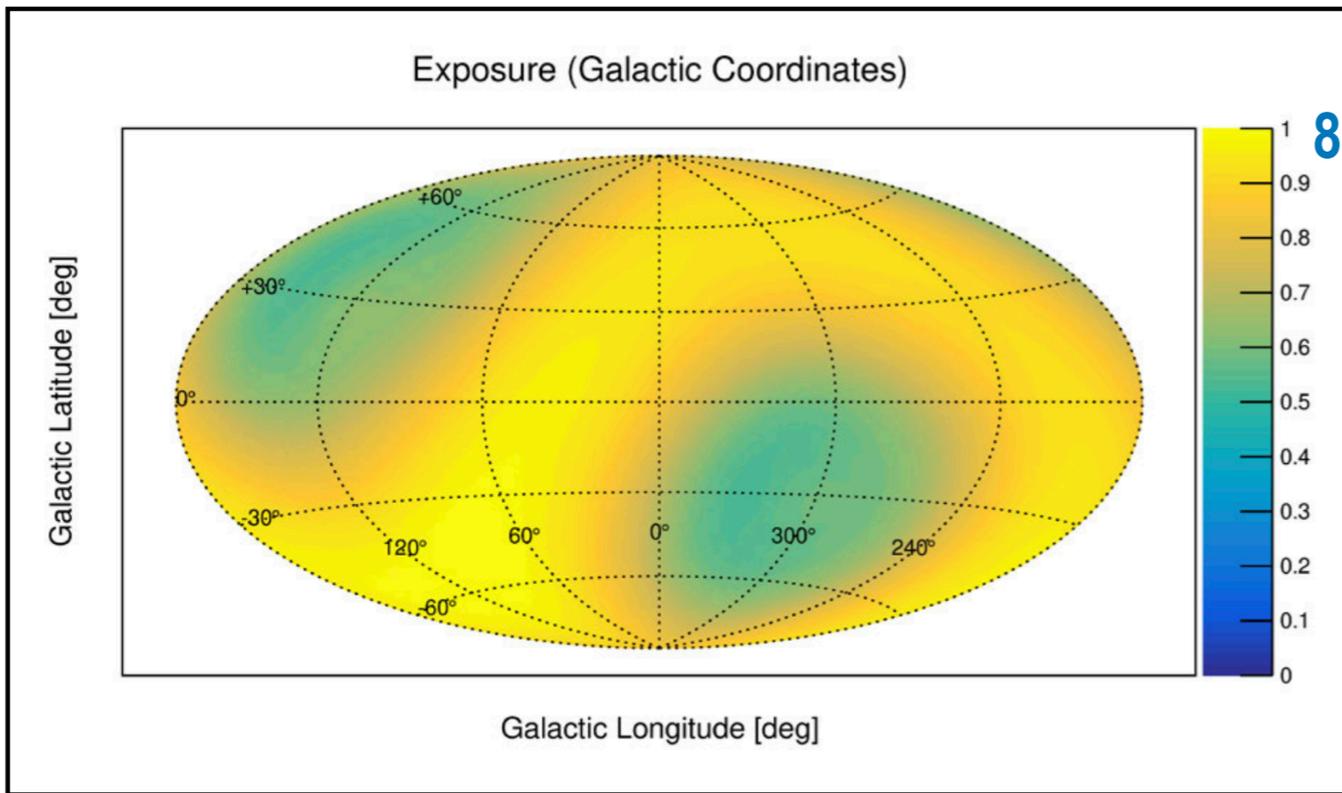
- GRB localizations
- GRB polarization
- Coverage of HE neutrino events
- Black hole transients

Extended portfolio:

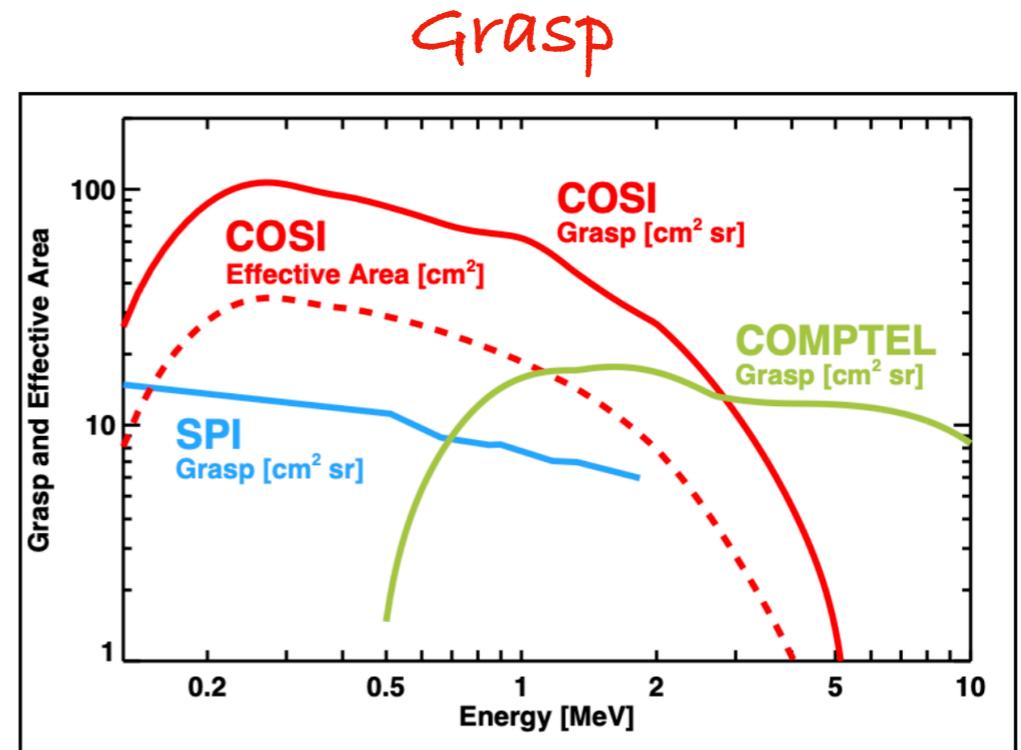
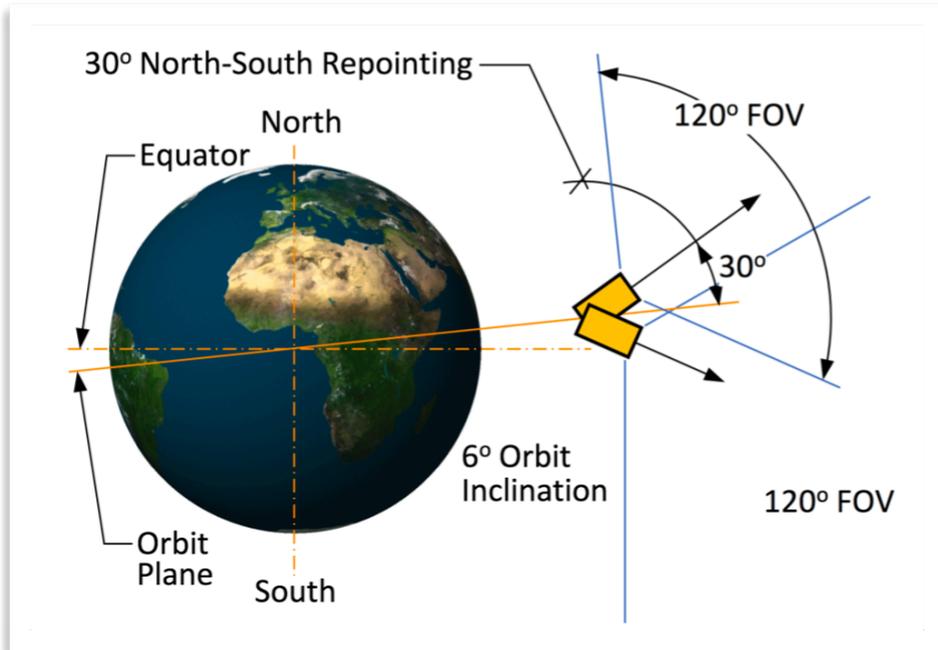
- Type Ia supernovae
- Flaring blazars

Persistent source polarization science

- Cygnus X-1
- Crab (calibration)
- Centaurus A

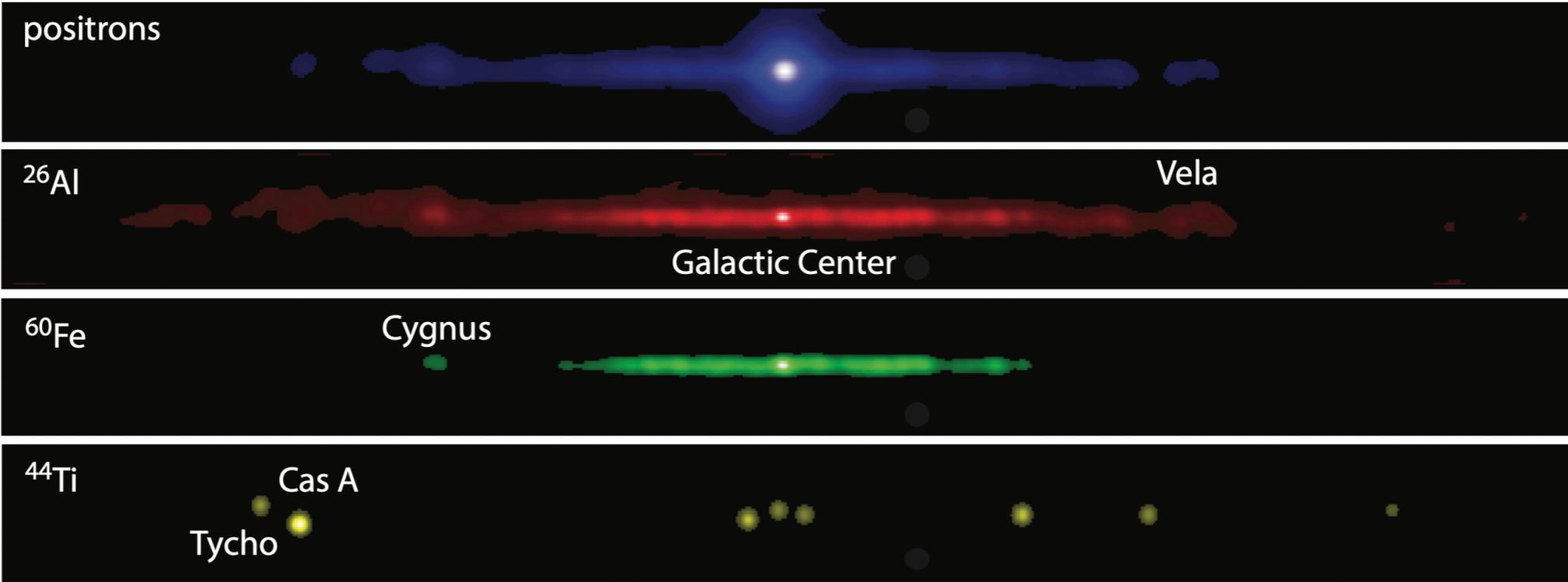
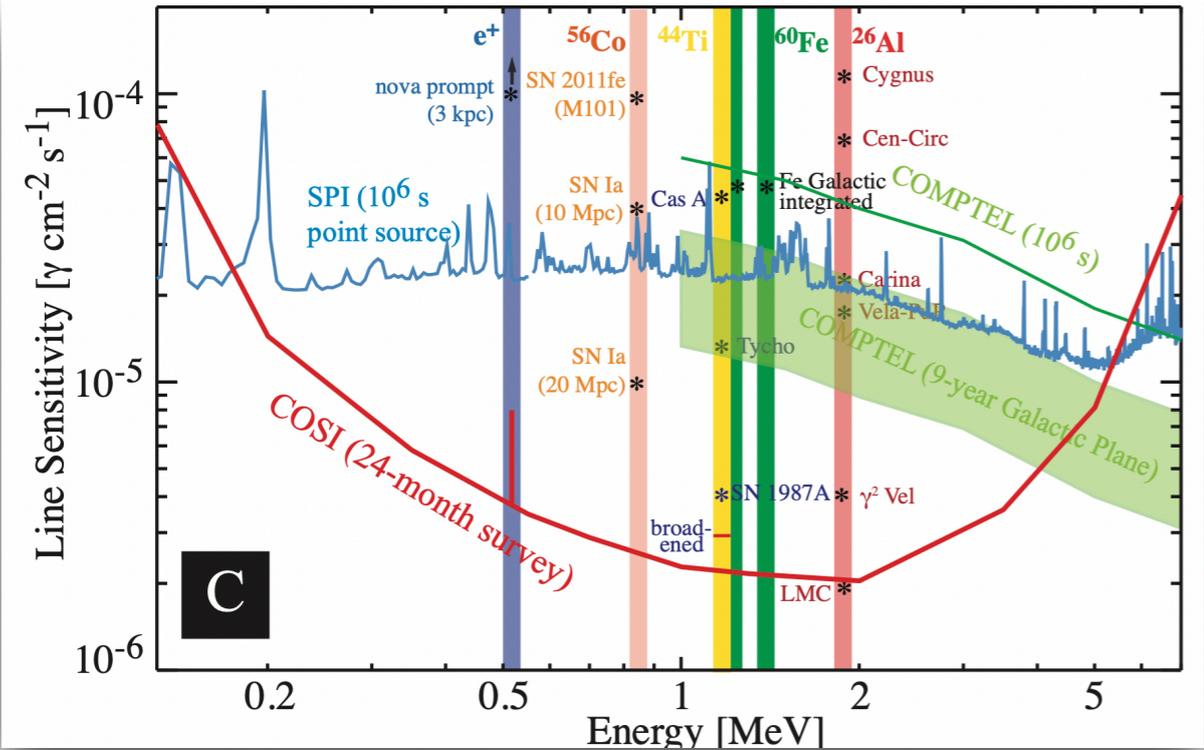


Daily sky exposure

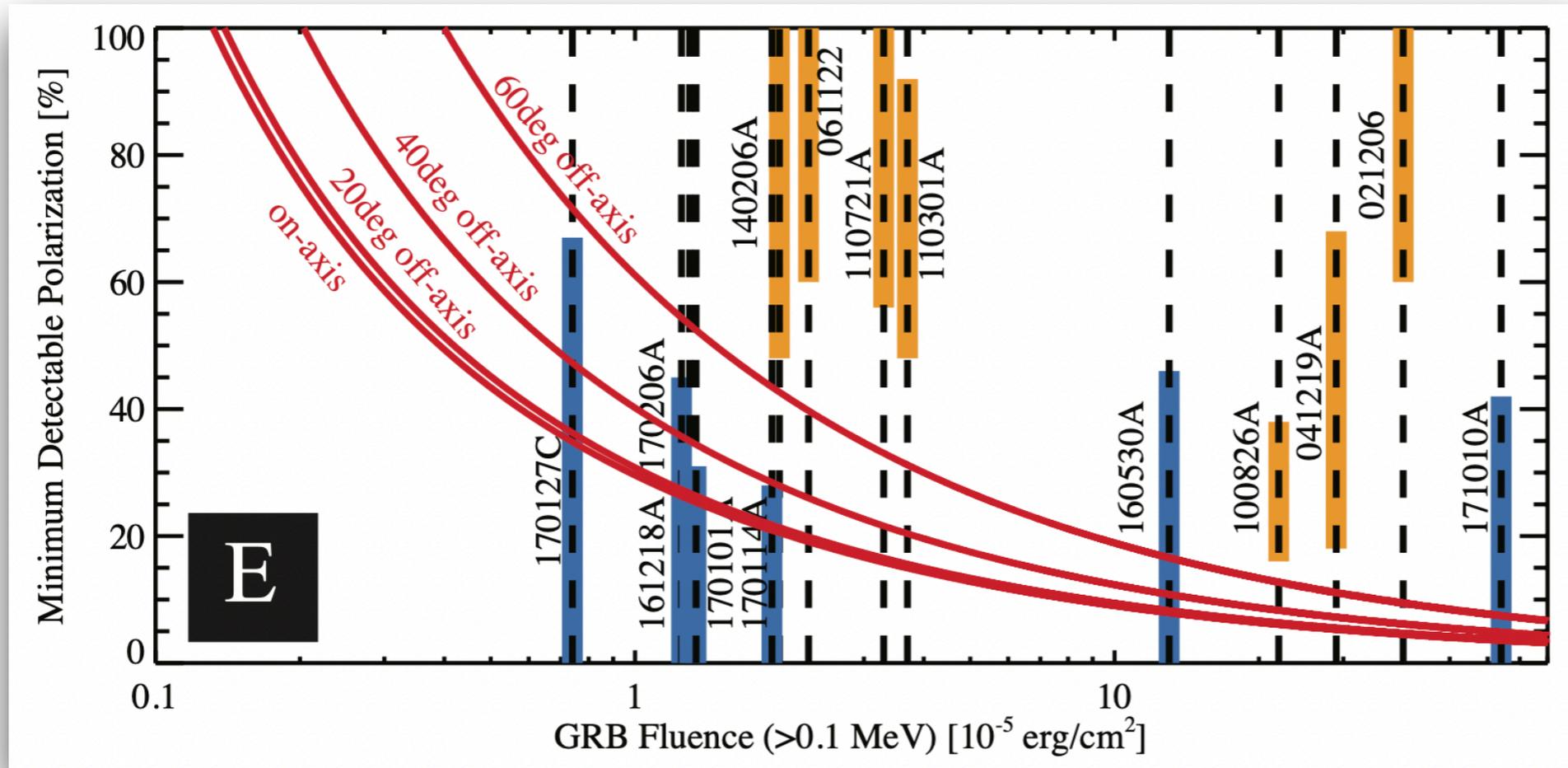


Expectations for transients
 About 20 short GRBs in 2 years
 At least 40 GRB 10 with $F > 10^{-6}$ cgs

Spectroscopy



Polarization

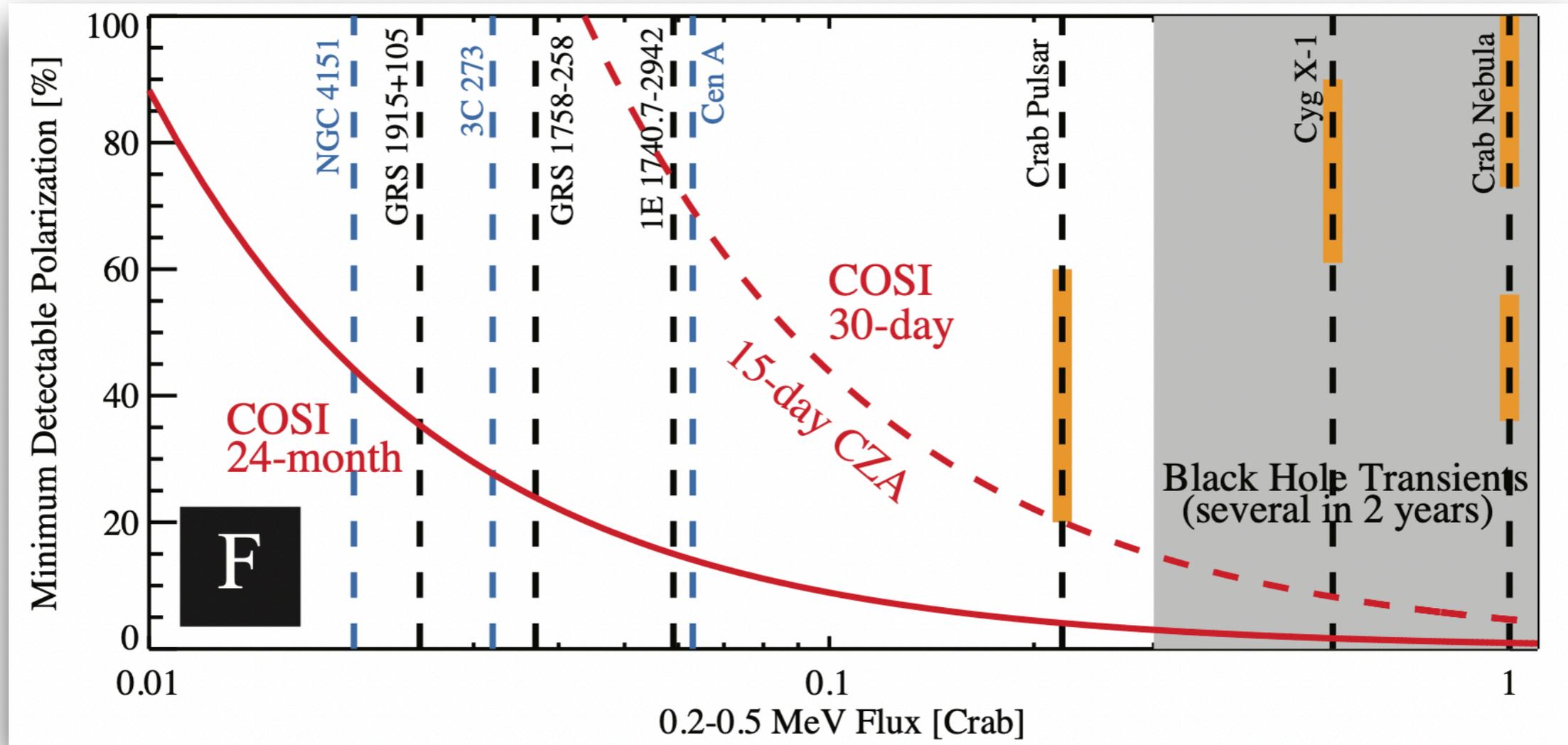


Expectations

- About 40 GRBs with MDP < 50%
- About 10 with MDP < 5-10%

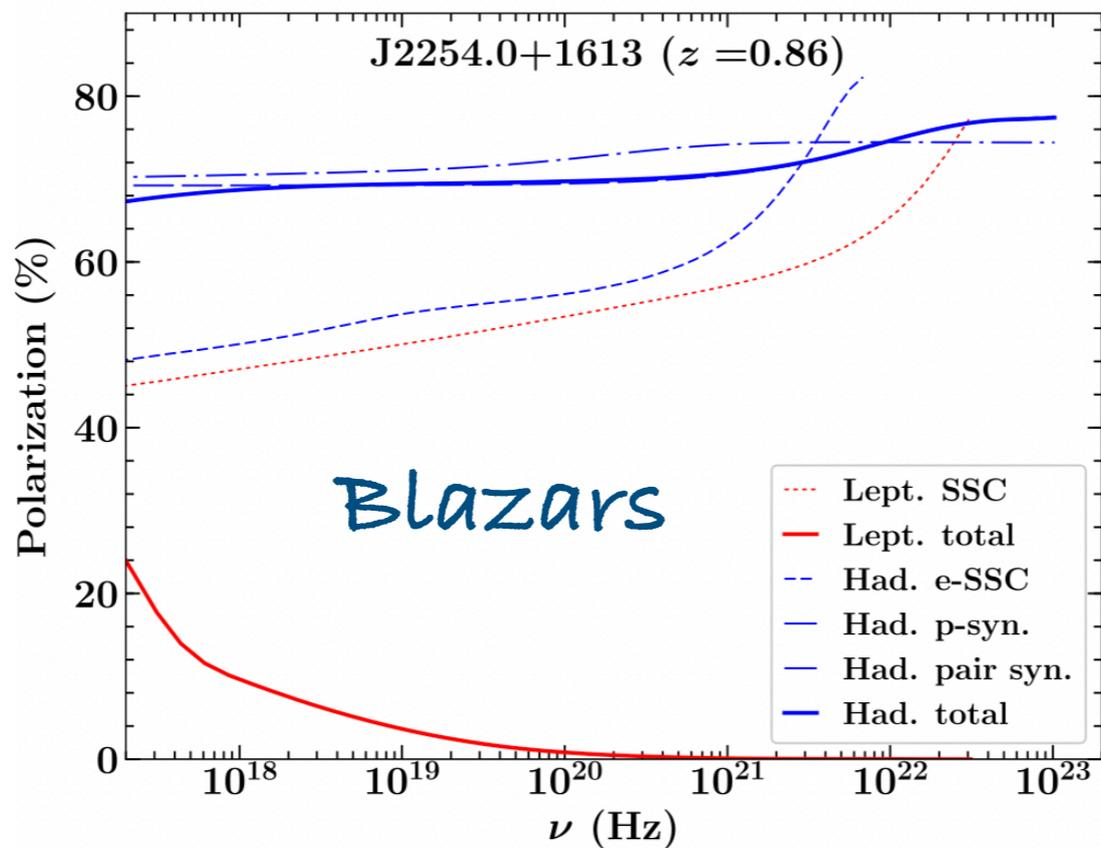
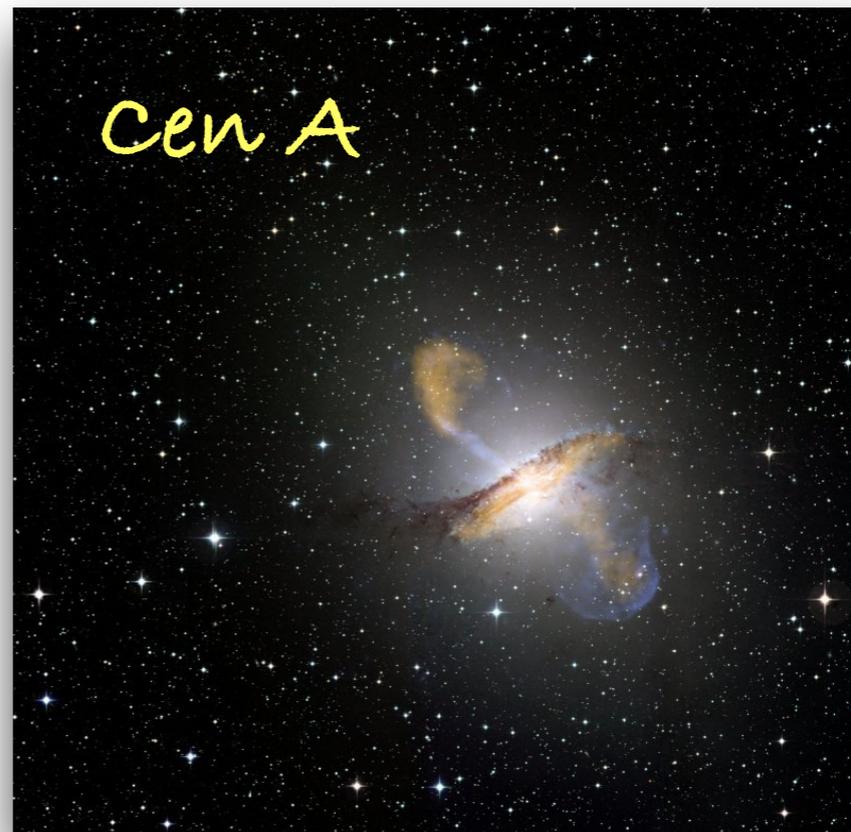
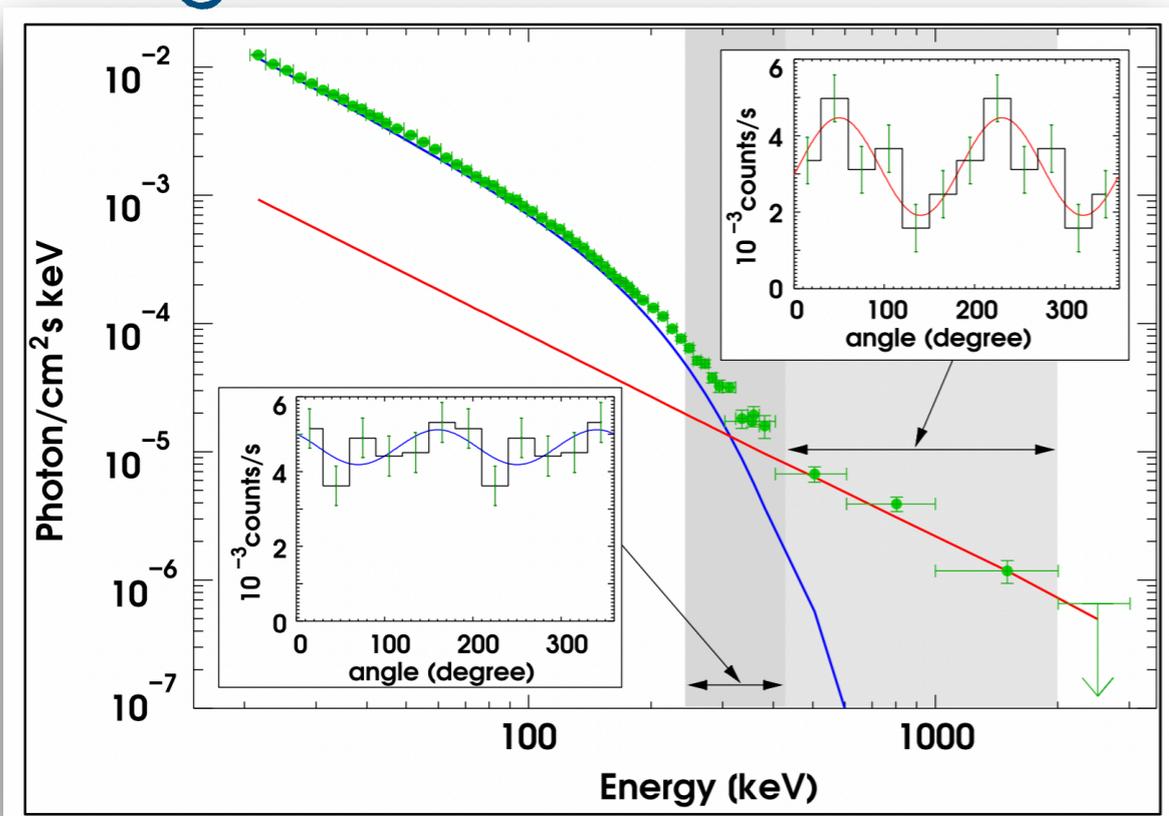
To be refined by using state-of-the-art population models...

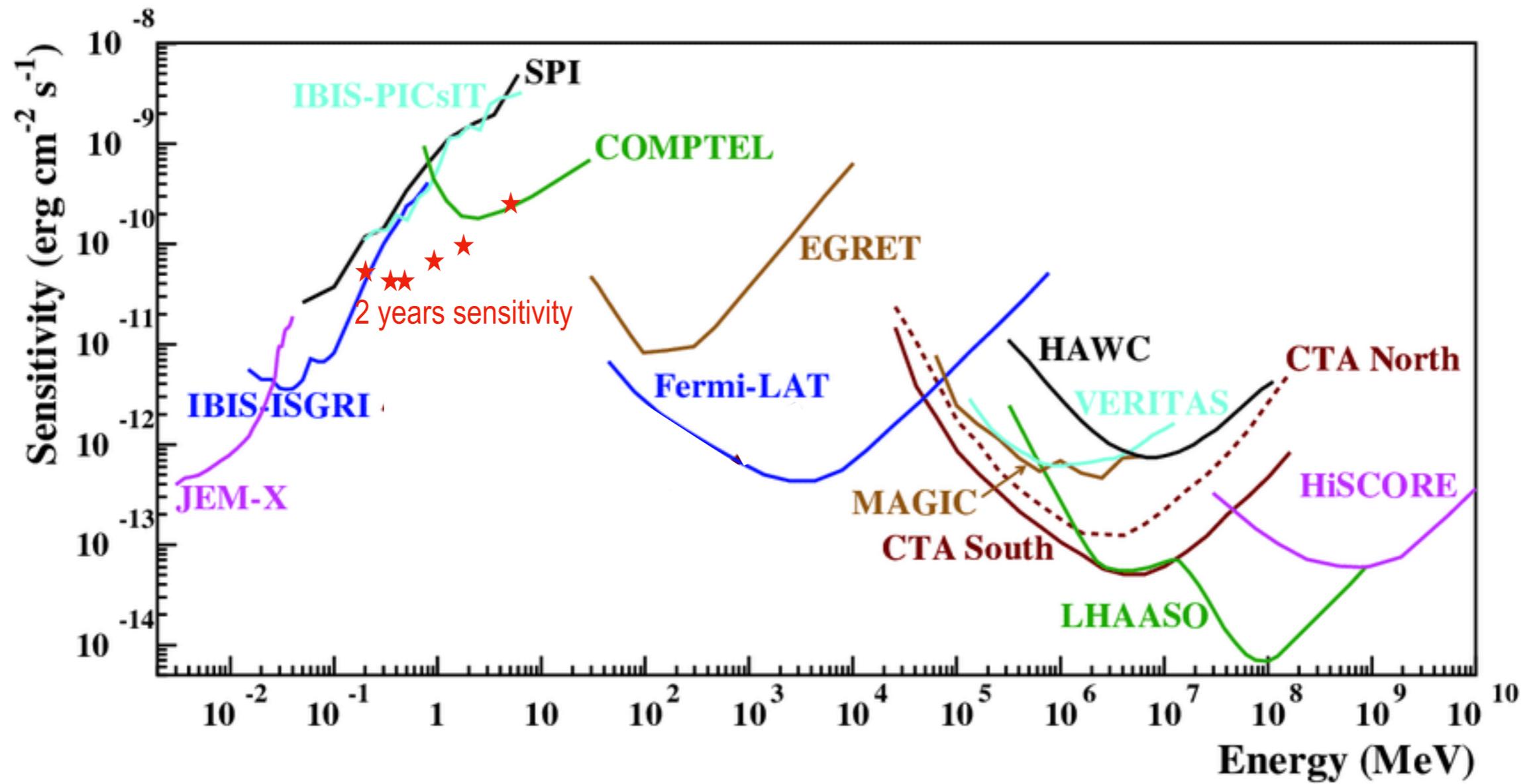
Polarization



Cyg X-1

Polarization

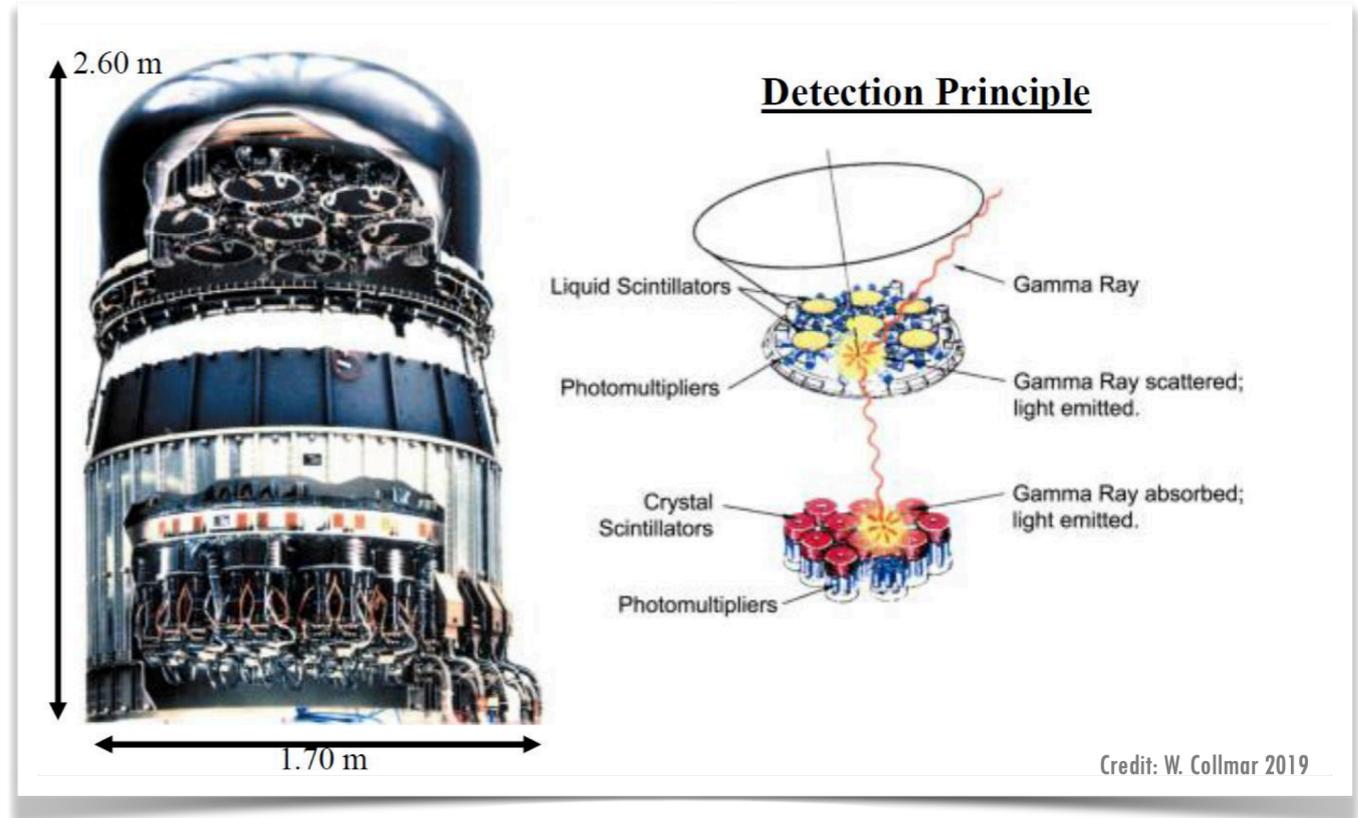




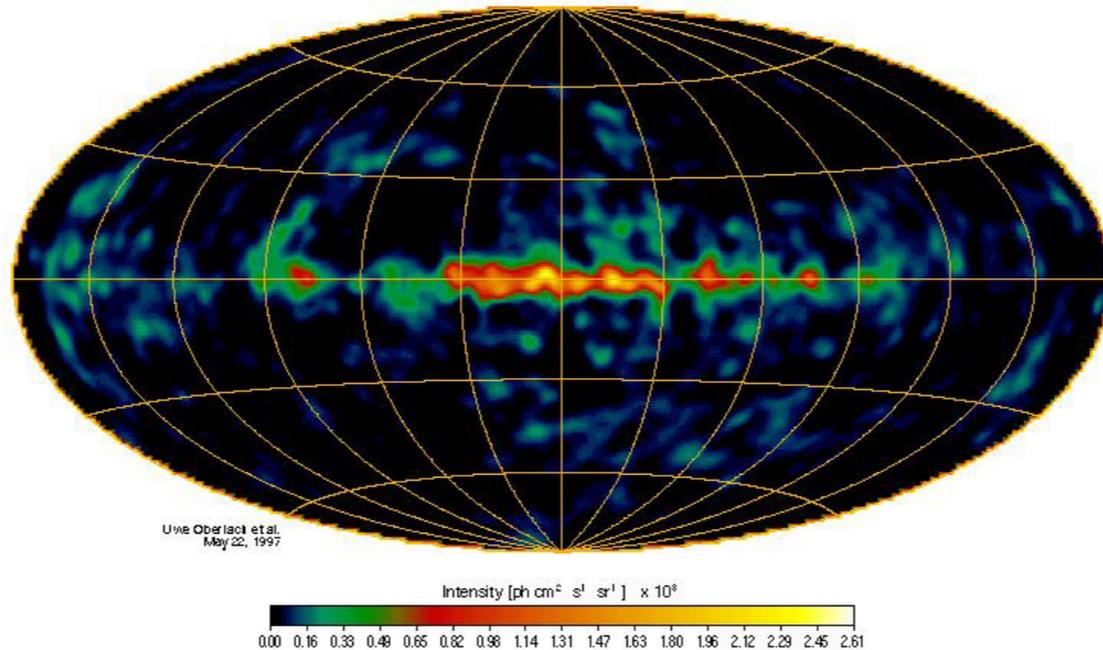
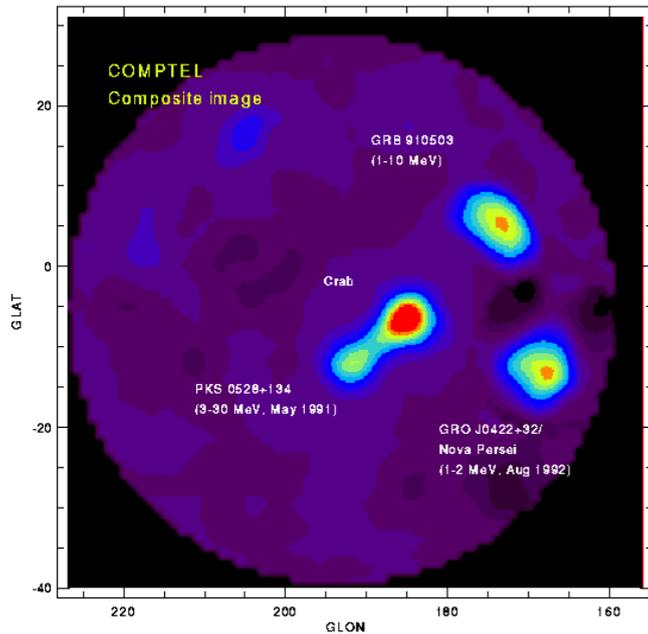
Comptel onboard CGRO



Operative 1991-2000



CGRO / COMPTEL 1.8 MeV, 5 Years Observing Time



Source Type	#
Pulsars	3
Stellar Binaries	2
SNR (continuum)	1
AGN	10