The Compton Spectrometer and Imager
COSI

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INAF-OAB

COSI in a nutshell

A satellite with a Compton Telescope (0.5-2 MeV) selected by NASA for the SMEX program

Launch: September 2025

Duration: 2 years

PI John Tomsick (UC Berkeley)

https://cosi.ssl.berkeley.edu

Institutions involved:

U. C. Berkeley

Naval Research Laboratory

Clemson Univ.

GSFC

ASI (Italy)

INAF (Italy)

IRAP (France)

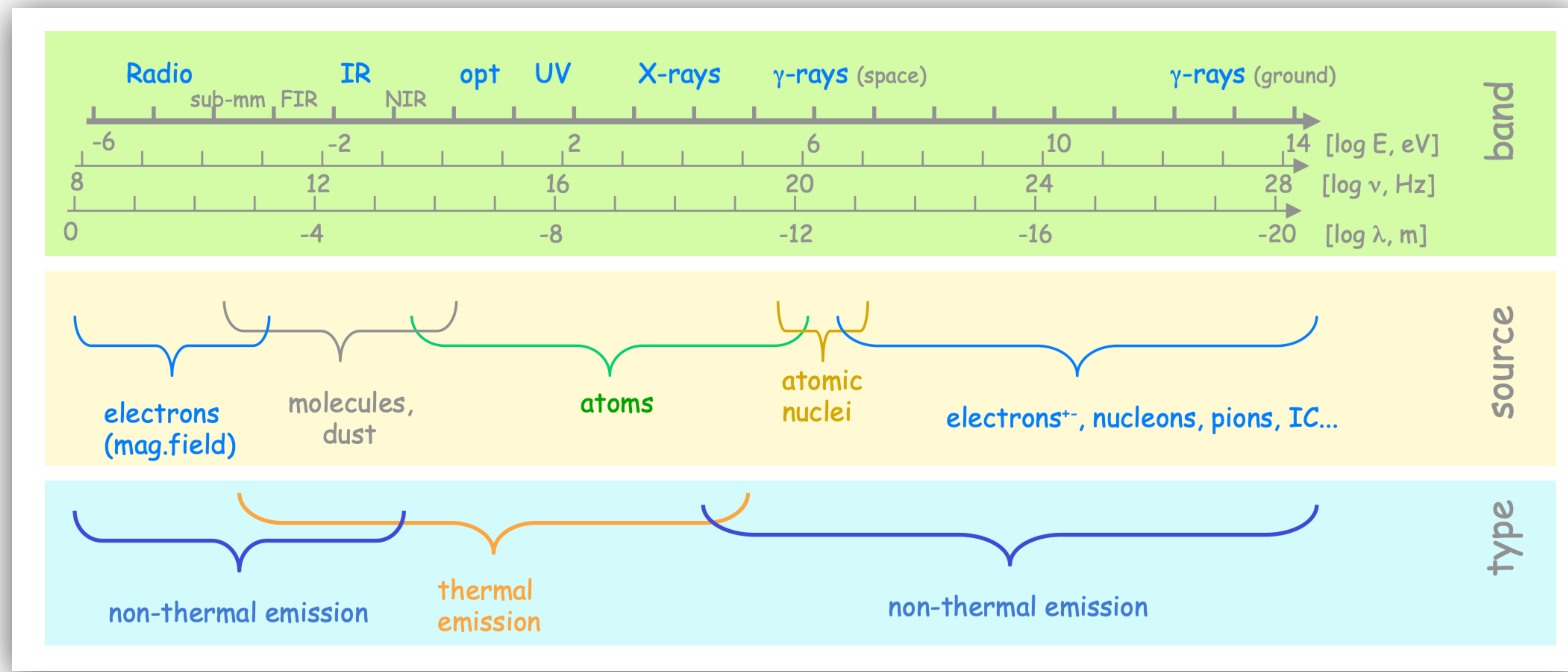
Tokio and Nagoya Univ.

Why the MeV band?

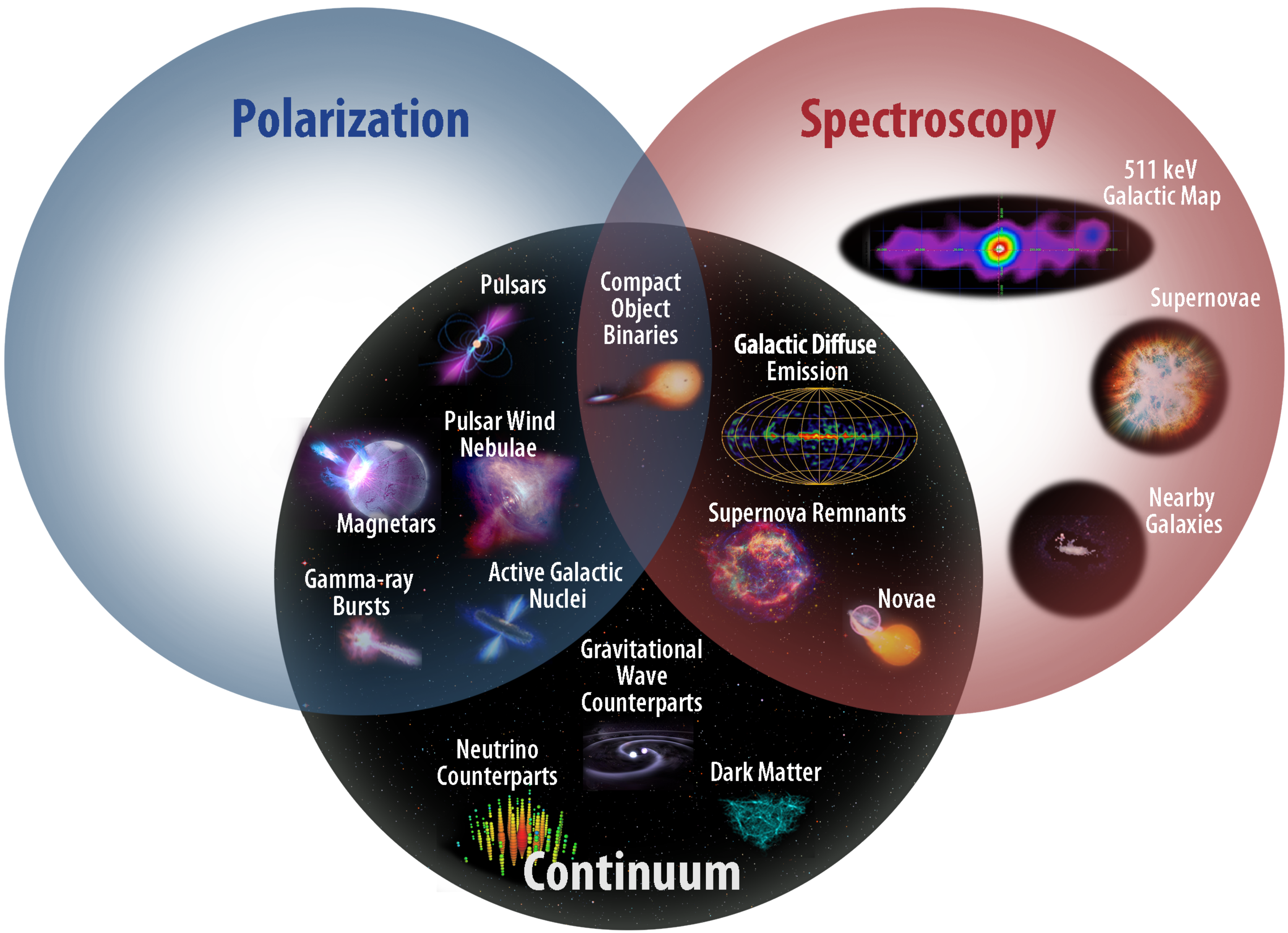
— The MeV band: a bridge between the thermal and non-thermal Universe

— Nuclear processes only accessible in this band (lines). Positron annihilation

— The output of several compact sources peaks in this band (e.g. GRB, blazars)



MeV astrophysics: a synoptic view



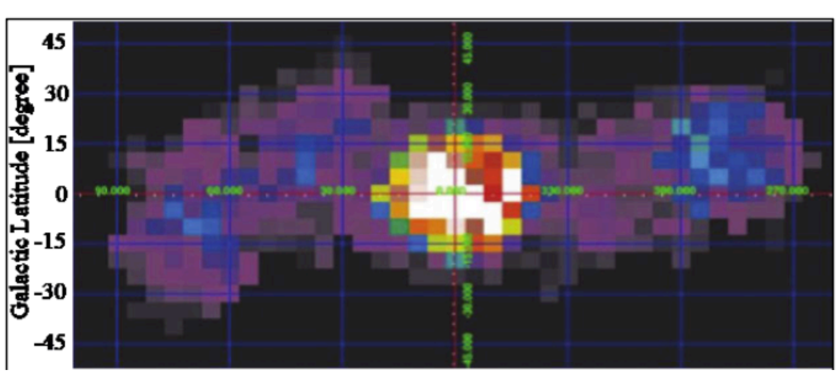
An illustrative example

The e± galactic annihilation line

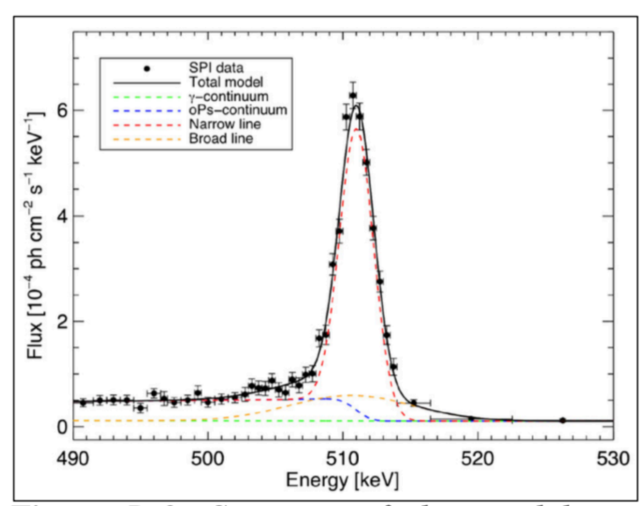
Discovered in the ’70, origin of e+ still a puzzle
The strongest persistent gamma-ray line in the sky
Strong excess from the GC but spatial distribution poorly known
A tool to study low-energy CR propagation in the Galaxy

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; *Iyudin 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]

SPI map (Bouchet et al. 2010)

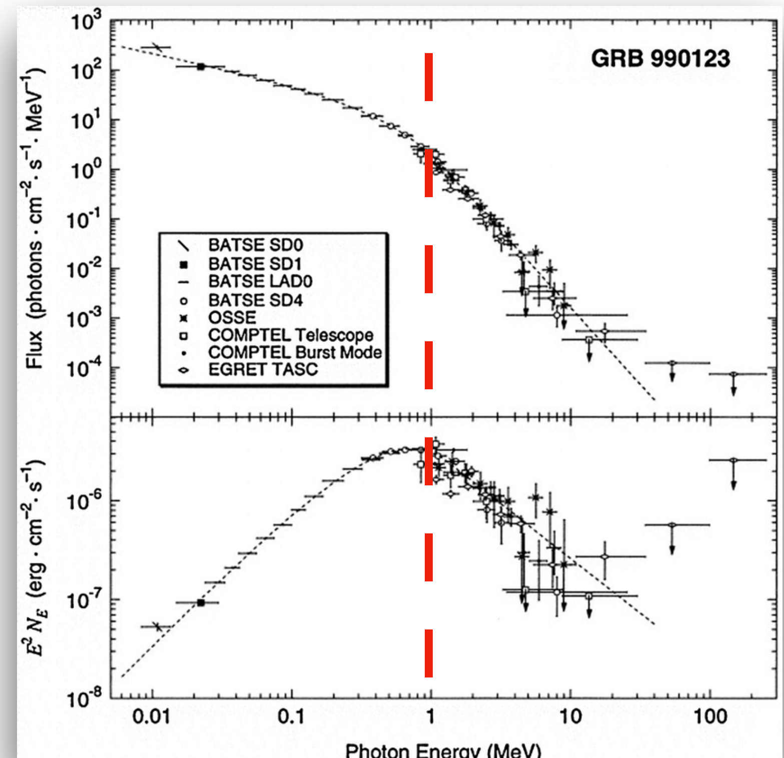


SPI spectrum (Siegert et al. 2019)

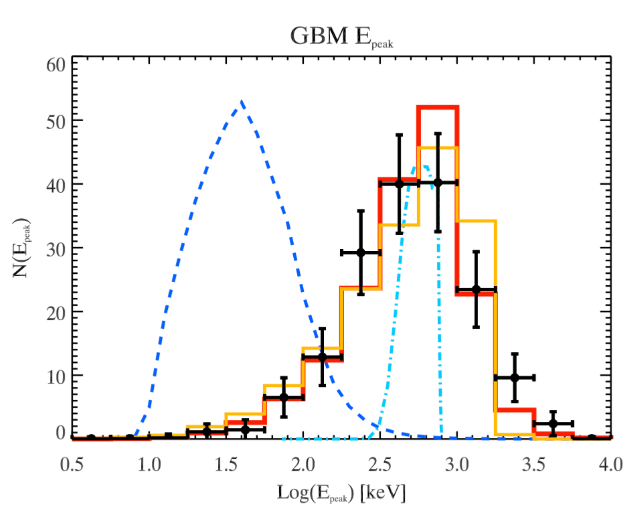


Compact objects and transients

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



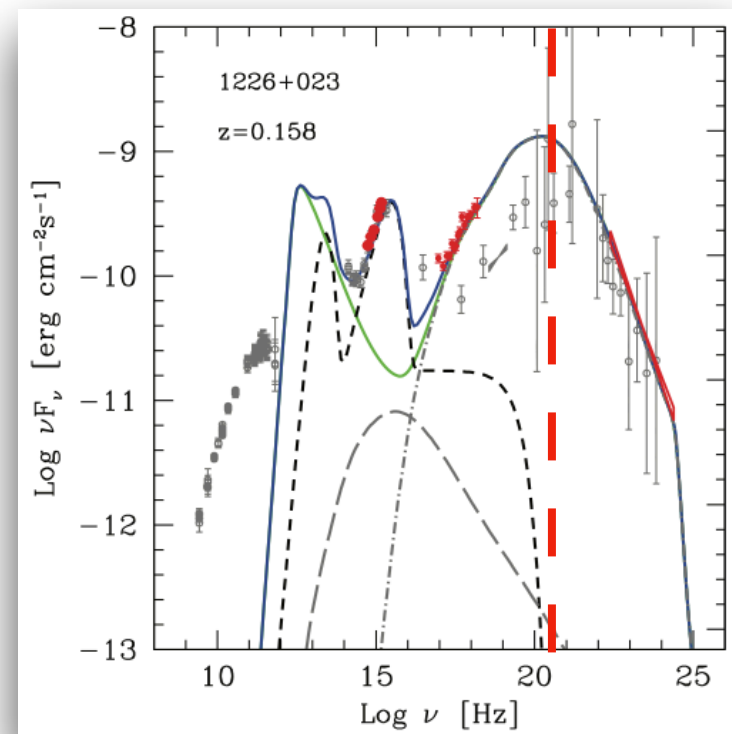
Gamma ray bursts



Ghirlanda et al. 2016

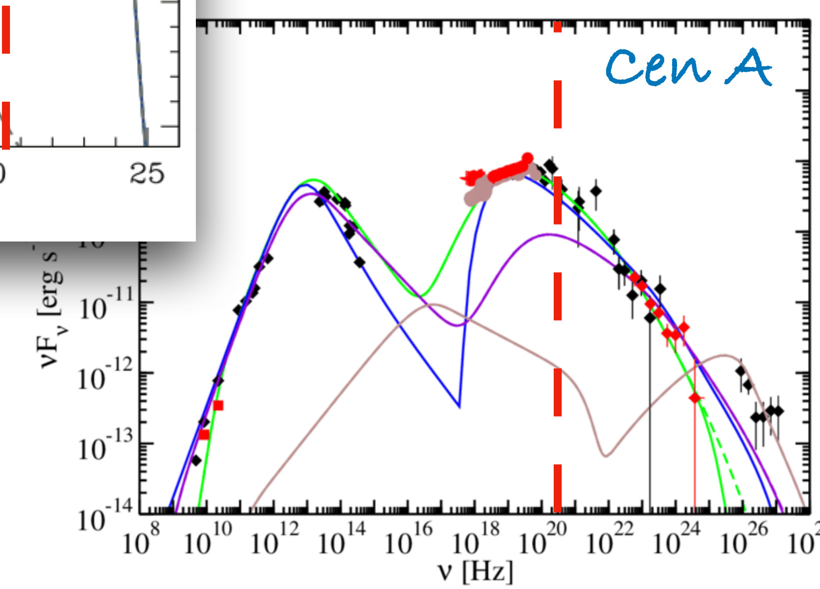
Peak of the high-energy bump around 1 MeV

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

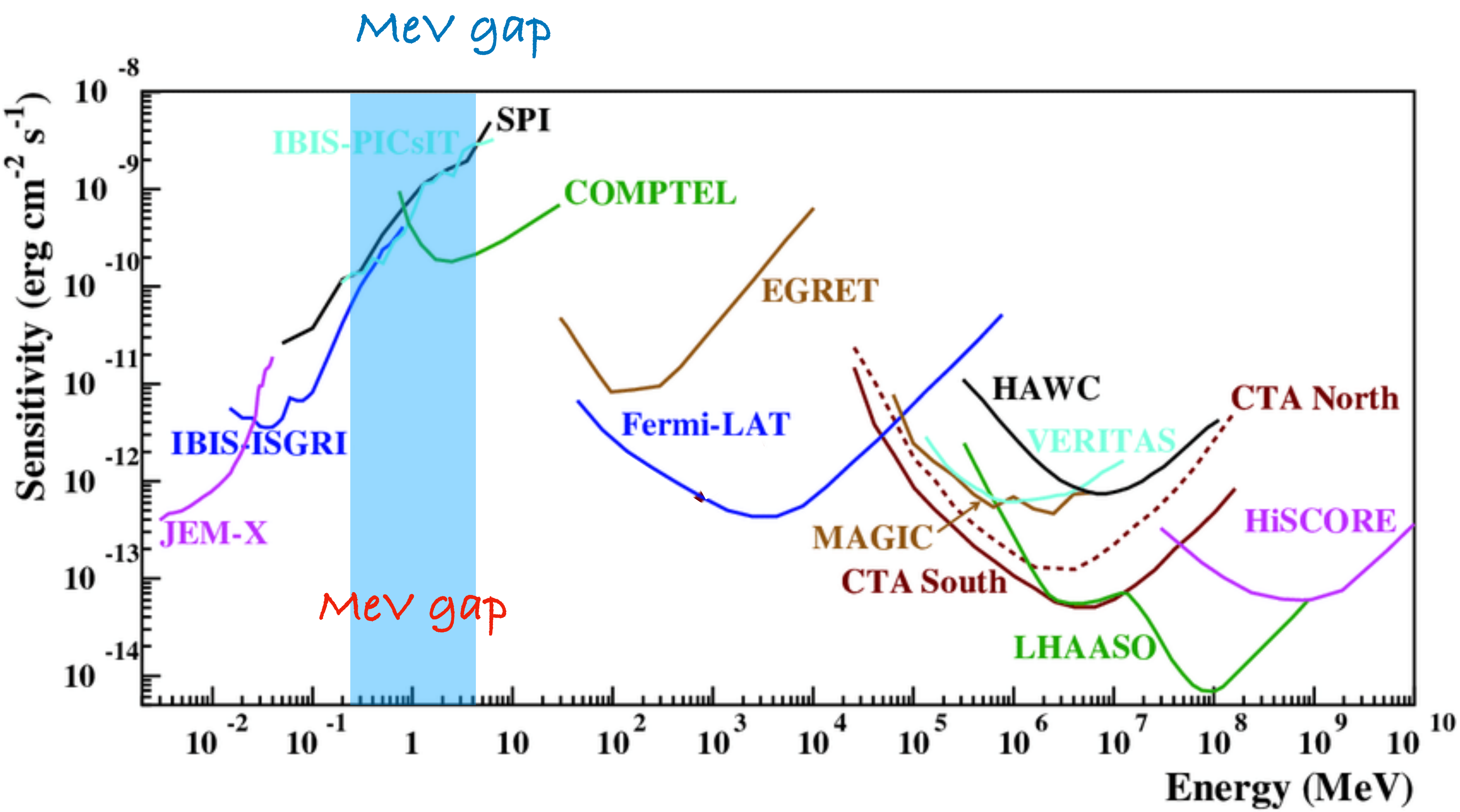


Ghisellini et al. 2009

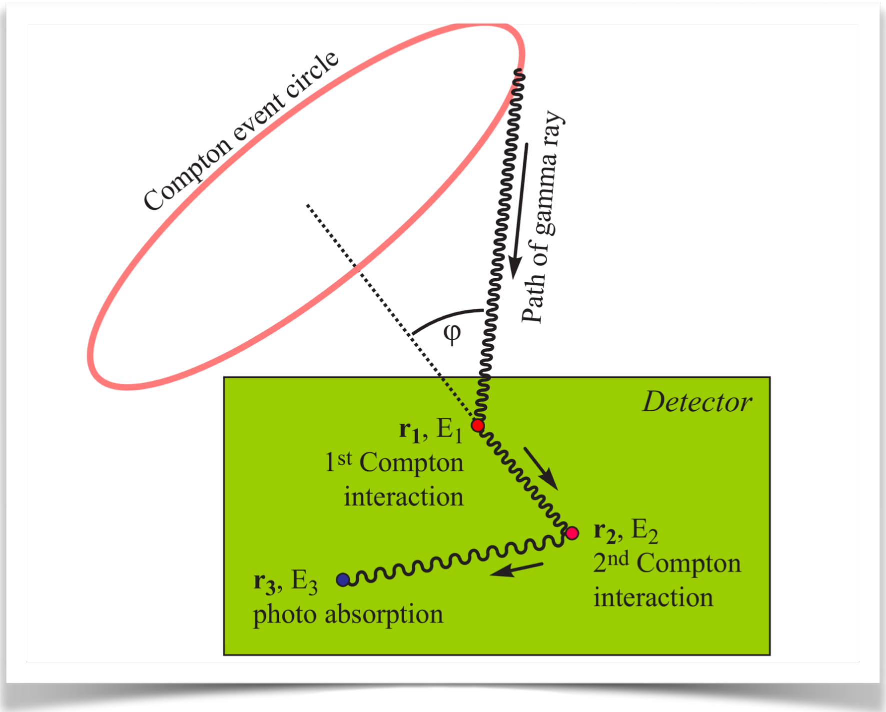
Abdo et al. 2010



Powerful blazars, radiogalaxies


MeV gap
Sensitivity (erg cm^{-2} s^{-1})
Energy (MeV)
SPI
IBIS-PICsIT
COMPTEL
EGRET
Fermi-LAT
IBIS-ISGRI
JEM-X
HAWC
CTA North
VERITAS
MAGIC
CTA South
LHAASO
HiSCORE
MeV gap

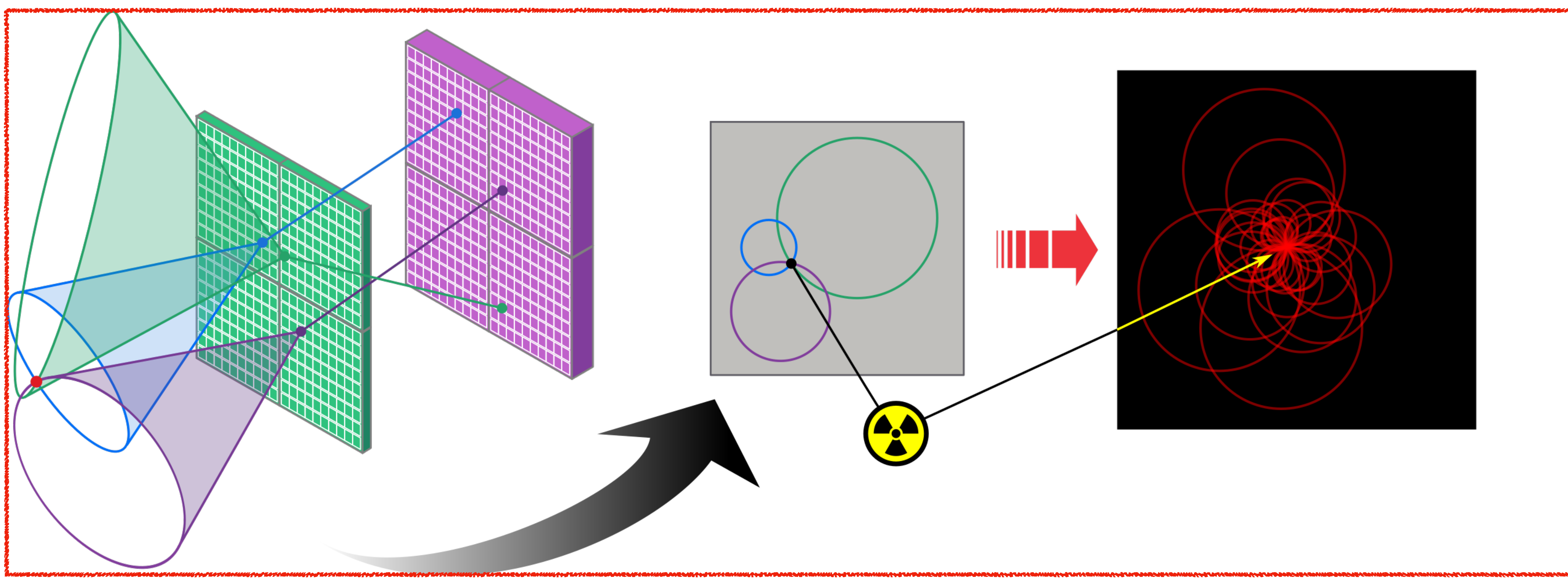
Compton Telescopes



- The detector records two successive scatterings

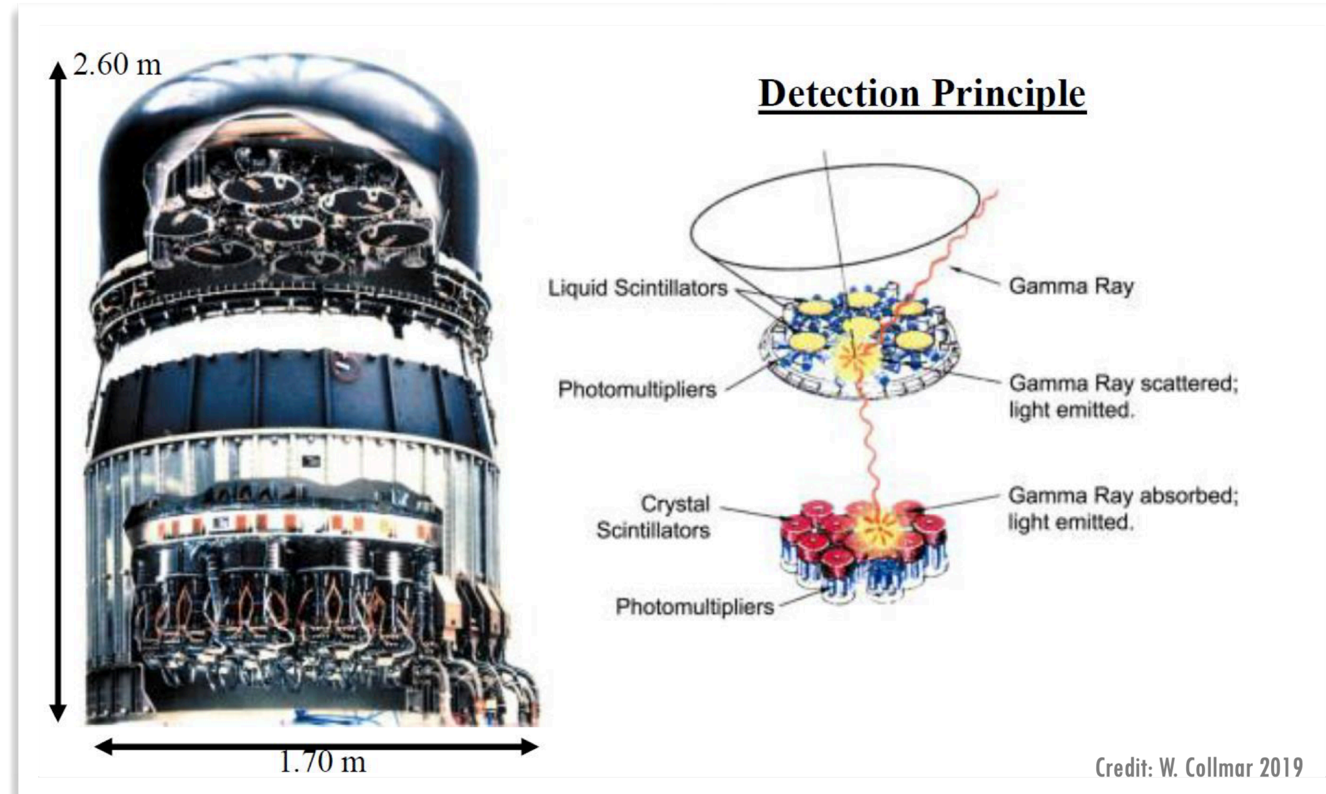
- An “event circle” is determined

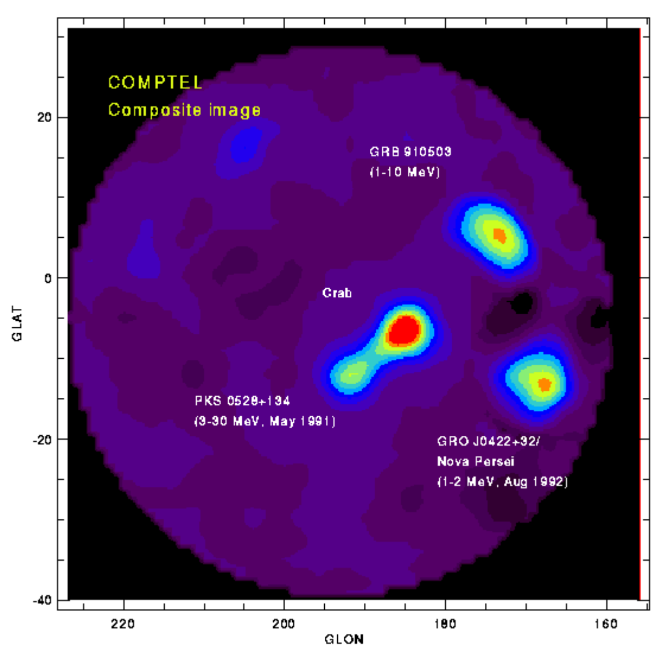
- The intersection of several circles provides the detection

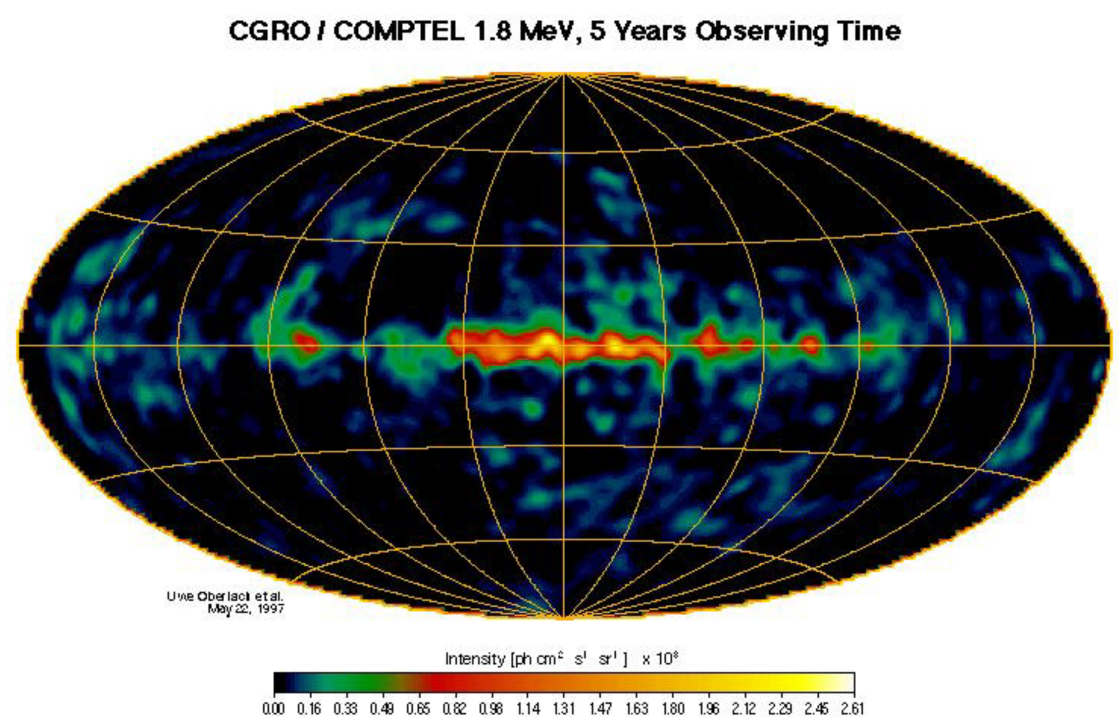


Comptel onboard CGRO

Operative 1991-2000







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

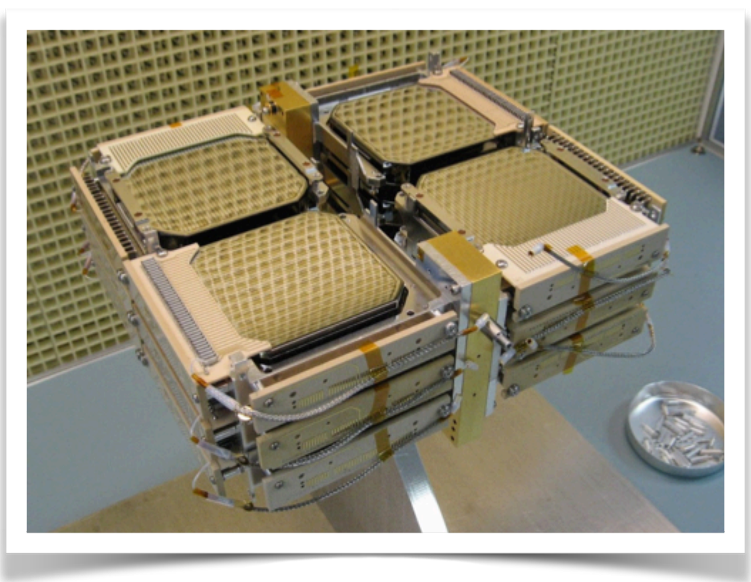
The Compton Spectrometer and Imager (COSI)

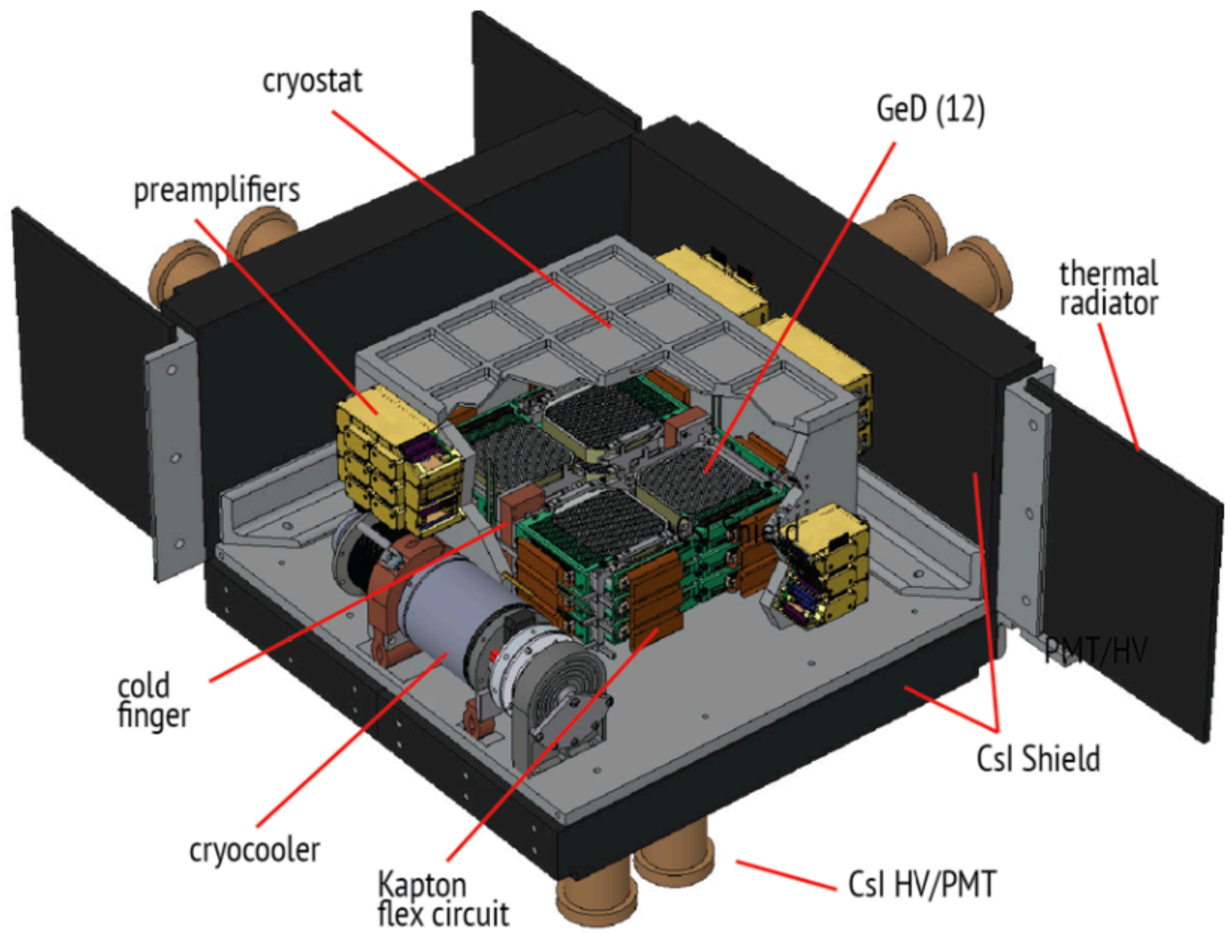
Balloon-borne Compton telescope

Evolution of Nuclear Compton Telescope

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

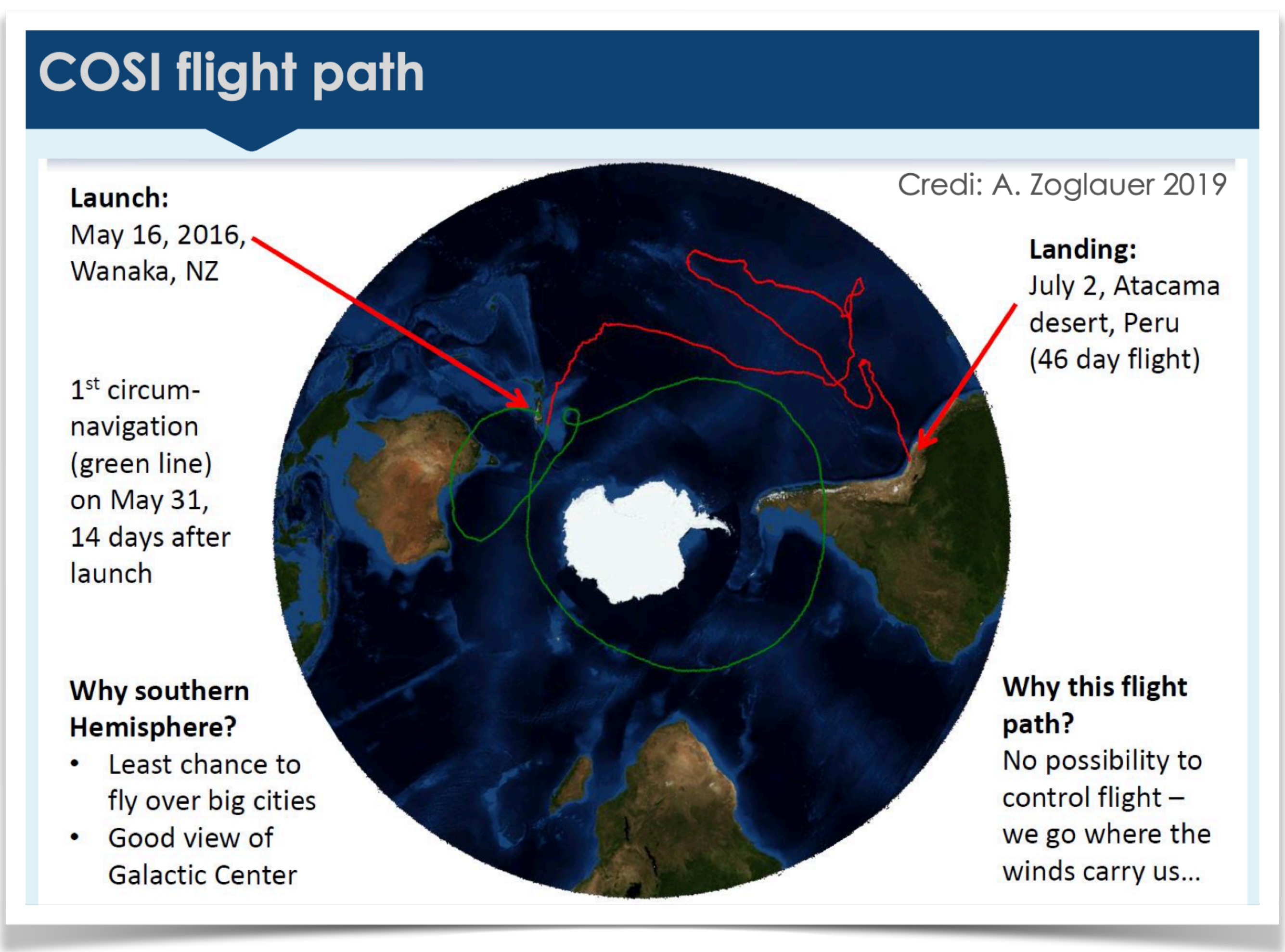
Ballon flights in 2014 and 2016





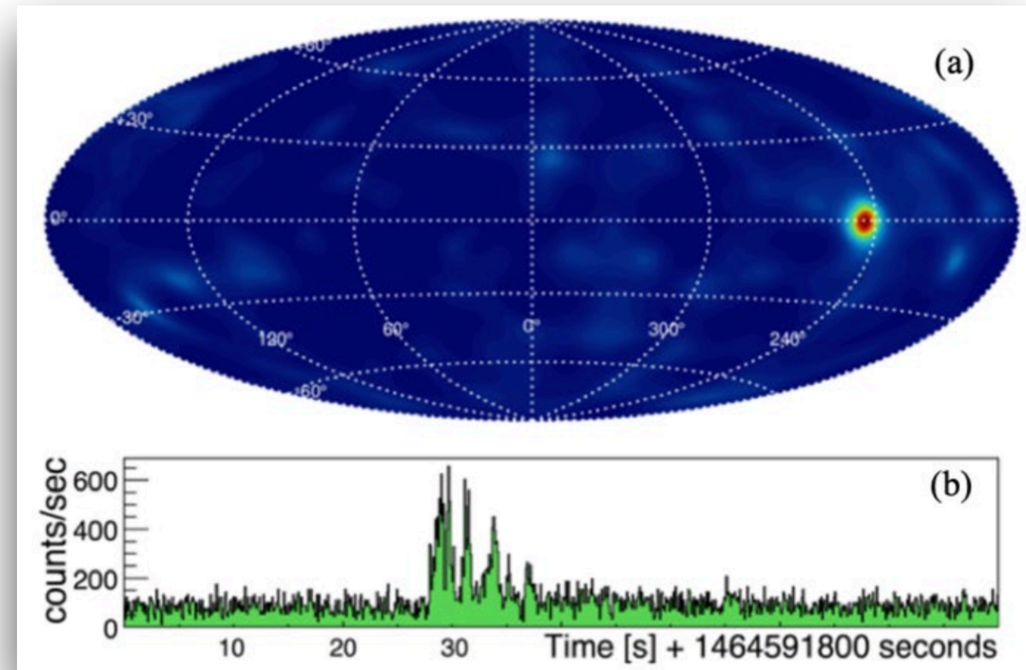
COSI 2016 campaign

46 days (May 16-July 2)

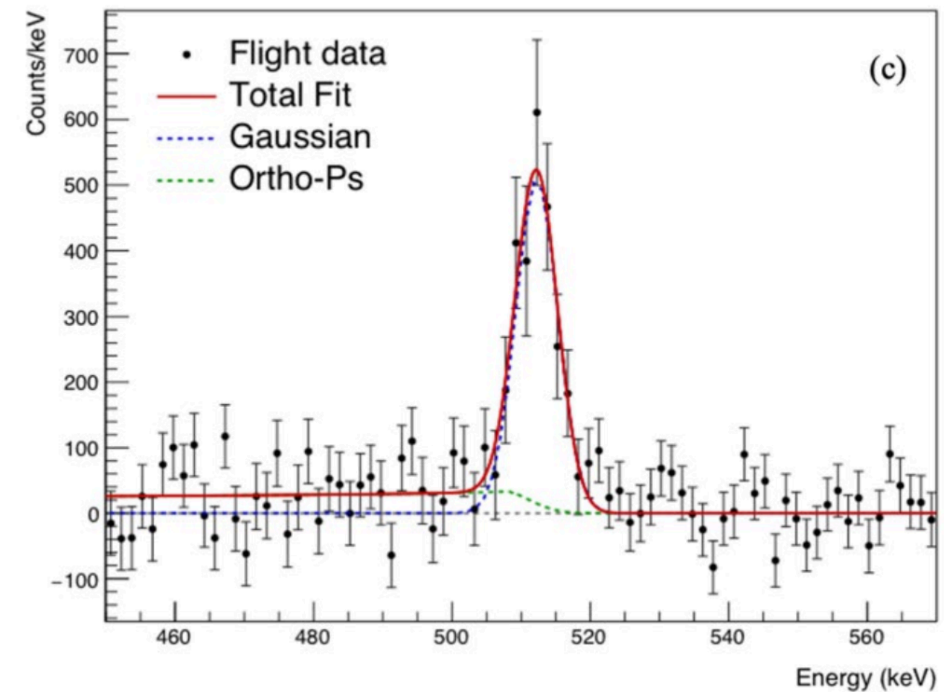


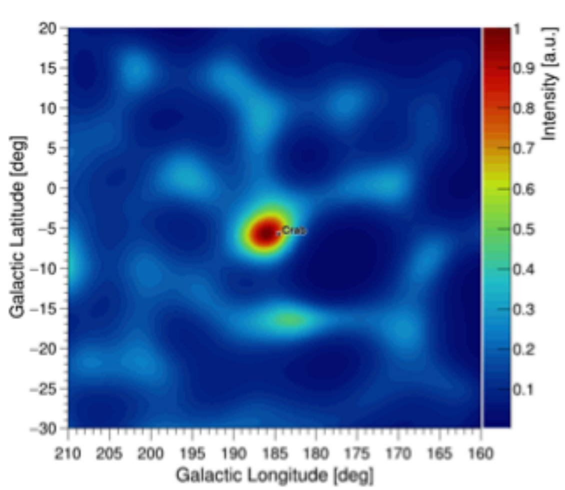
2016 flight: results

A gamma-ray burst, GRB 160530A

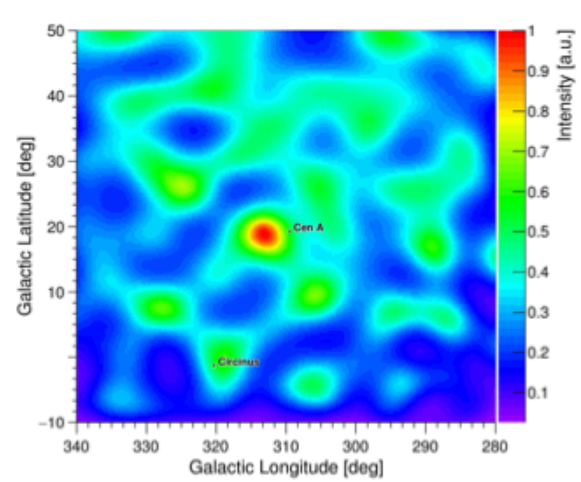


The 511 keV annihilation line

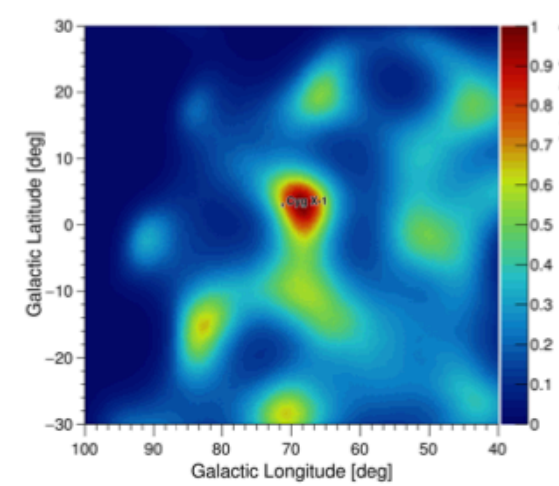




(a) Crab Nebula



(b) Centaurus A



(c) Cygnus X-1

Kierans et al. 2017

COSI - SMEX

Selected by NASA for the SMEX program

Launch: September 2025
(no later than October 15, 2025 with 1 month/year reserve).

Duration: 26 months (1 month checkout + 2 year science mission + 1 month decommissioning).

PI John Tomsick (UC Berkeley)

https://cosi.ssl.berkeley.edu

Institutions involved:

U. C. Berkeley

Naval Research Laboratory

Clemson Univ.

GSFC

ASI (Italy)

INAF (Italy)

IRAP (France)

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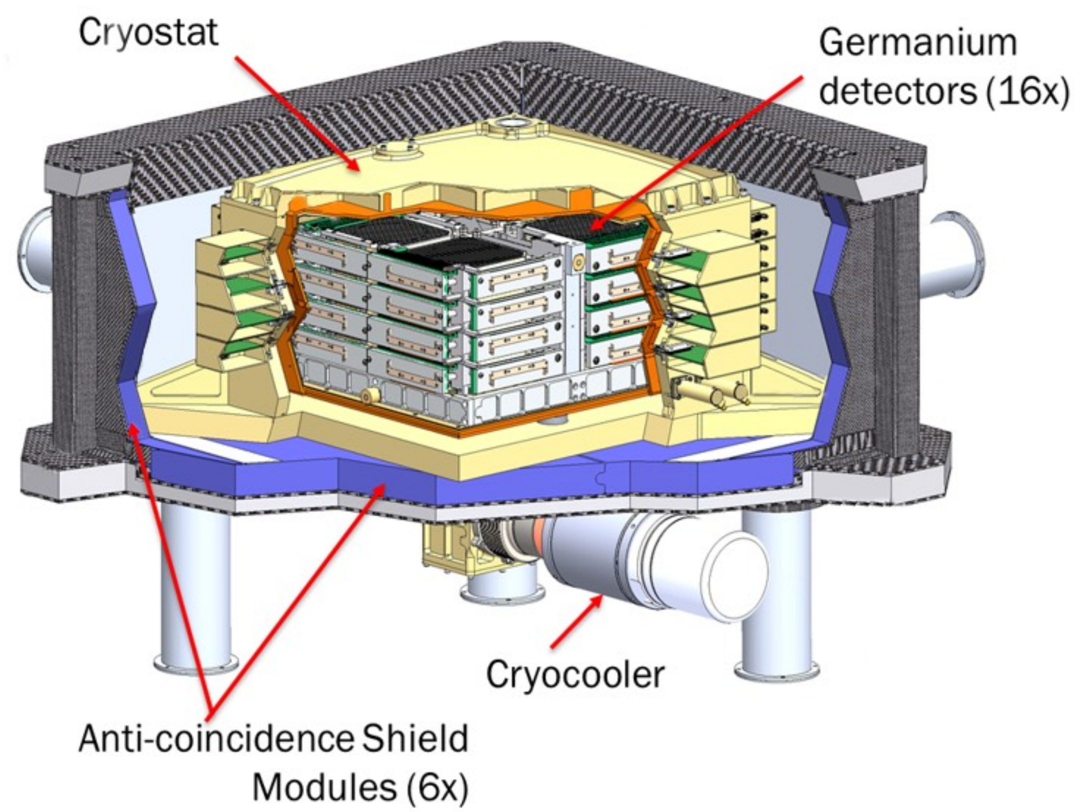
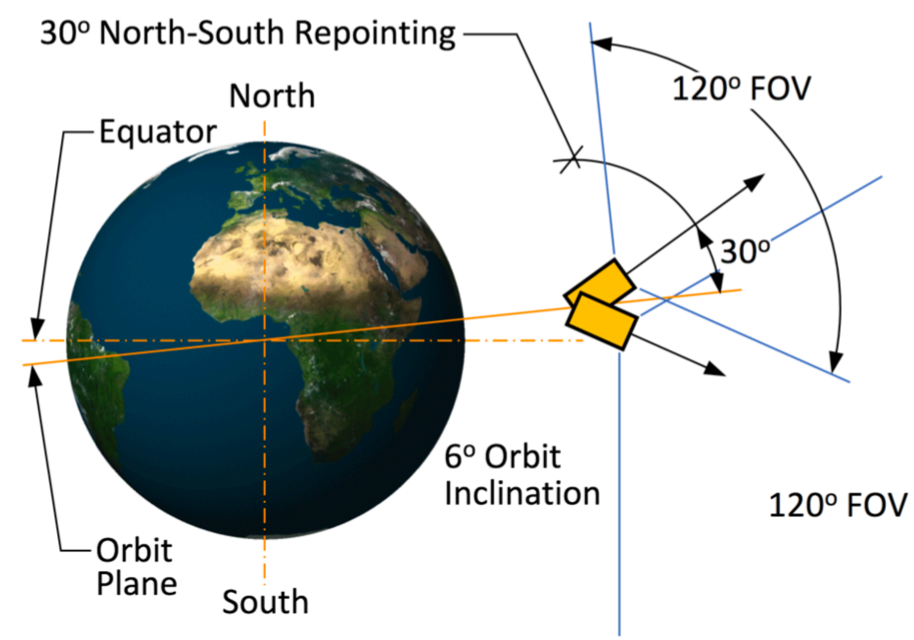
COSI has a unique combination of excellent energy resolution and large field of view

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



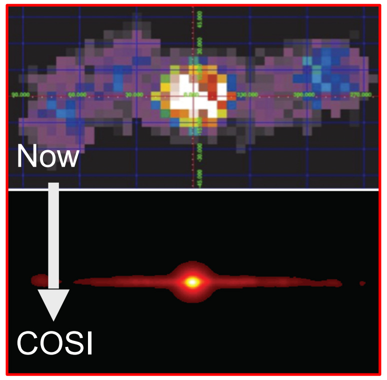
- COSI constantly points away from Earth and alternates between North and South to **cover the whole sky in 24 hours**
  - COSI's instantaneous FOV is:
    - >4x larger than COMPTEL
    - >12x larger than INTEGRAL/SPI



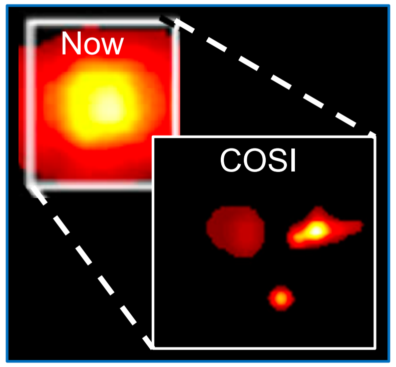
Overview of basic requirements

Parameter	Requirements
Energy range	0.5-2 MeV for emission lines 0.2-1 MeV for polarization 0.4-0.5 MeV ortho-positronium continuum 0.5-5 MeV for positron continuum (e^+ injection energy)
Field of view	25% sky (instantaneous) 100% sky (daily) for transient surveys and all-Galaxy coverage
Energy resolution	0.8% FWHM @ 1.157 MeV for ^{44}Ti emission lines
Angular resolution	2.0º FWHM @ 1.809 MeV for ^{26}Al imaging
Localizations	<1.0º for GRBs

COSI science goals

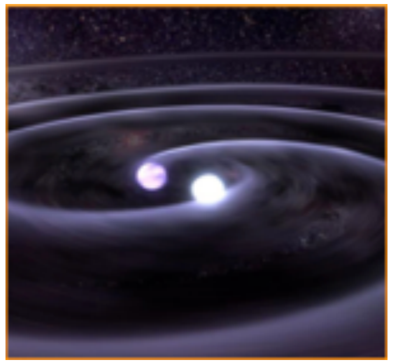


1. Uncover the origin of Galactic positrons



2. Reveal the dynamics of element formation

3. Gain insight into extreme environments with polarization



4. Probe the physics of multimessenger events

INAF team

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

Andrea Bulgarelli: MM, data pipeline, real-time analysis
Giancarlo Ghirlanda: MM, GRB, transients
Valentina Fioretti: simulations, data pipeline
Fabrizio Tavecchio: polarization, AGNs, MM.

The definition of the working groups is ongoing

Scientific Working Groups	**FT: Co-lead of extragalactic and DM SWGs**
Developer team	**VF and AB: leads of two sub-WPs**

Extended INAF team:

In total 20 INAF researchers (building on the experience gained with AGILE, eASTROGAM) are involved for a total of 0.8 FTE/yr (2022-2024)

INAF contribution

Currently planned:

Pipeline for real-time analysis (leaded by AB):
development of a simulation tools for transients (GRB, SGR, AGN)

Instrument simulations (leaded by VF):
detector performances

Contribution to data challenge(s) (GG, FT):
input models for GRB, AGNs, polarization

Critical issues

No dedicated funds still allocated.

Discussion with ASI on possible fundings of the activities are ongoing

1-2 dedicated postDocs (science, SW)?

Expected (minimal) x 6 years

- **1AdR x 6 years**
- **Collaboration meetings**
- **National workshop**

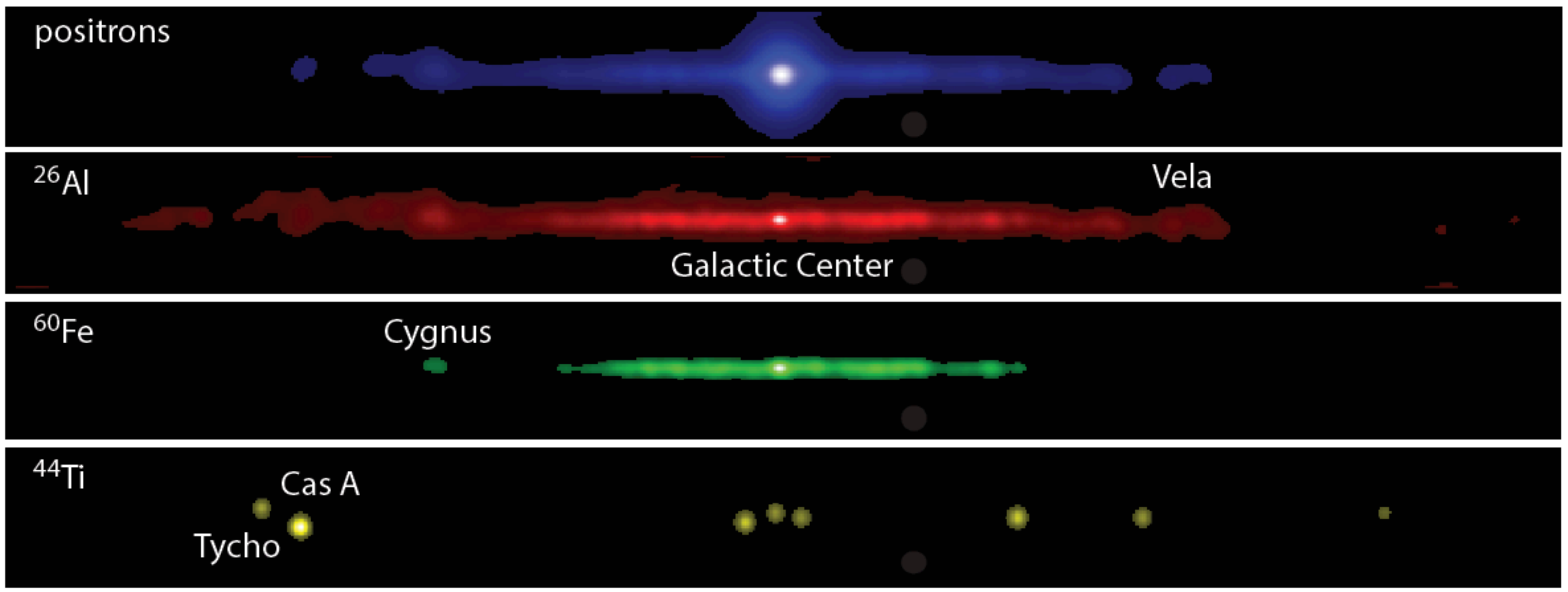
= 300 keuros

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

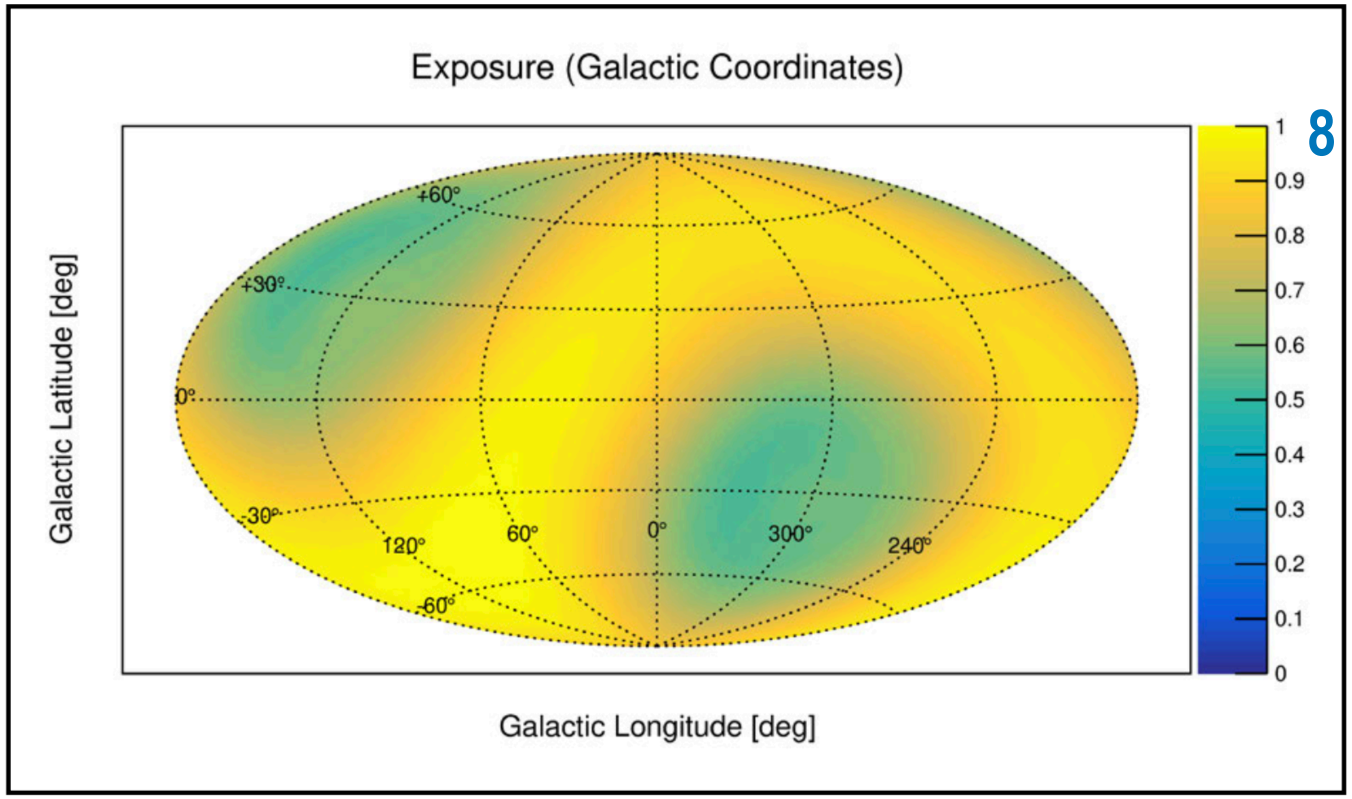
- GRB localizations
- ❑ GRB polarization
- ❑ Coverage of HE neutrino events
- ❑ Black hole transients

Extended portfolio:

- Type Ia supernovae
- Flaring blazars

Persistent source polarization science

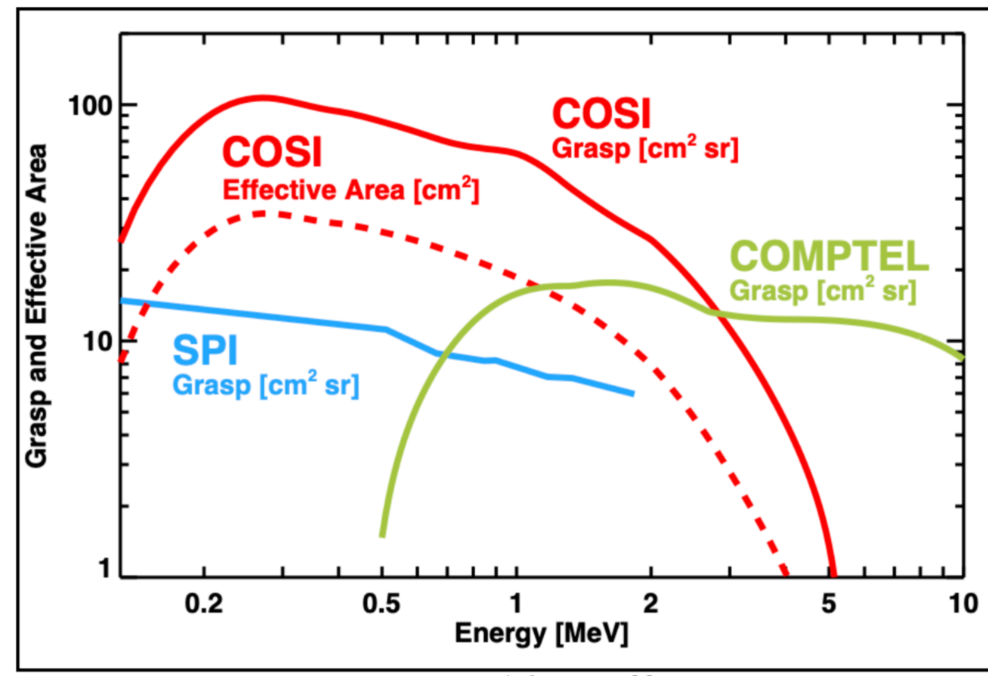
- Cygnus X-1
- ❑ Crab (calibration)
- ❑ Centaurus A

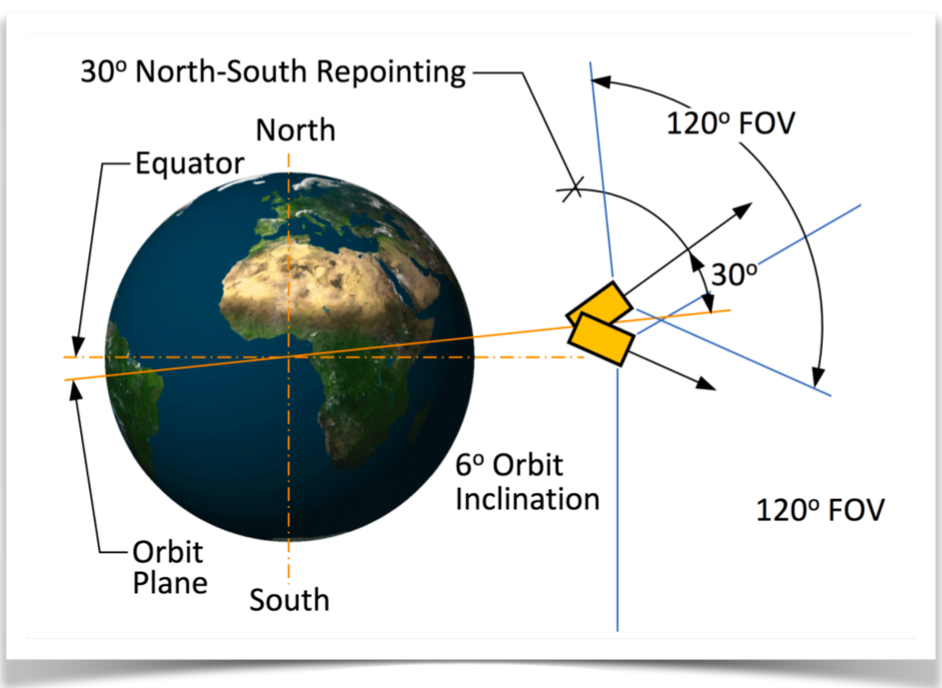


8 hours/day

Daily sky exposure

Grasp



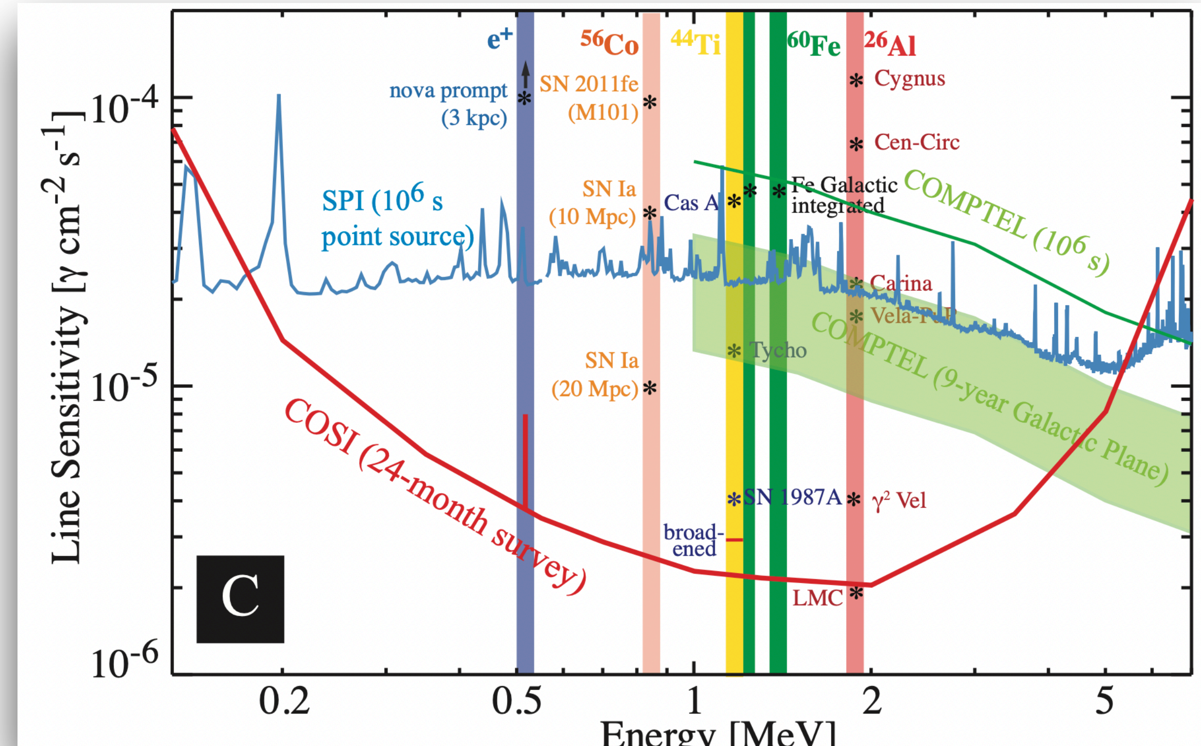


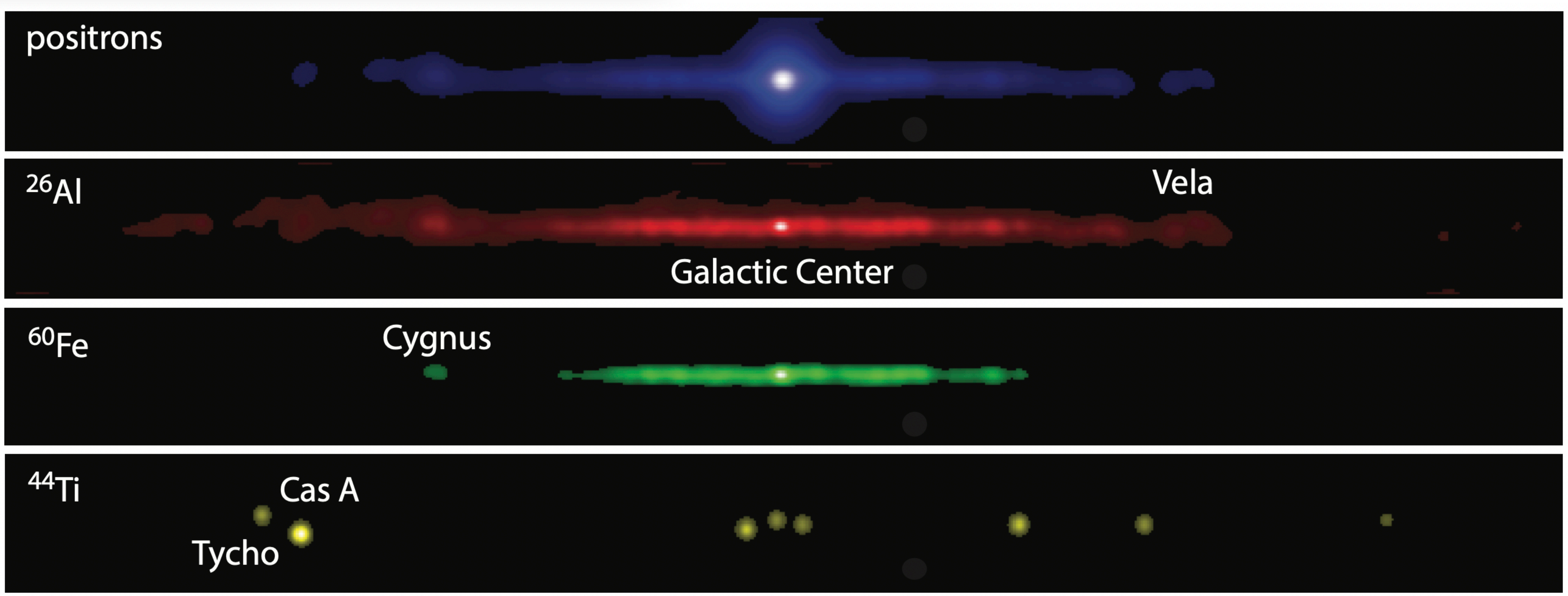
Expectations for transients

About 20 short GRBs in 2 years

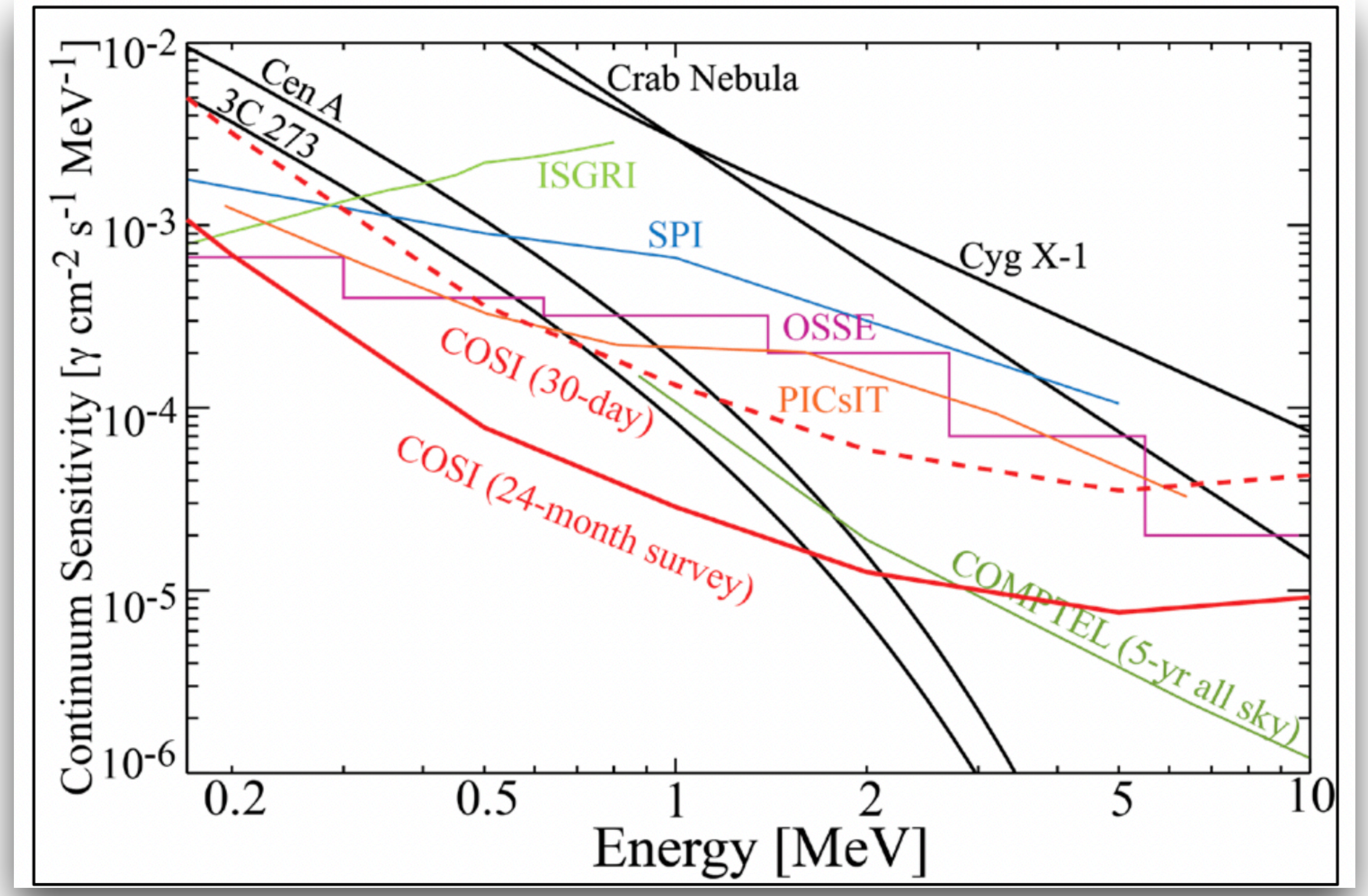
At least 40 GRB 10 with $F>10^{-6}$ cgs

Spectroscopy



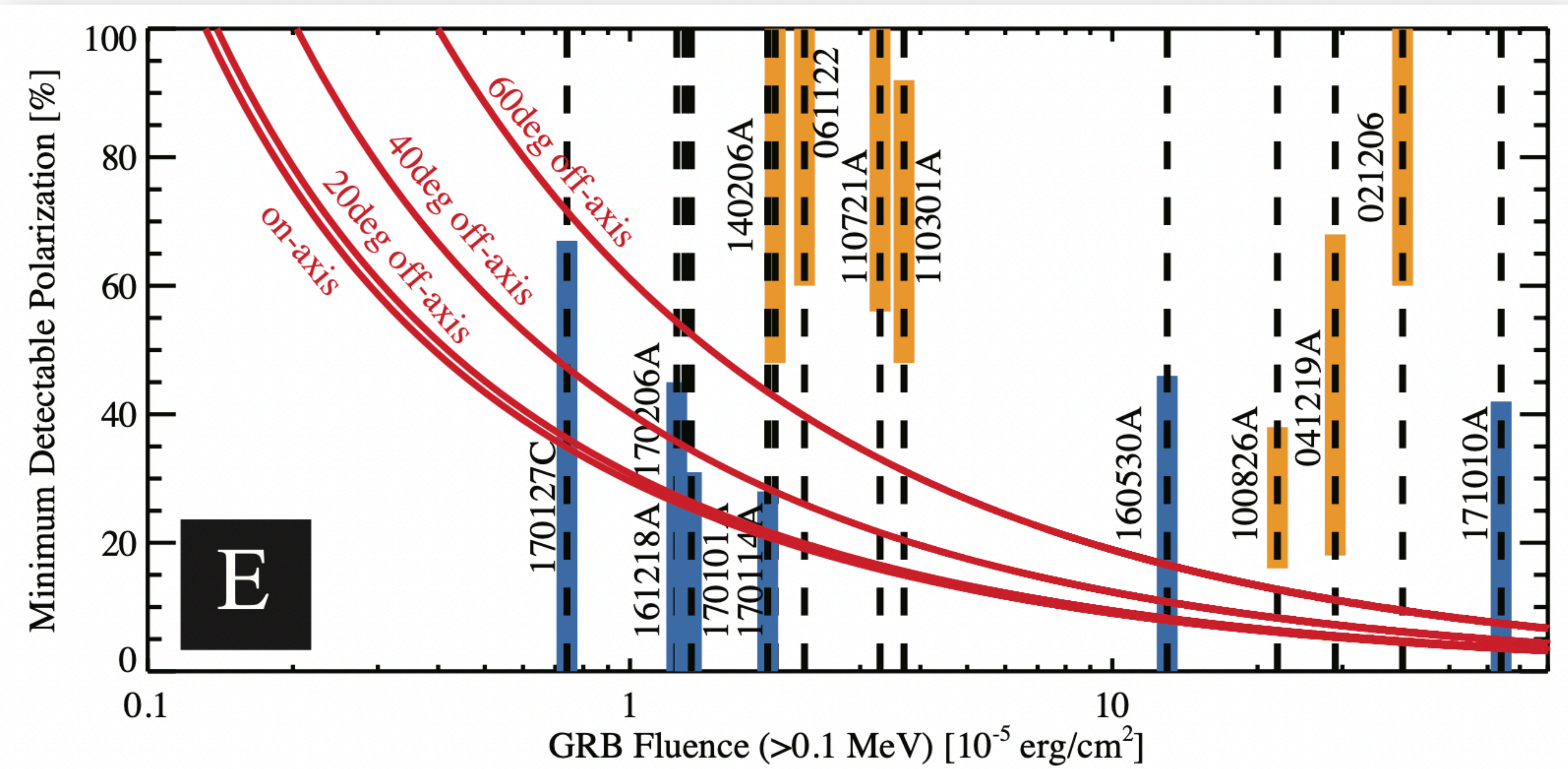


Continuum



Continuum Sensitivity [γ cm-2 s-1 MeV-1]
Energy [MeV]
Cen A
3C 273
Crab Nebula
Cyg X-1
ISGRI
SPI
OSSE
PICsIT
COSI (30-day)
COSI (24-month survey)
COMPTEL (5-yr all sky)

Polarization



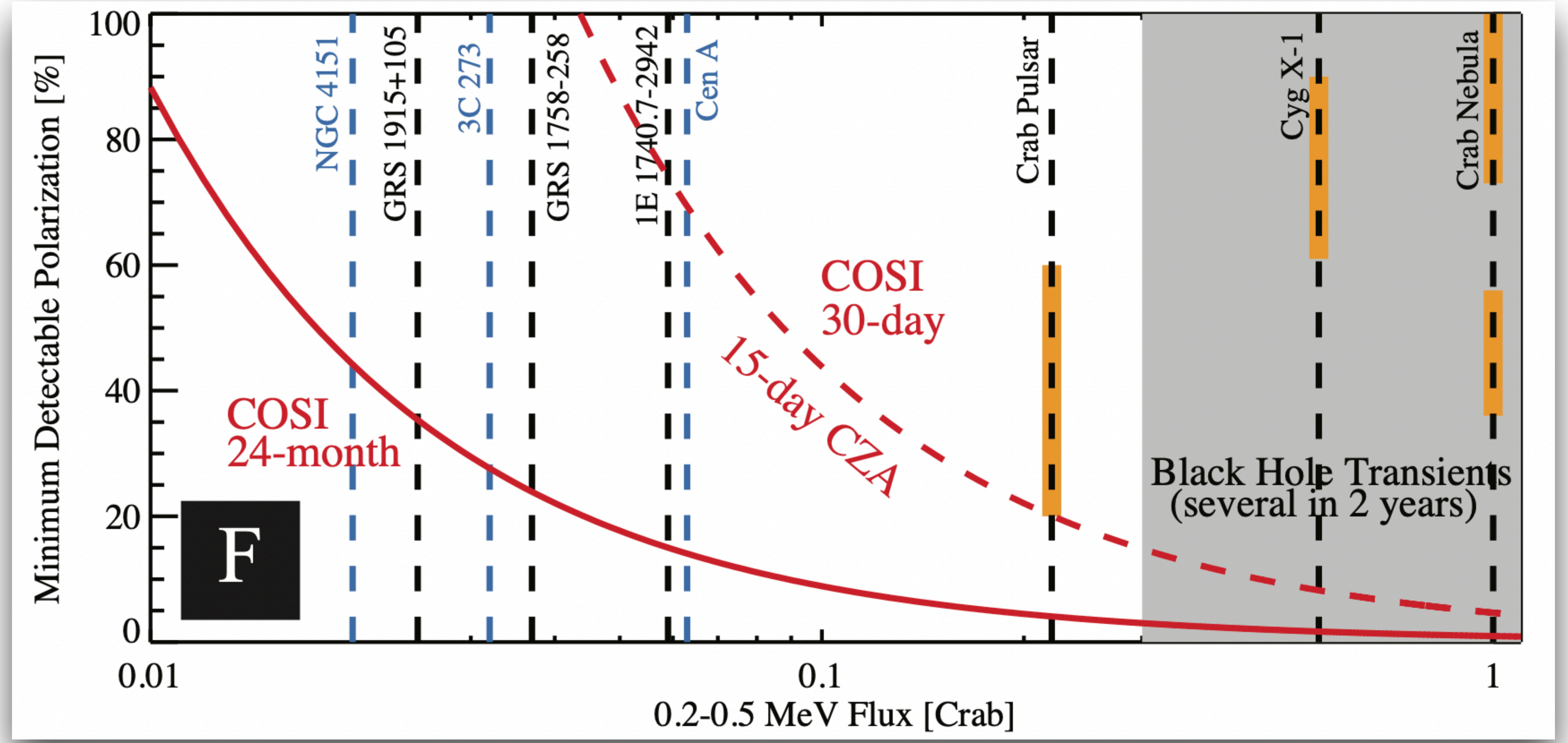
Expectations

About 40 GRBs with MDP < 50%

About 10 with MDP < 5-10%

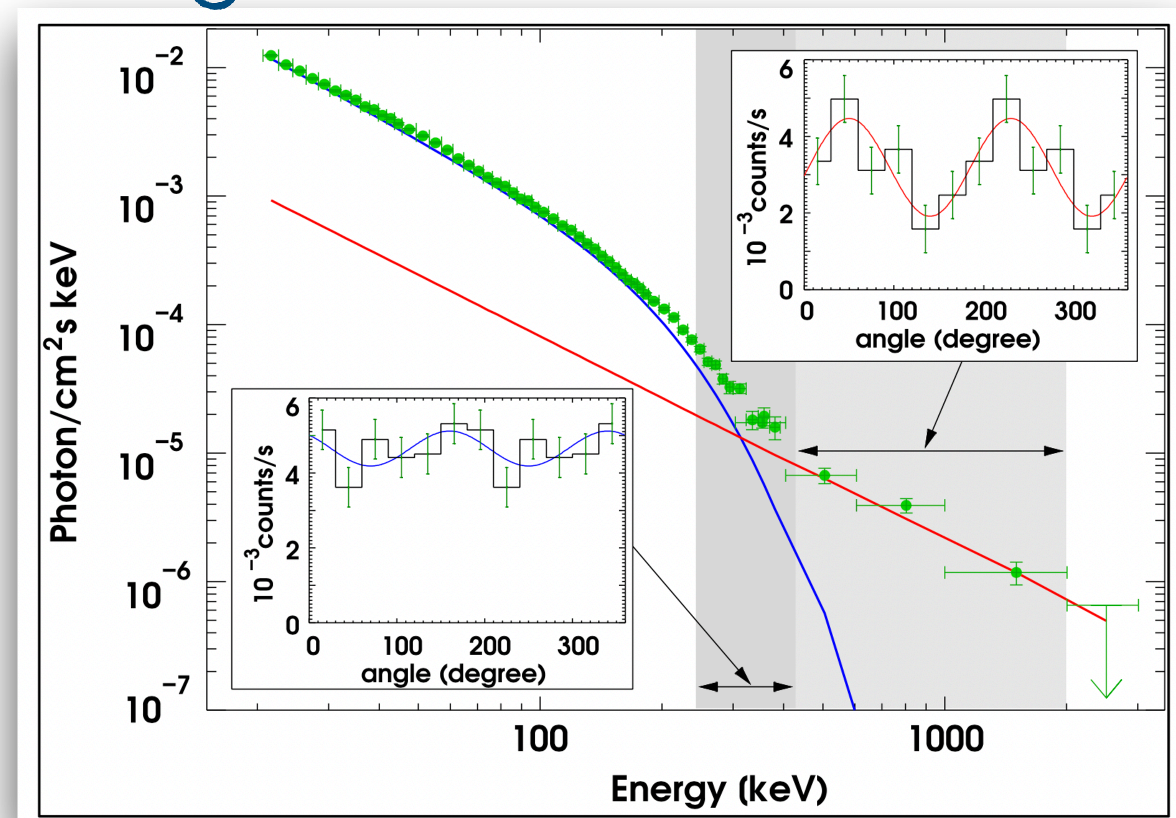
To be refined by using state-of-the-art population models…

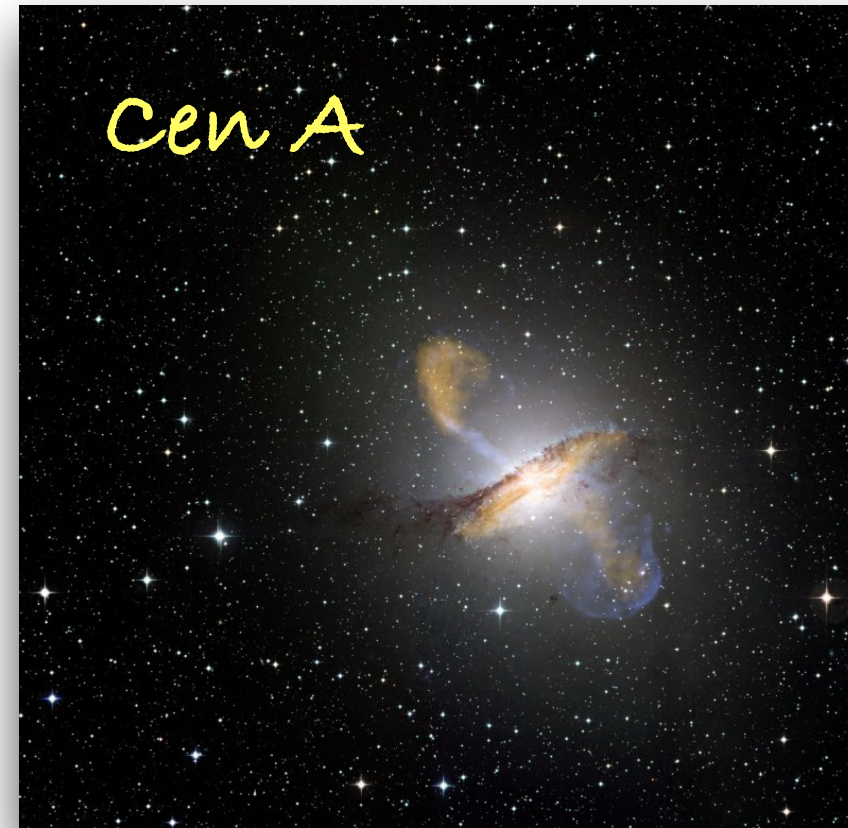
Polarization

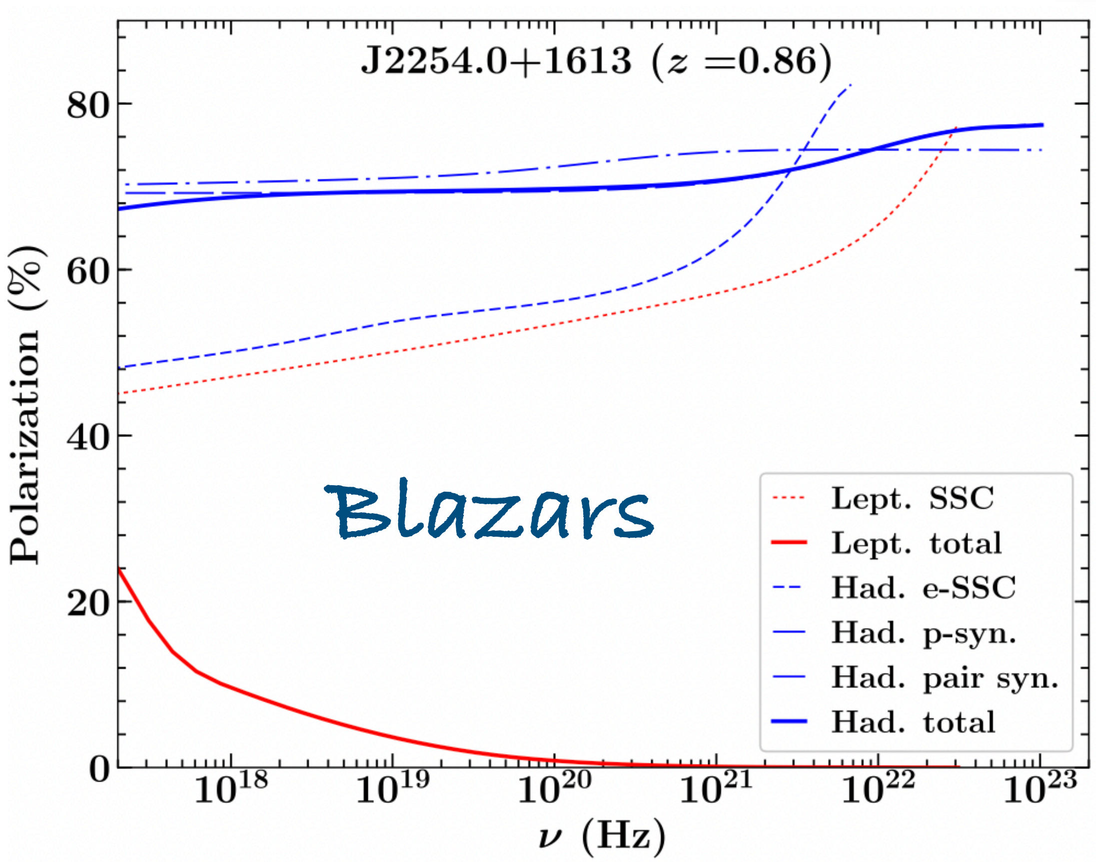


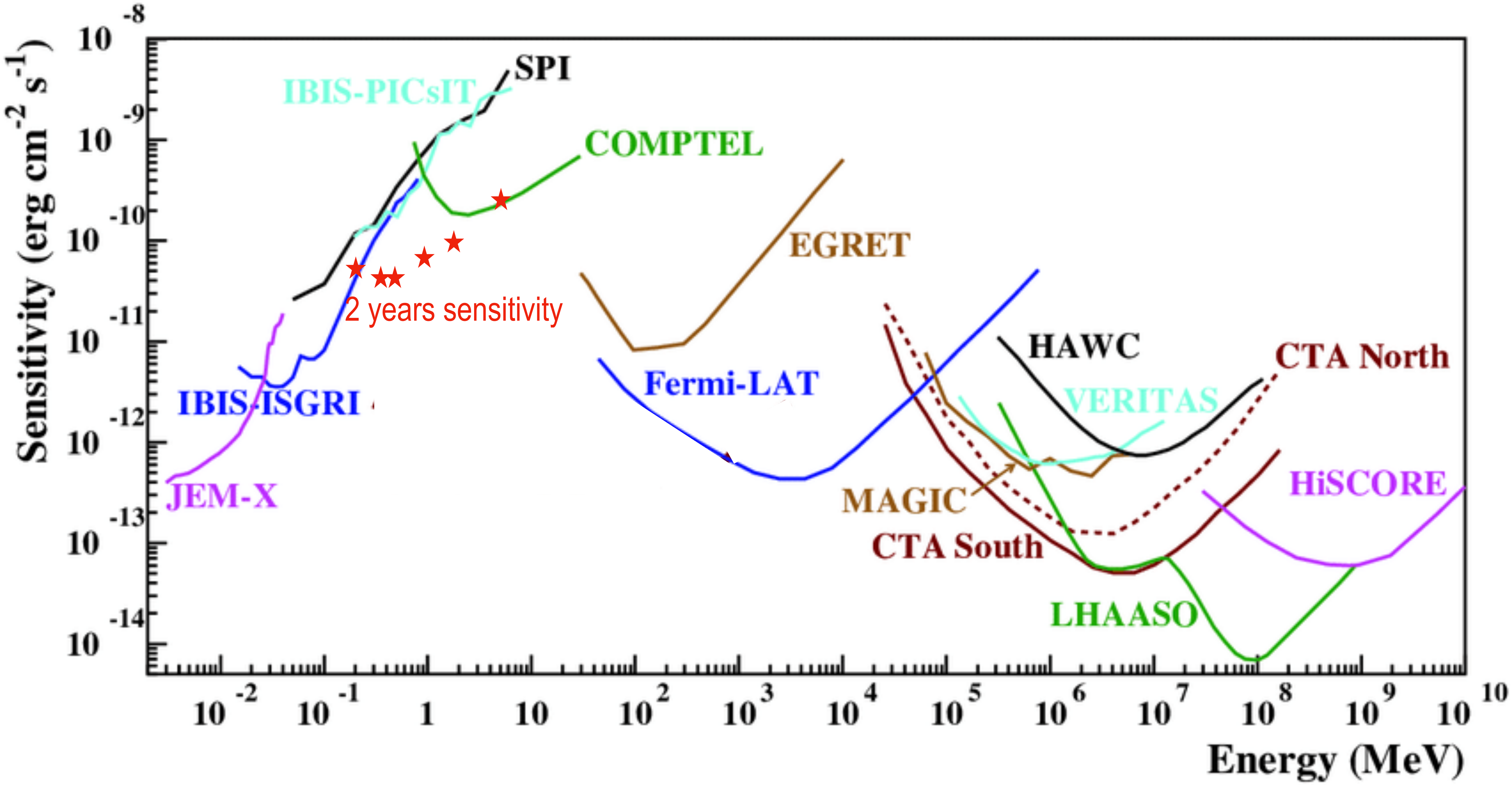
Polarization

Cyg X-1









SPI
IBIS-PICsIT
COMPTEL
EGRET
2 years sensitivity
IBIS-ISGRI
JEM-X
Fermi-LAT
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Sensitivity (erg cm^{-2} s^{-1})
Energy (MeV)