

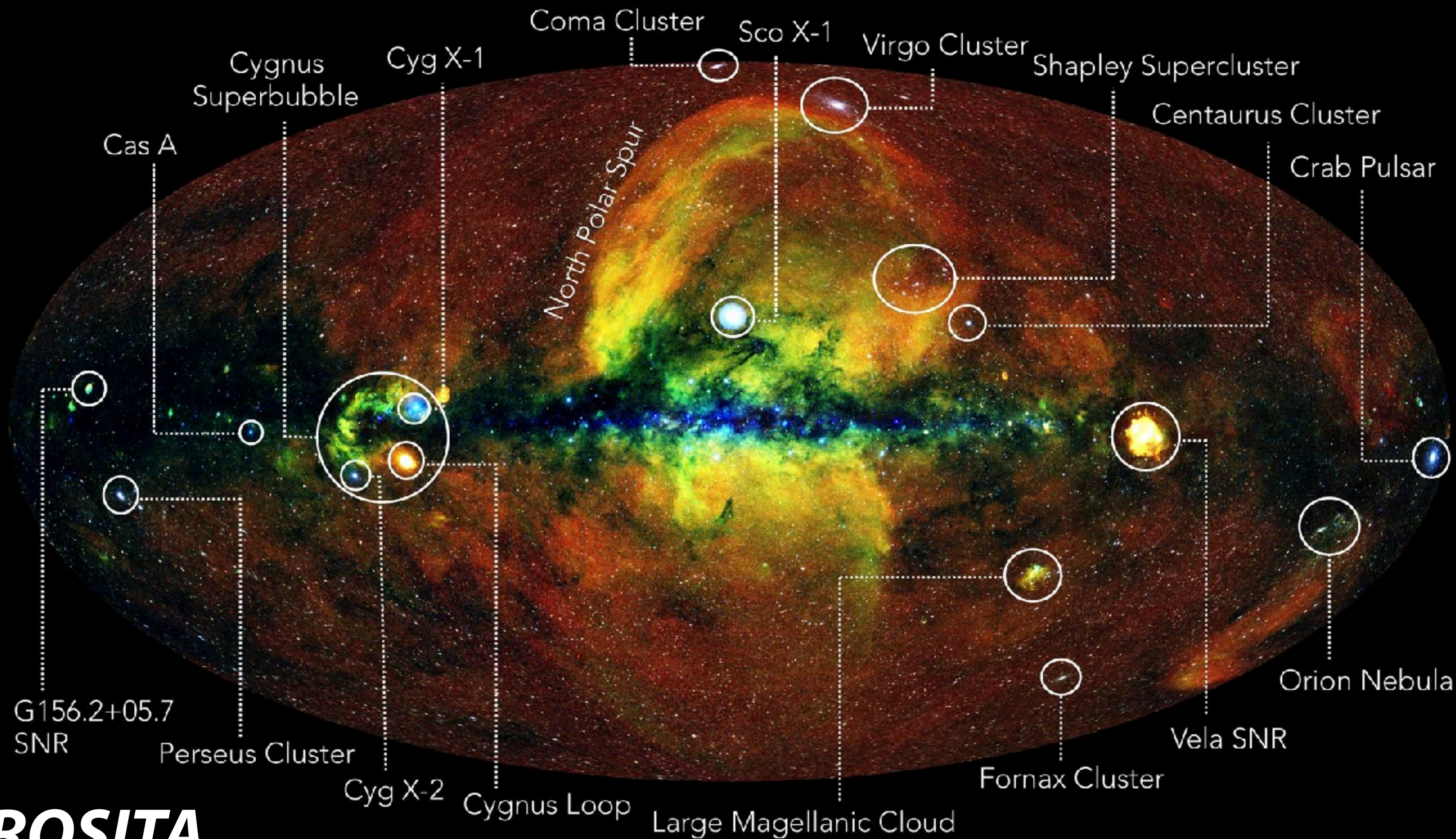
Future Prospects of MeV Gamma-ray Astronomy

Yoshiyuki Inoue

Connecting high-energy astroparticle physics for origins of cosmic rays and future perspectives
@ Online, 2020-12-09



Soft X-ray Sky (0.3-2.3 keV)

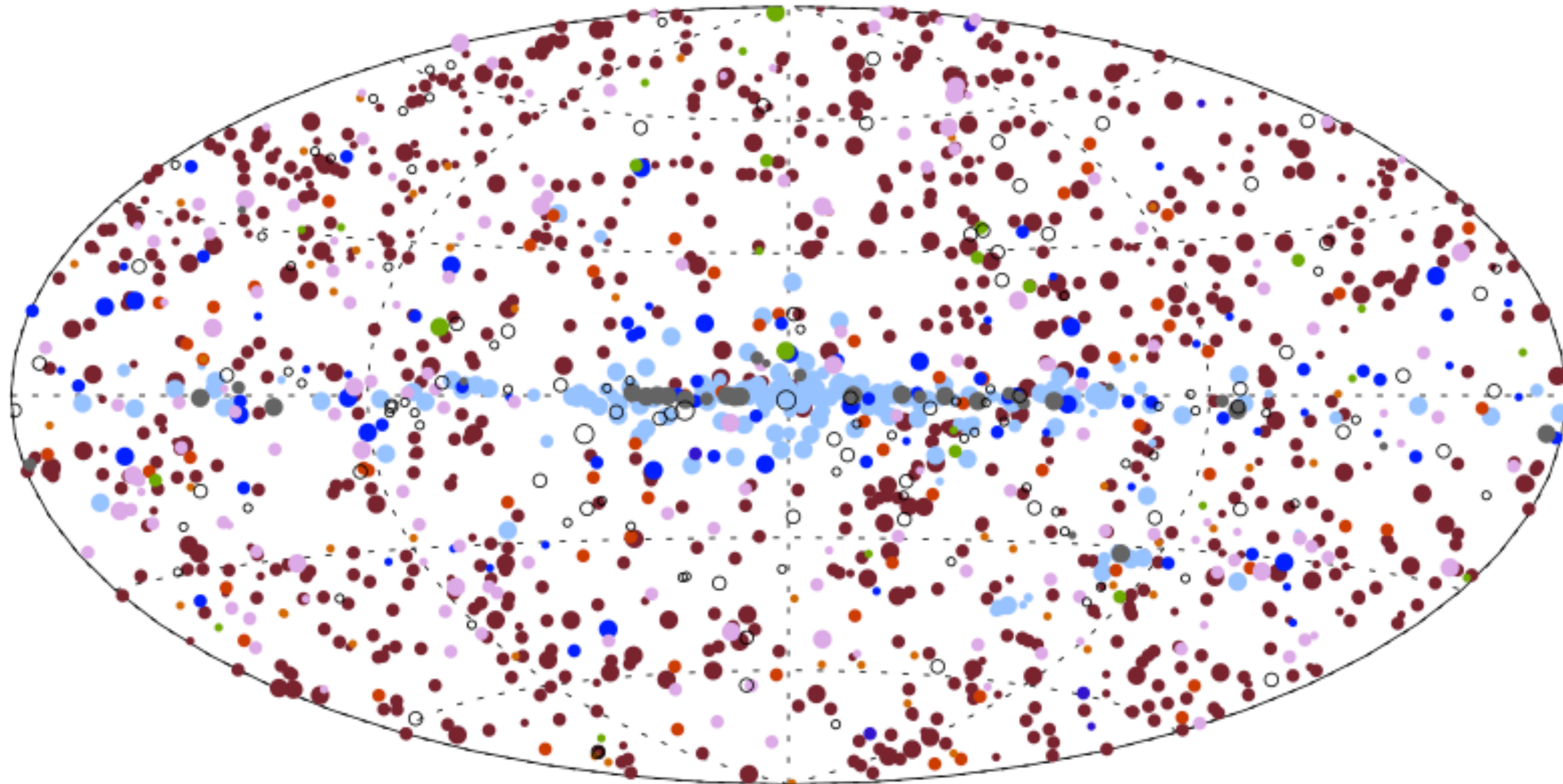


SRG/e-ROSITA
6-month survey

$> 1 \times 10^{-14}$ erg/cm²/s

~10⁶ objects

Hard X-ray Sky (14-195 keV)



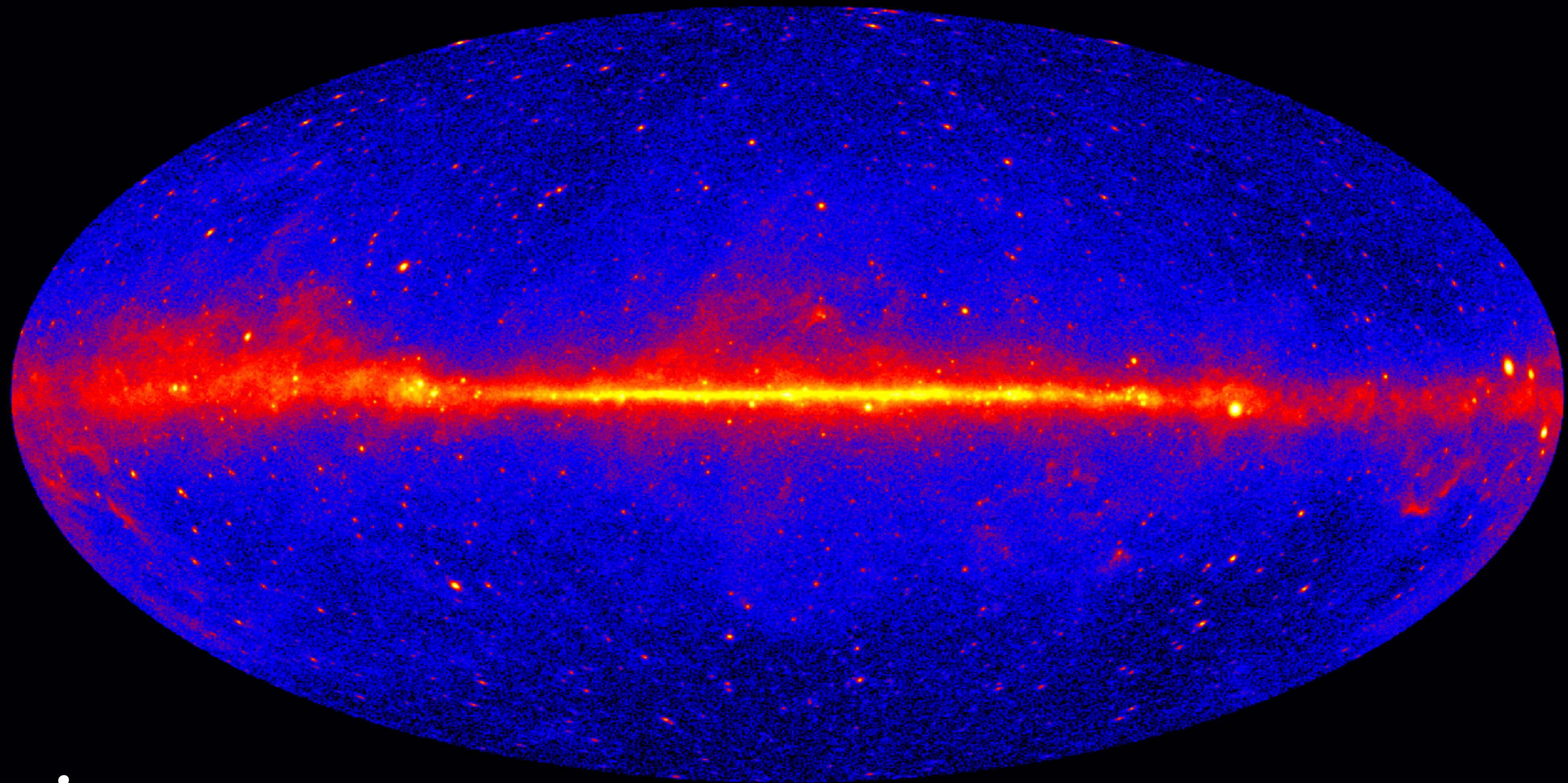
Swift/BAT

105-month survey

$> 7 \times 10^{-12}$ erg/cm²/s

~1600 objects

GeV Gamma-ray Sky (0.1-100 GeV)



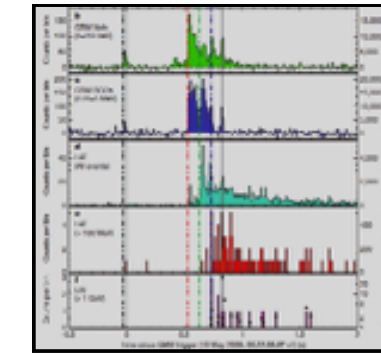
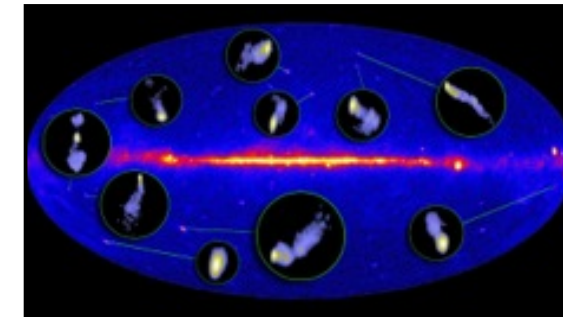
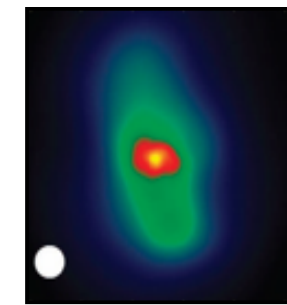
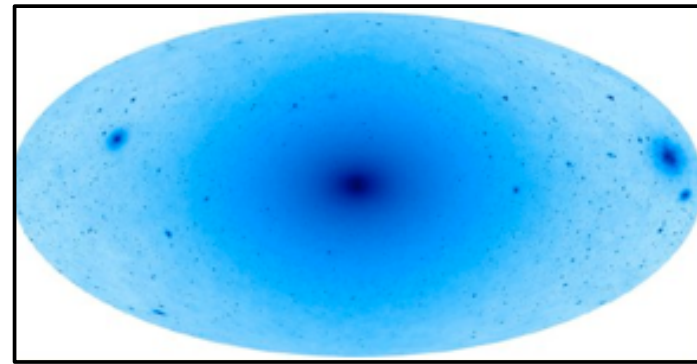
Fermi
5-year survey

$> 2 \times 10^{-12}$ erg/cm²/s

~5000 objects

GeV Gamma-ray Objects

Dark Matter searches



GRBs

Blazars

Radio Galaxies

Starburst Galaxies

LMC & SMC

Globular Clusters

Fermi Bubbles

SNRs & PWN

γ -ray Binaries

Novae

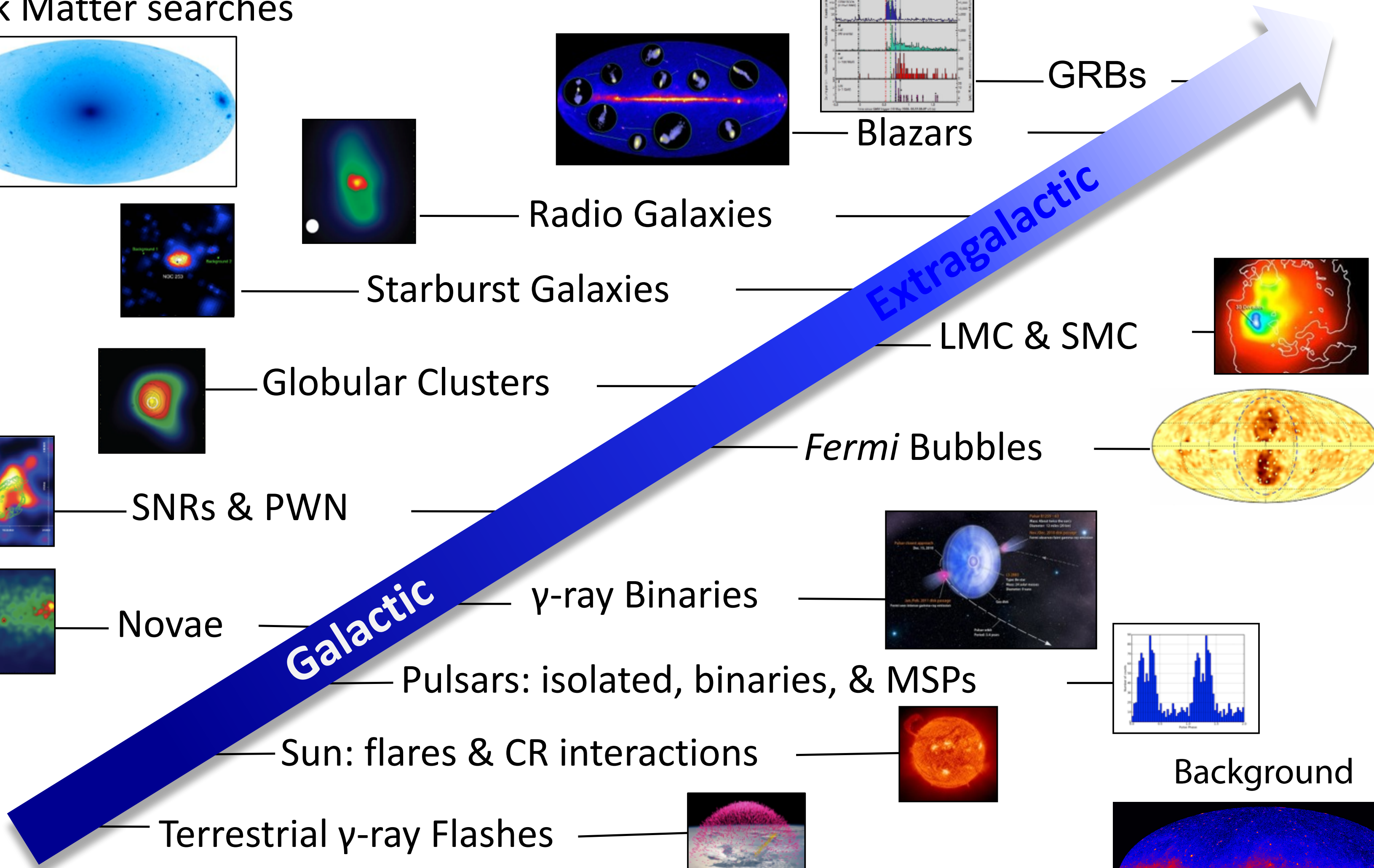
Pulsars: isolated, binaries, & MSPs

Sun: flares & CR interactions

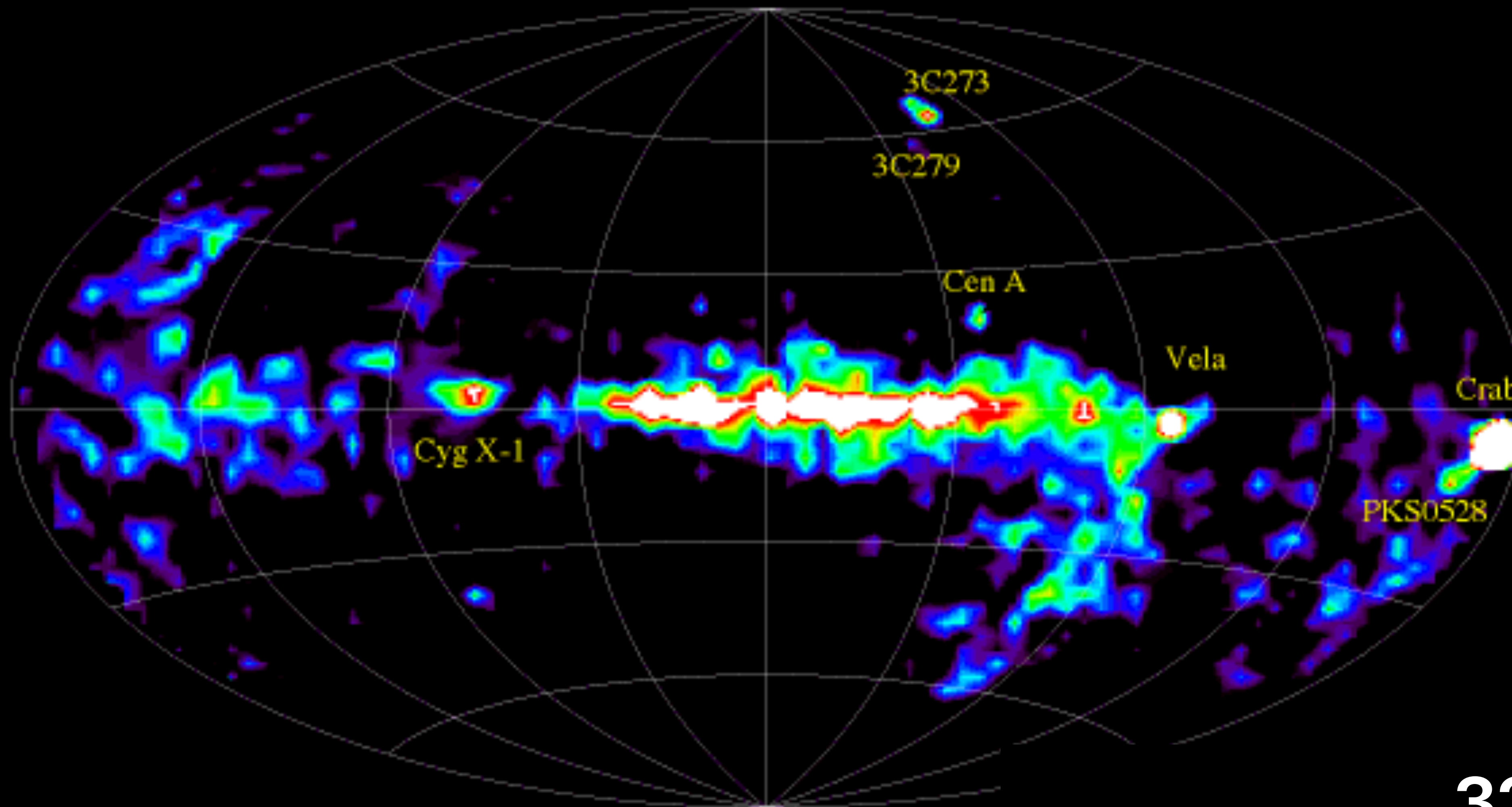
Terrestrial γ -ray Flashes

Background

Unidentified Sources



MeV Gamma-ray Sky



32 objects

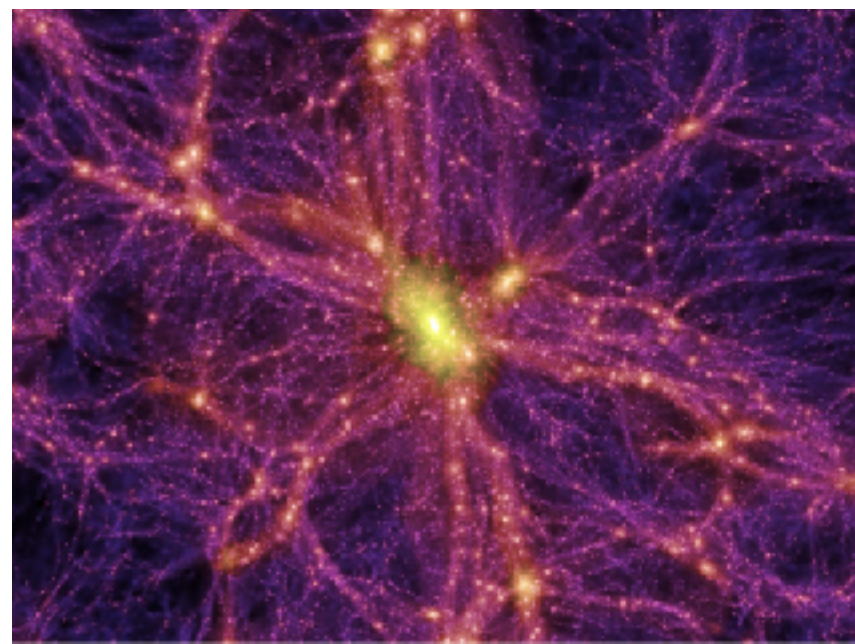
COMPTEL

$> 1 \times 10^{-10}$ erg/cm²/s

Note: >50 Candidates in GW now

MeV Gamma-ray Science

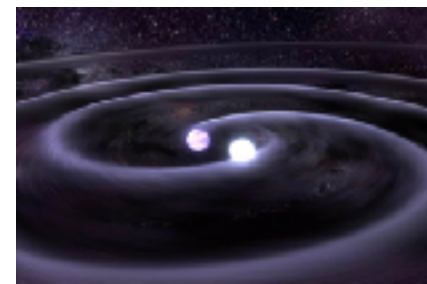
Dark Matter



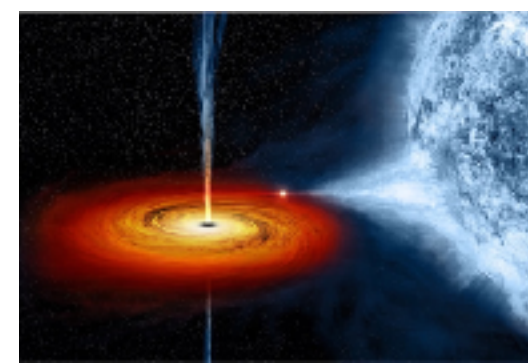
Starburst Galaxies



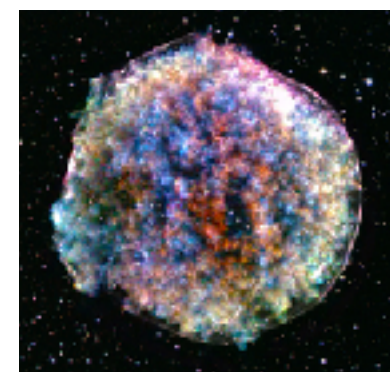
NS merger



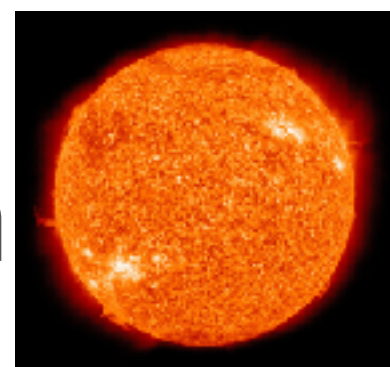
X-ray/ γ -ray Binaries



SNRs & PWN



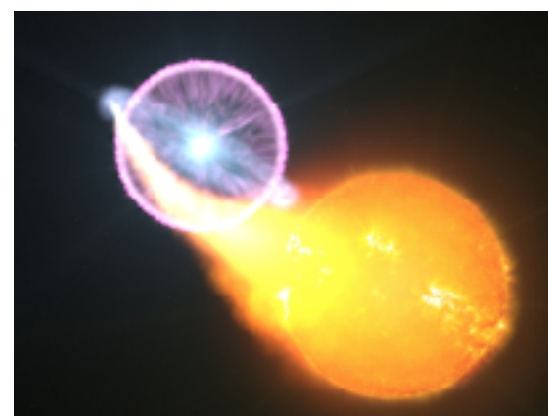
Sun



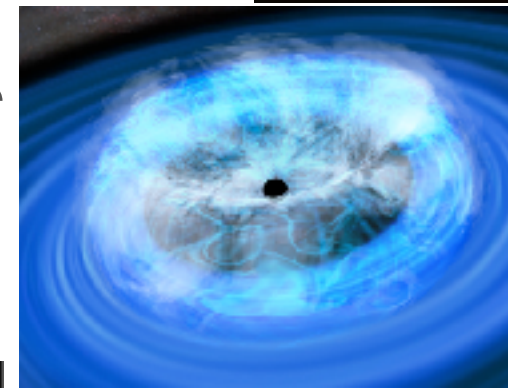
Terrestrial
Flashes



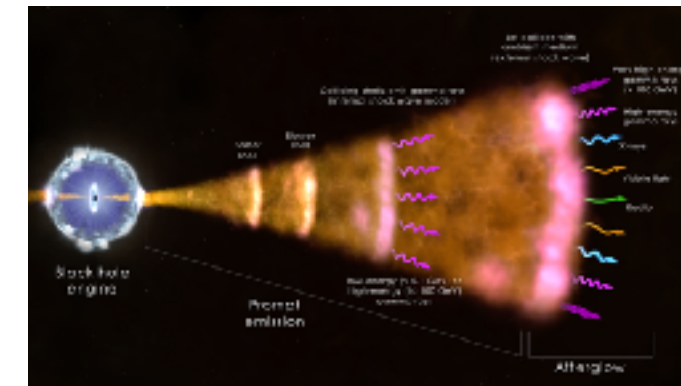
Novae



Seyferts



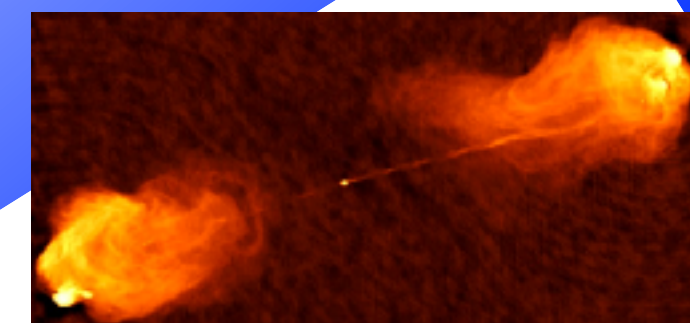
Gamma-ray bursts



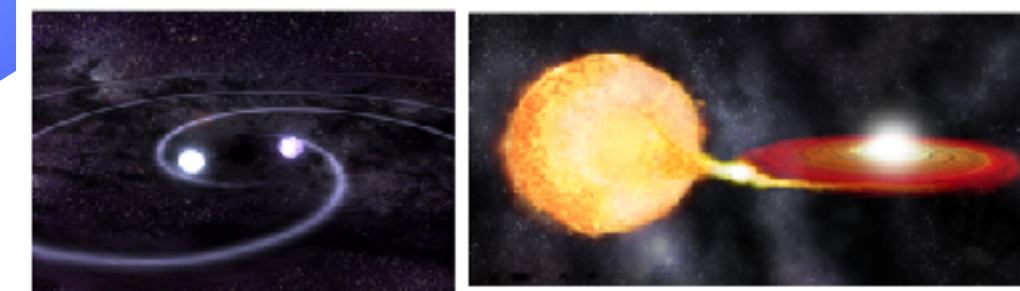
Blazars



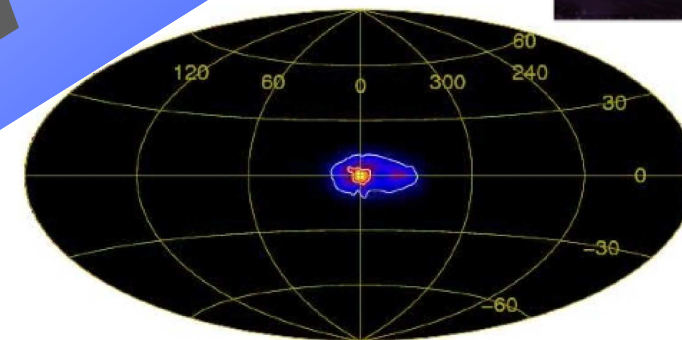
Radio
Galaxies



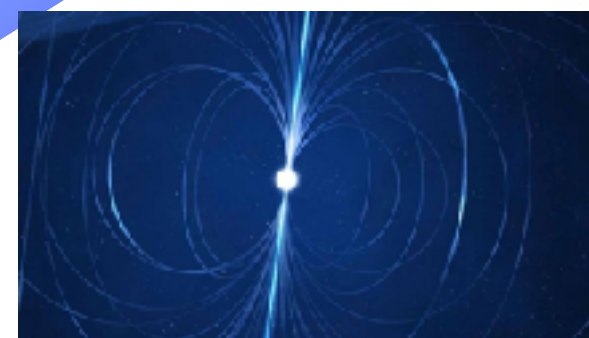
Type-Ia
SNe



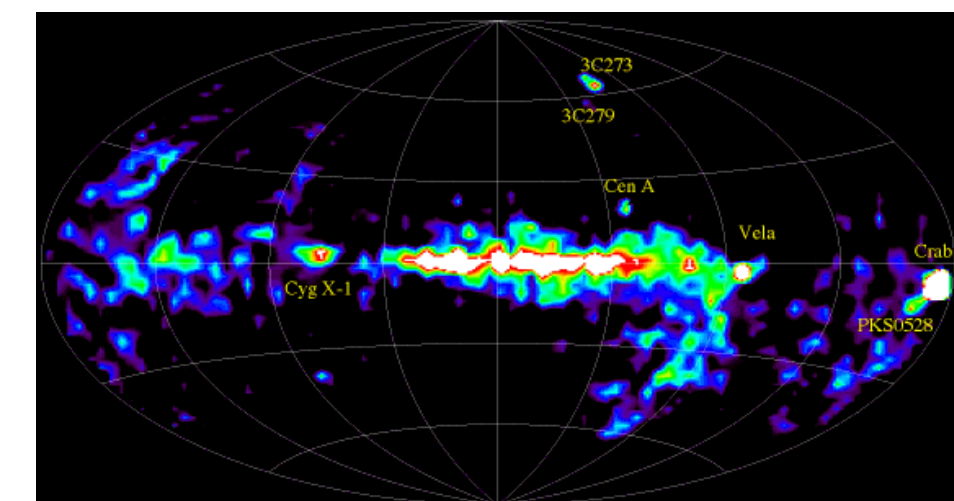
Galactic Center



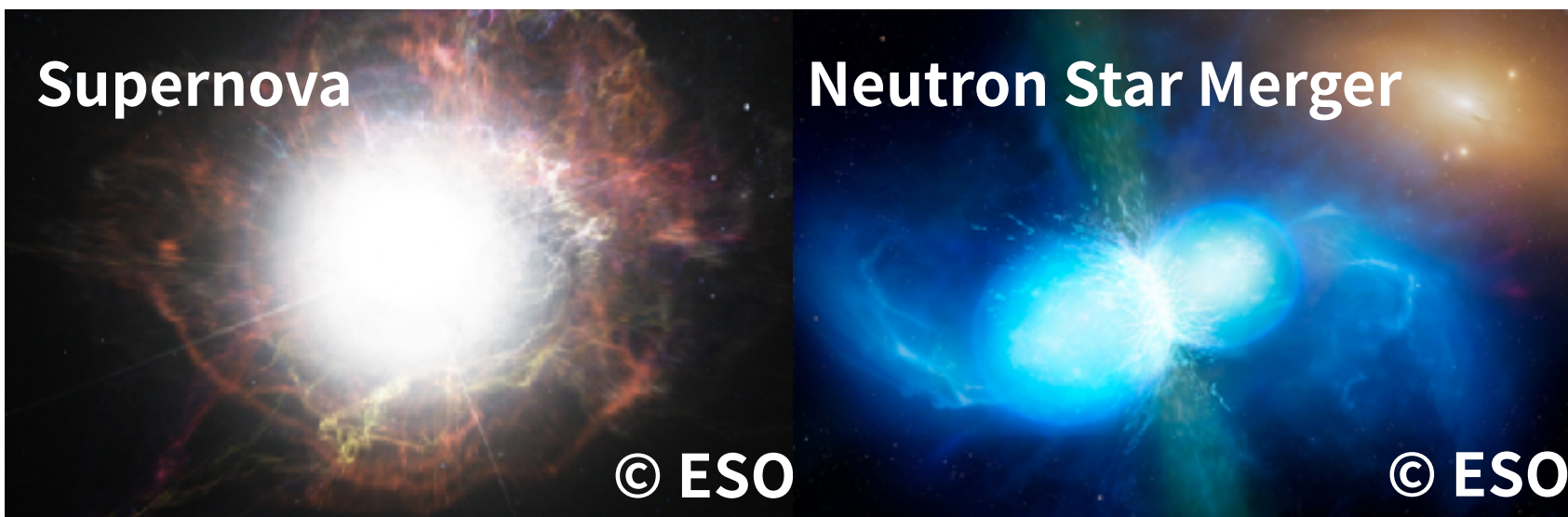
Pulsars & Magnetars



Background

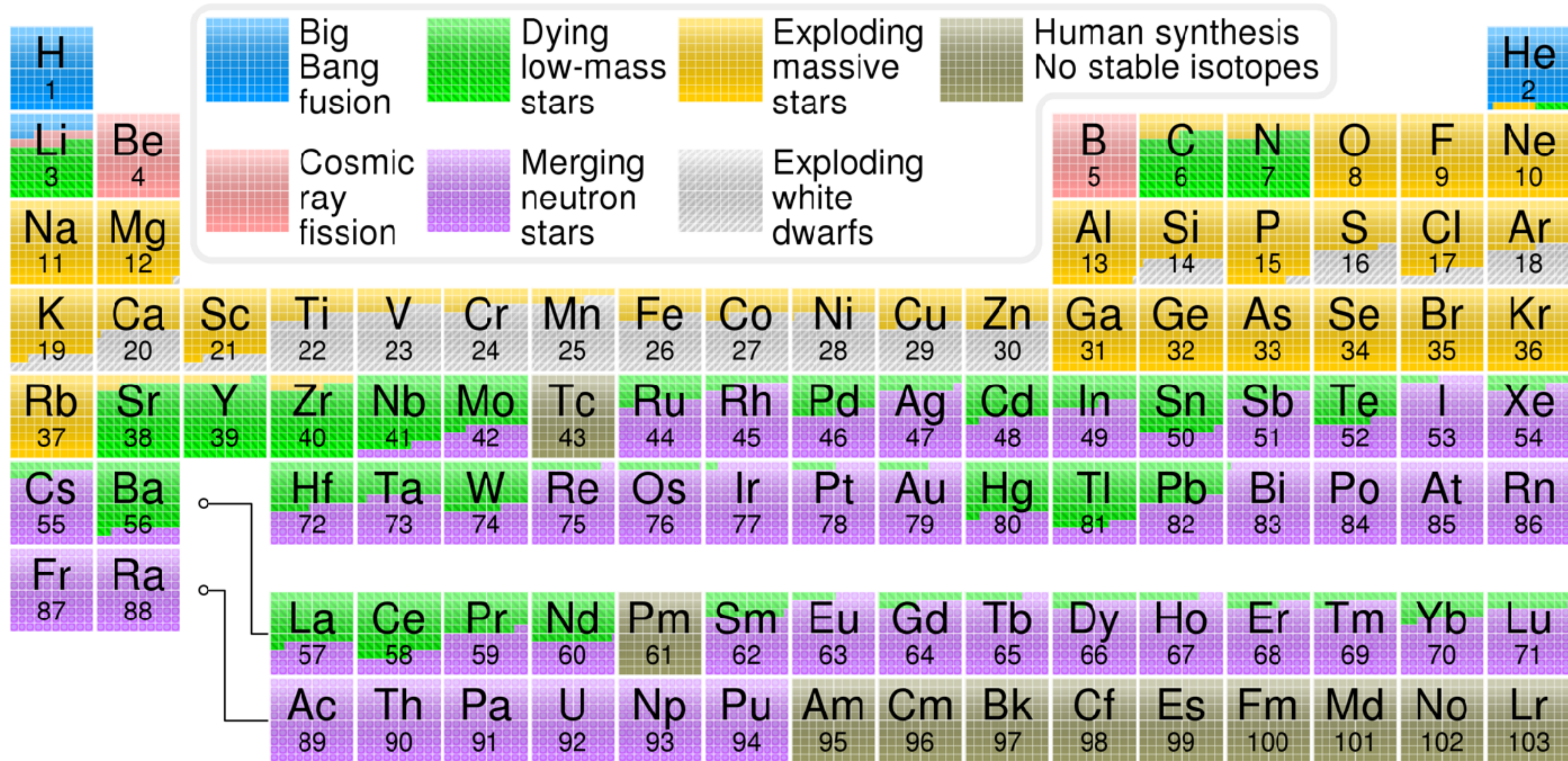


DISTANCE



Nuclear processes: Gamma-ray Lines

Transitions between nuclear energy levels

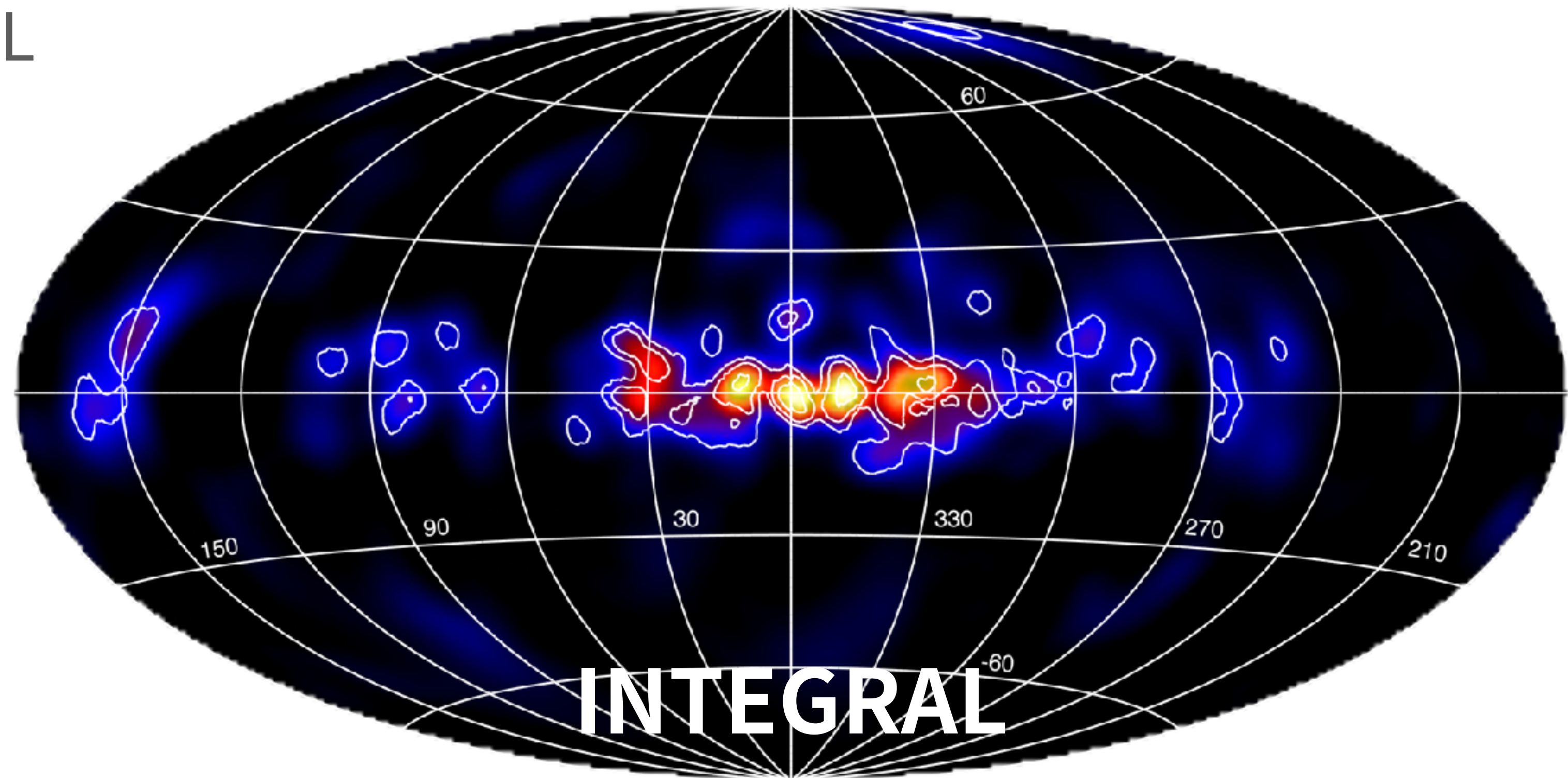


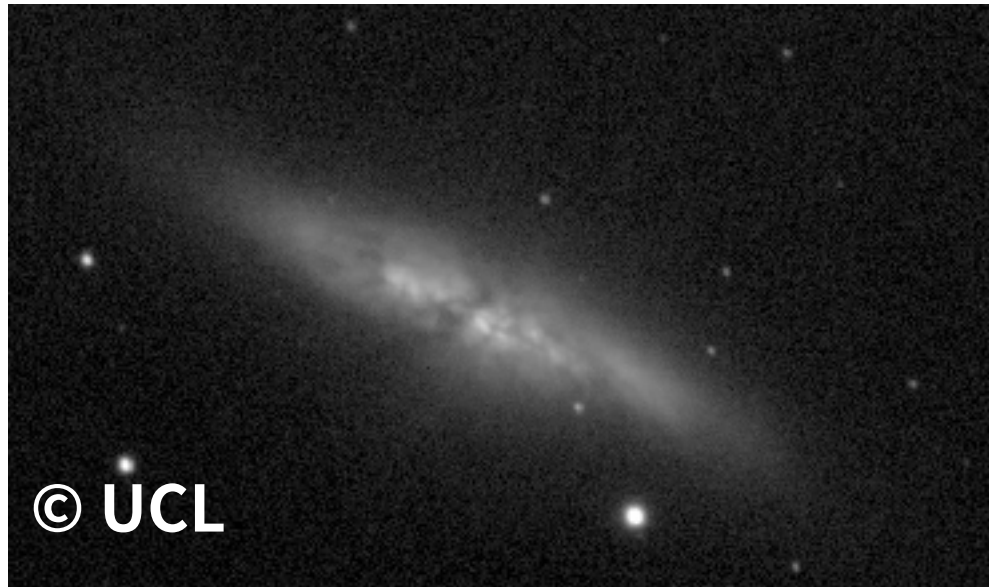
All-sky image of 1.8 MeV ^{26}Al gamma-ray line

Tracing massive young star formation activity



- INTEGRAL confirms COMPTEL
 - confined in the galaxy.
- scale height: ~ 800 pc
(Pleintinger+'19; Wang+'20)
 - ~ 50 pc for young stars
- Foreground local structure?
(Fujimoto+'20)



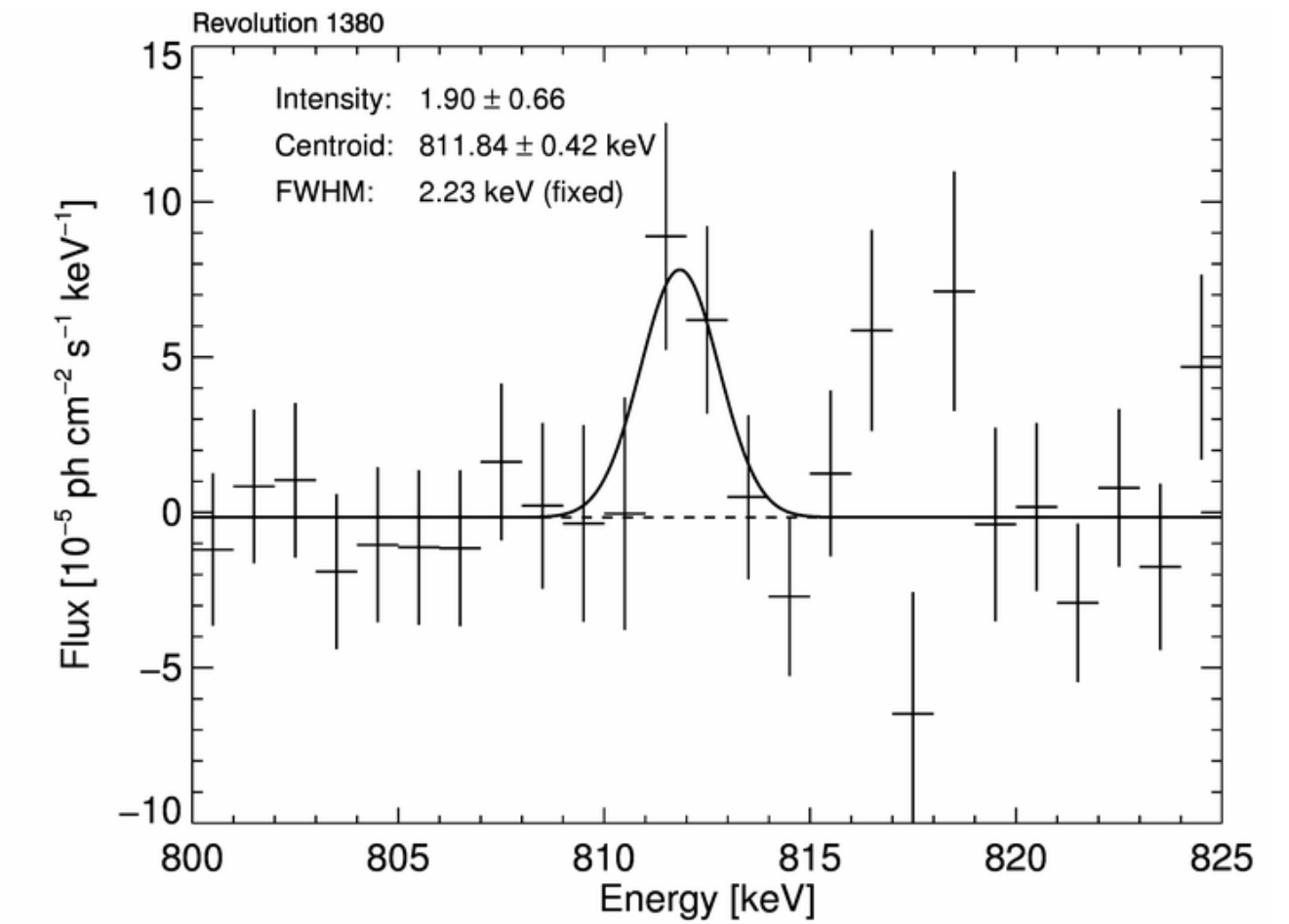
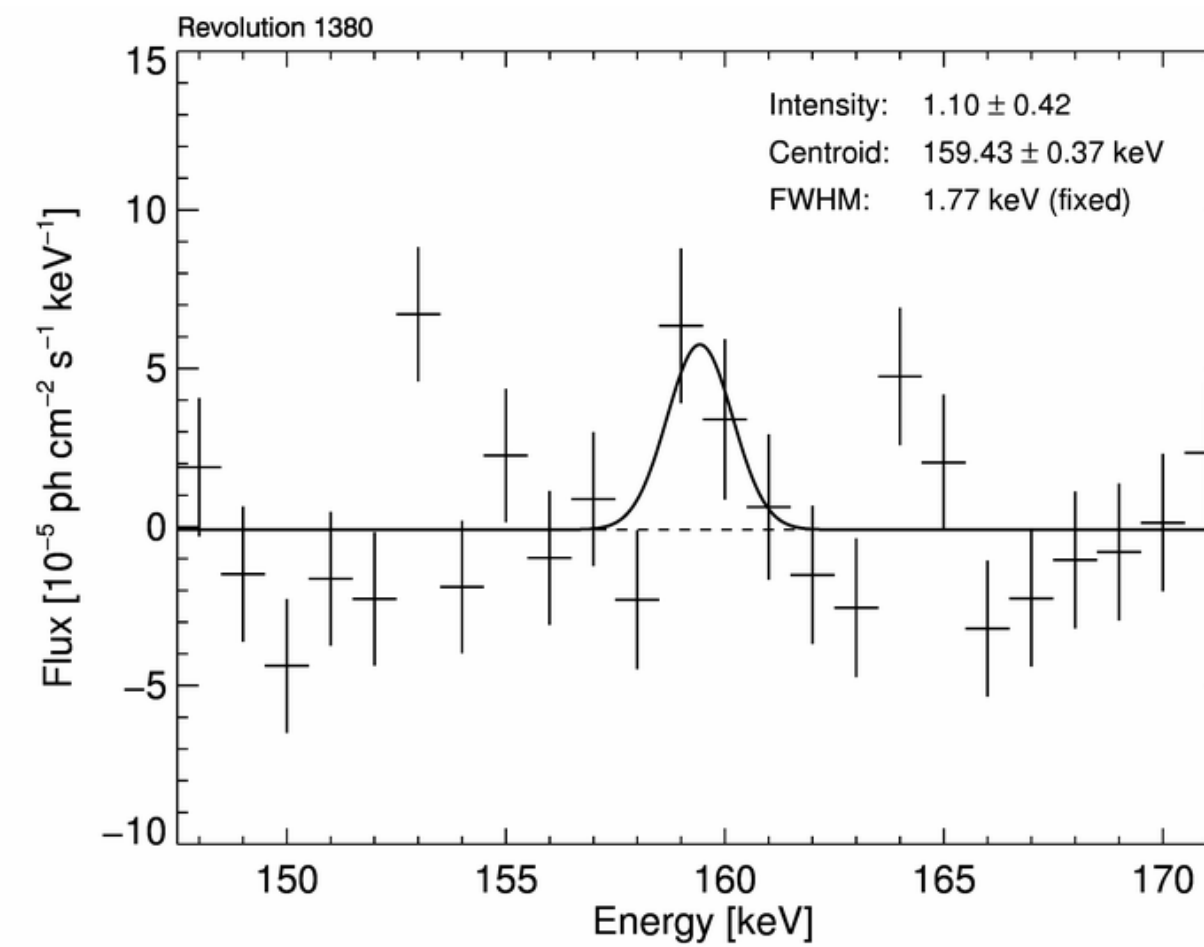
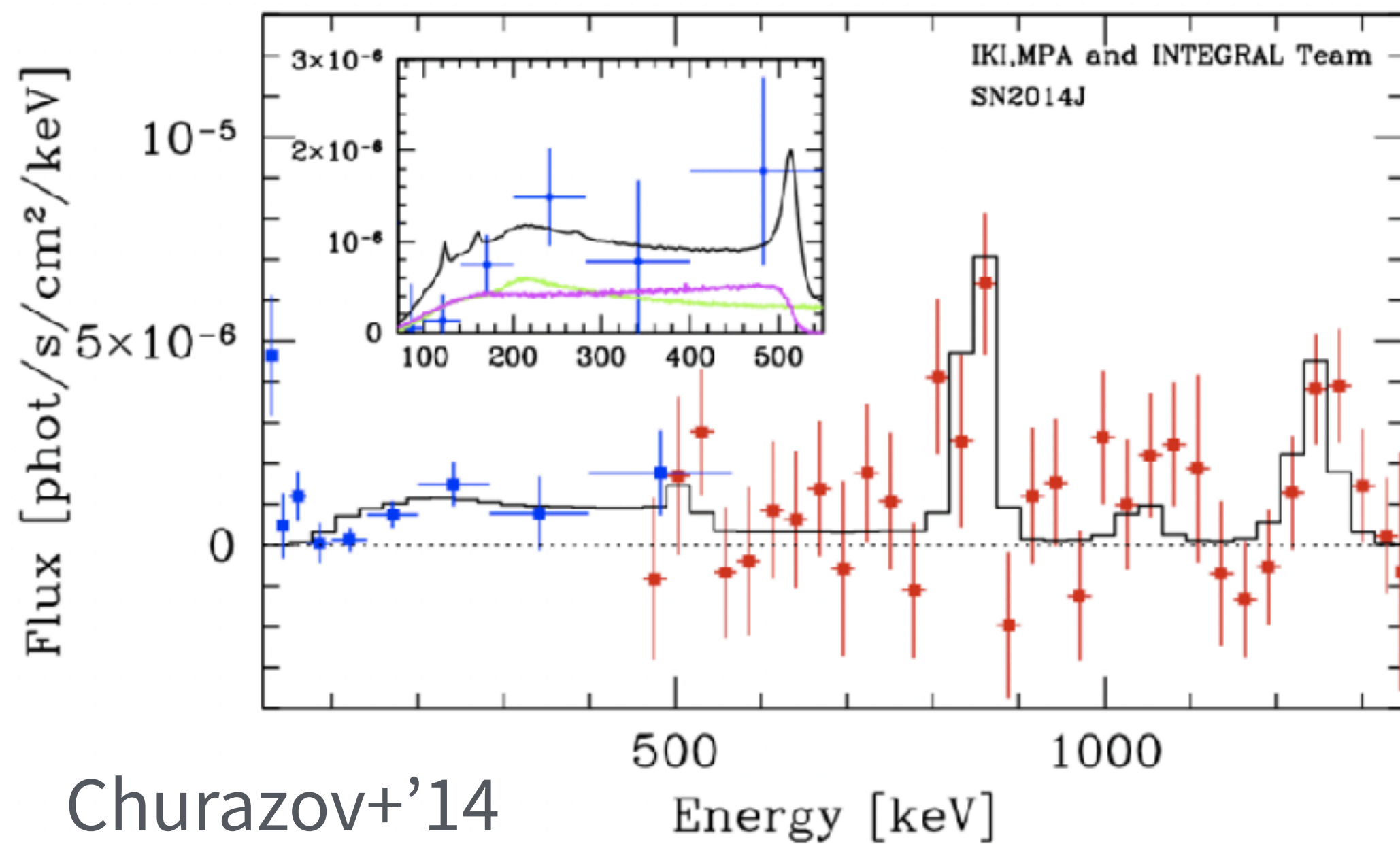


SN 2014J in M 82

Type Ia SN: Thermonuclear explosion $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$

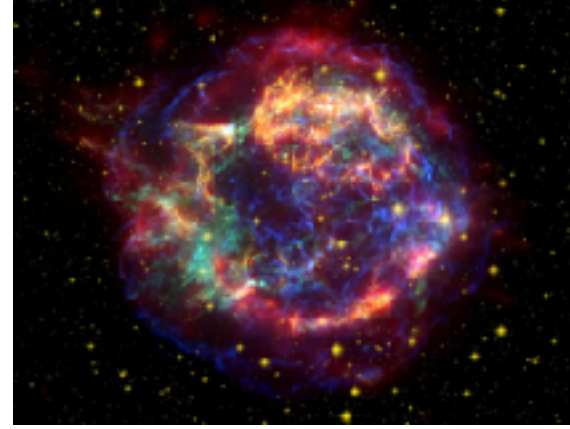
^{56}Ni Lines: ~17.5 days after the explosion

^{56}Co Lines: 50-100 days after the explosion



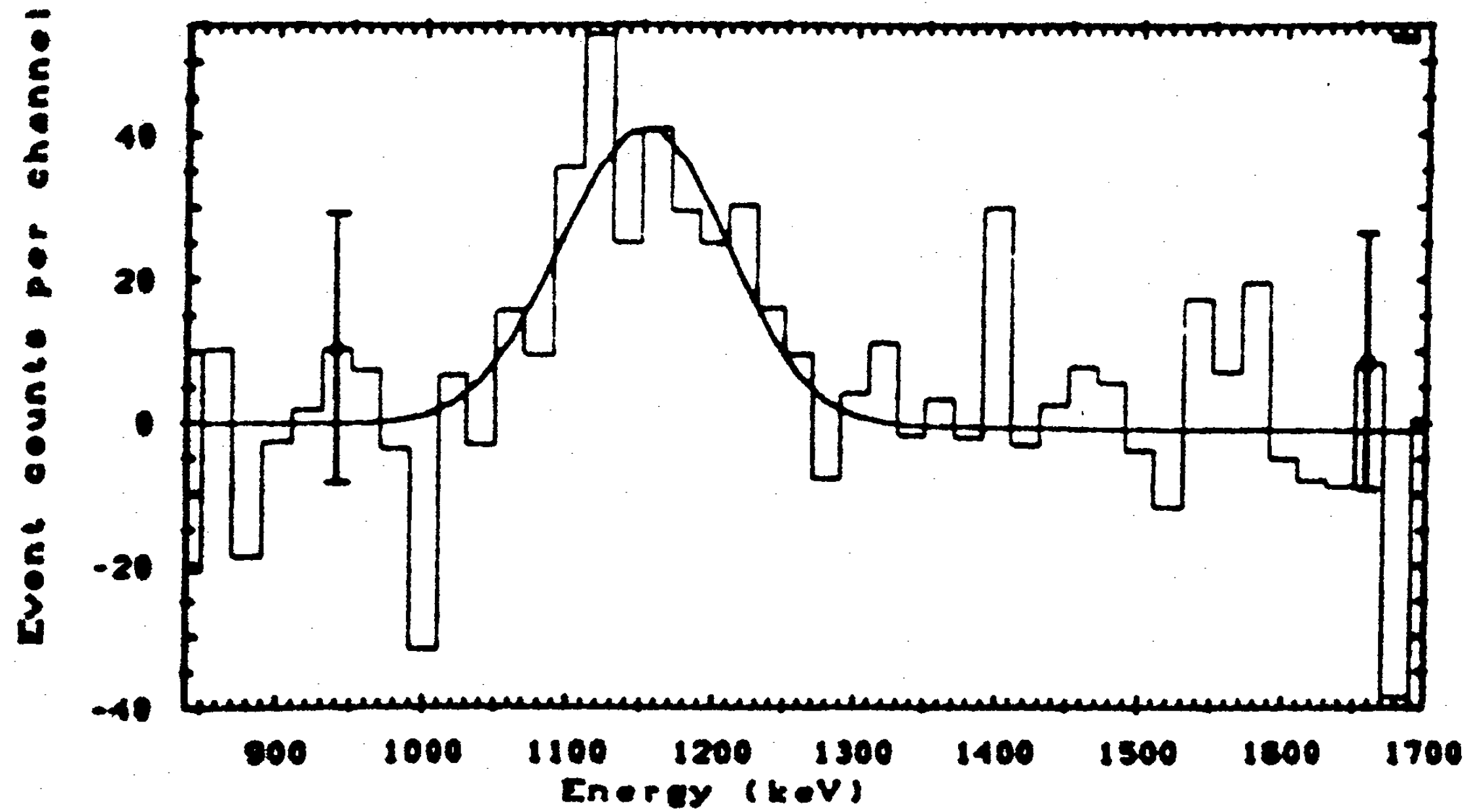
Diehl+'14

- 158 & 812 keV lines from ^{56}Ni ($\tau \sim 8.8$ days)
- 847 & 1238 keV lines from ^{56}Co ($\tau \sim 77$ days)
- $\sim 0.6M_{\odot}$ of ^{56}Ni

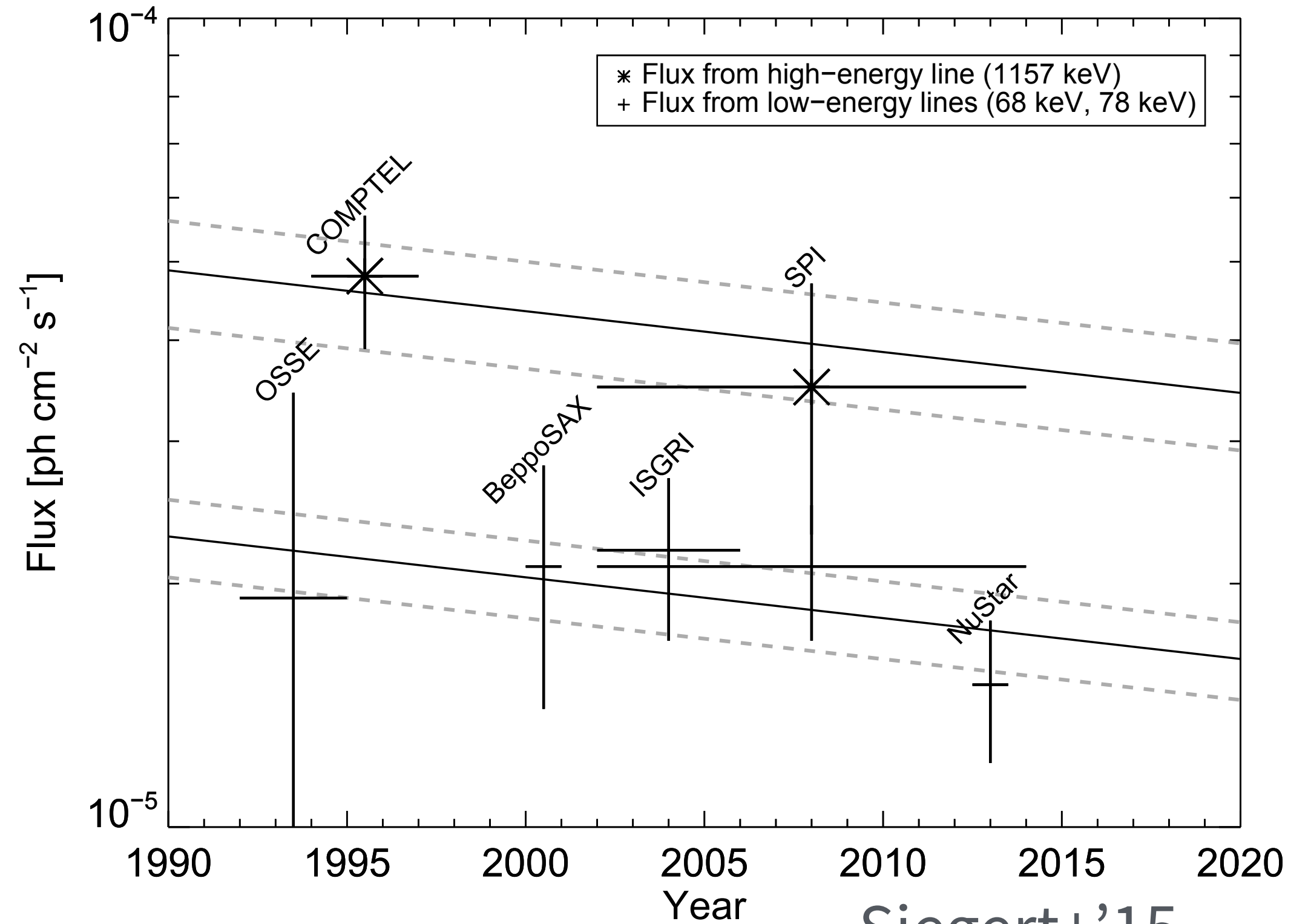


COMPTEL/INTEGRAL observation of Cas A

^{44}Ti line @ 1.16 MeV

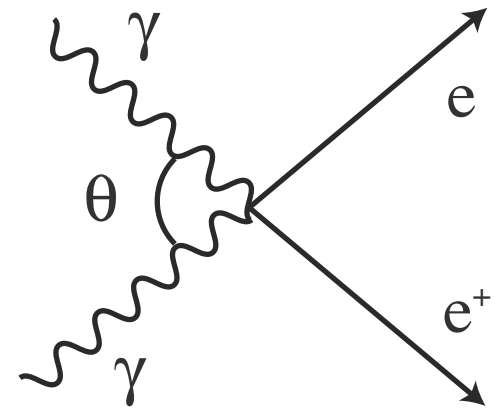


Iyudin+'94



Siegert+'15

- 1.16 MeV ^{44}Ti line from Cas A is detected
- Flux should change with time.



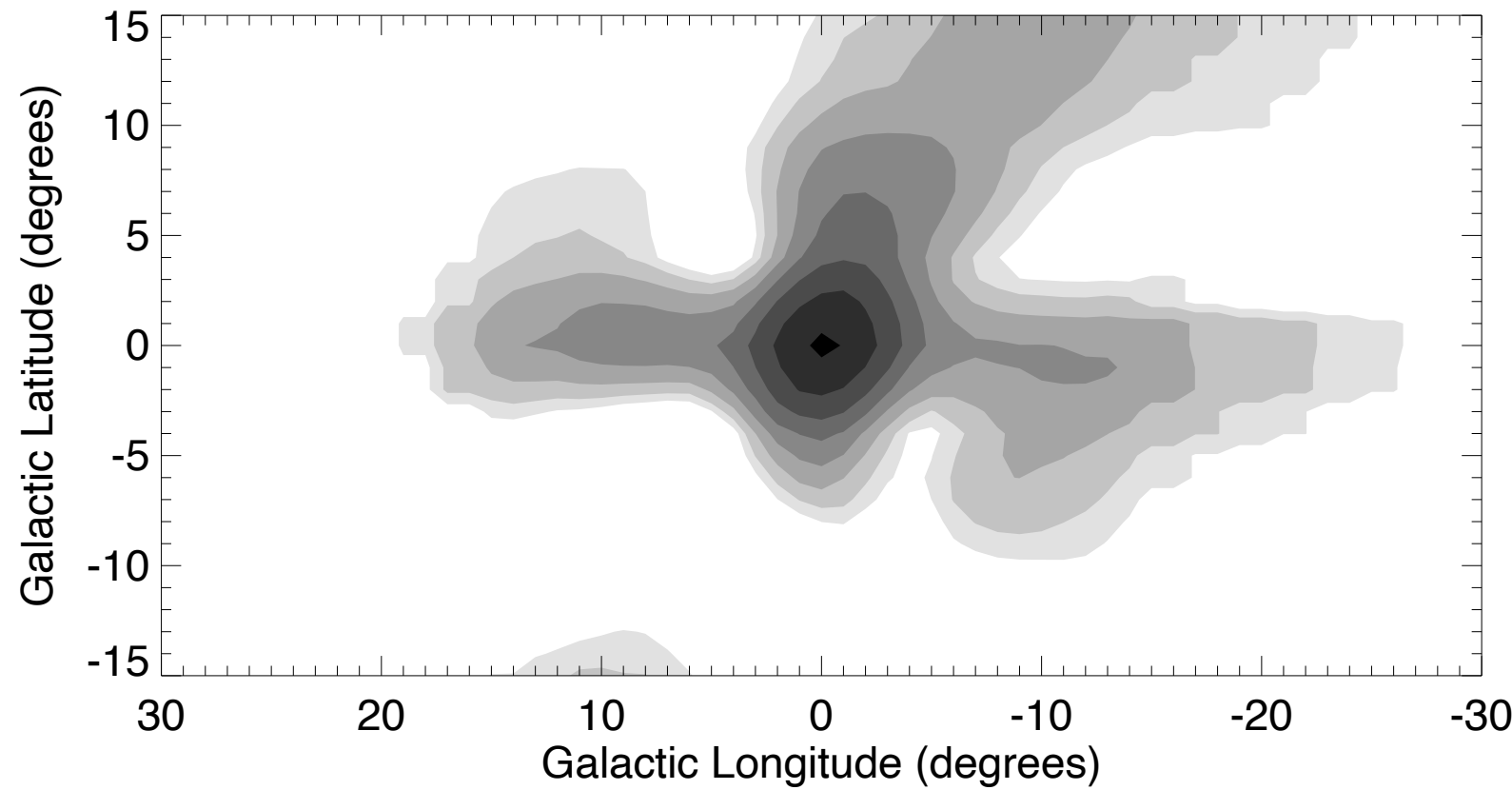
Particle physics processes: Gamma-ray Lines

511 keV e^+e^- annihilation line from Galactic Center

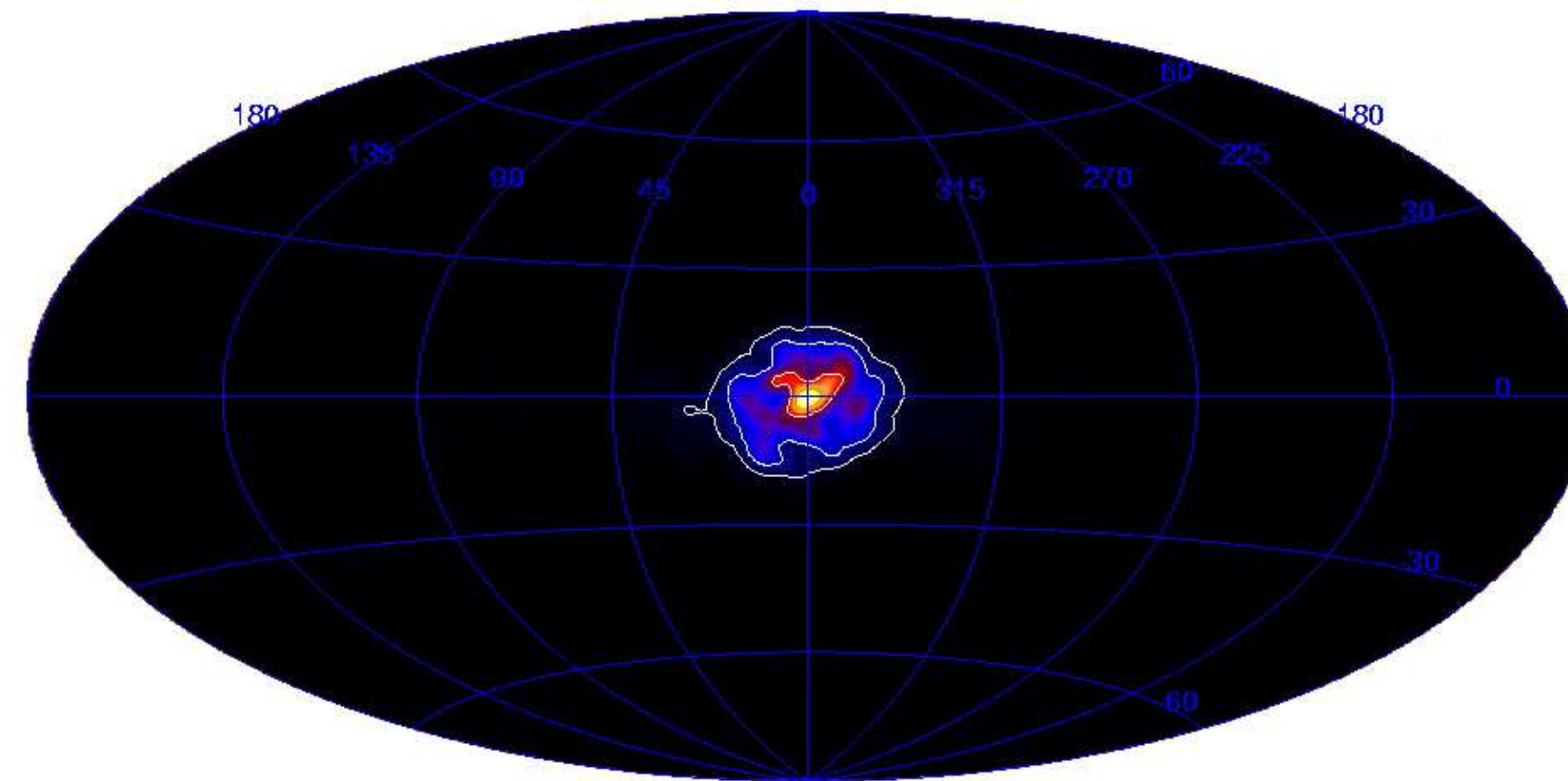
OSSE

INTEGRAL

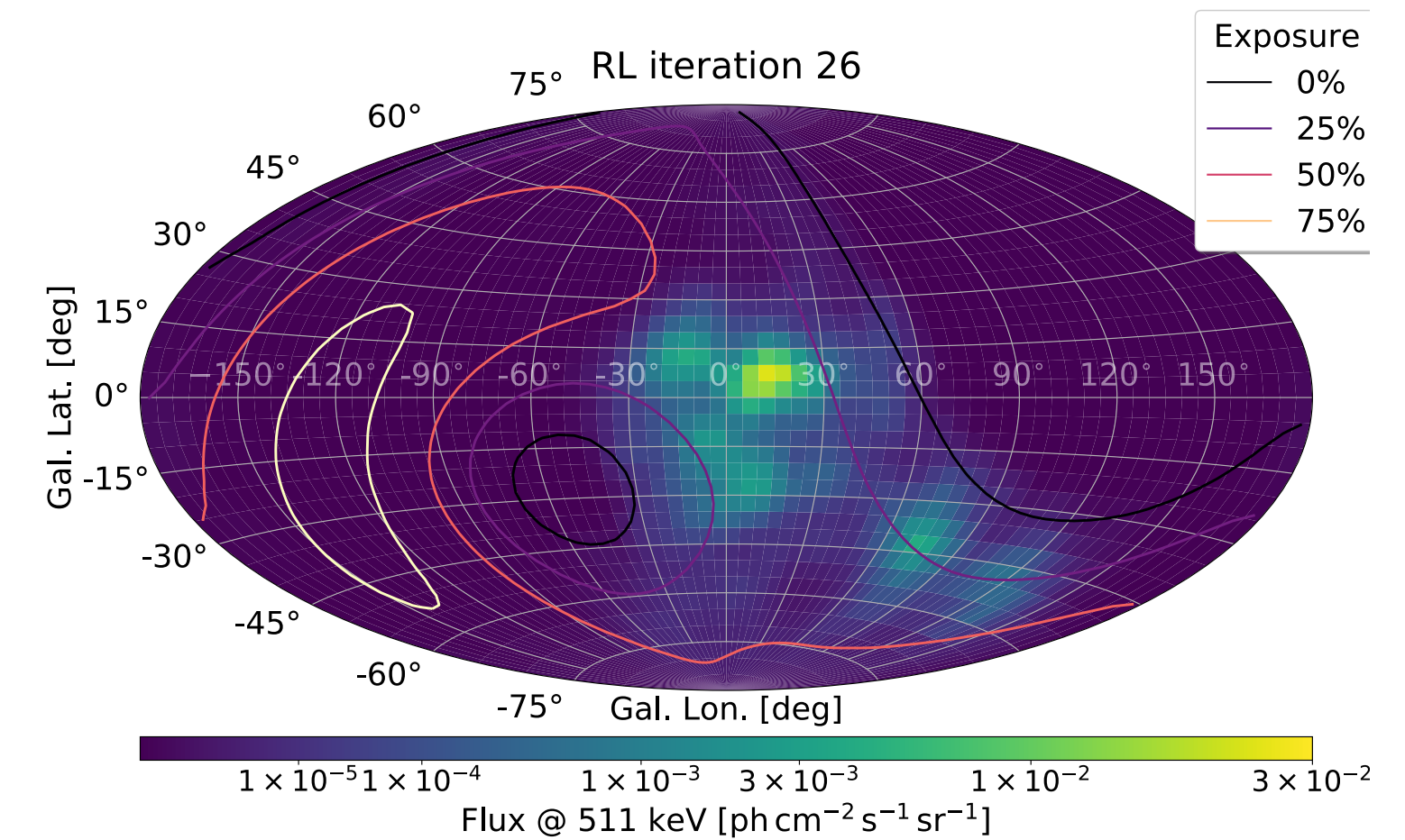
COSI



Purcell+'97



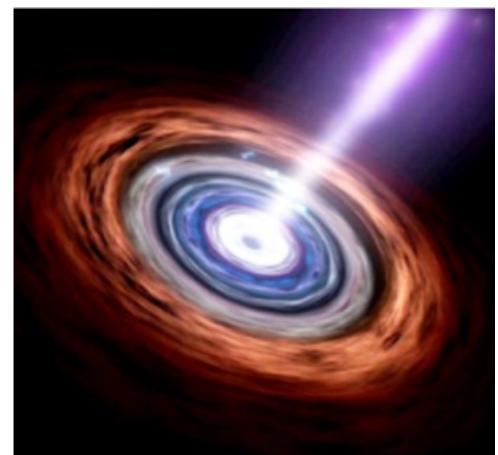
Knödlseeder+'05



Siegert+'20

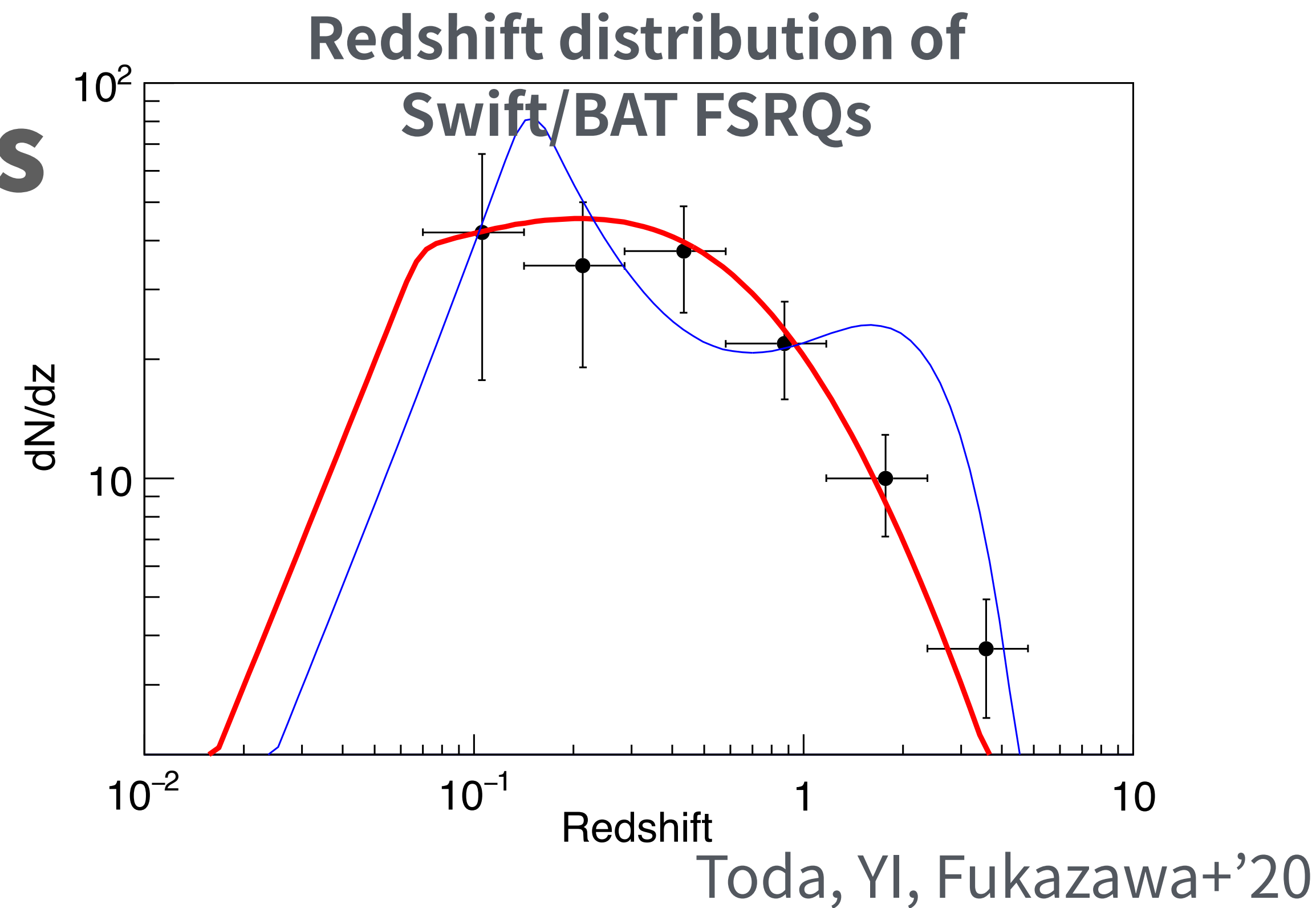
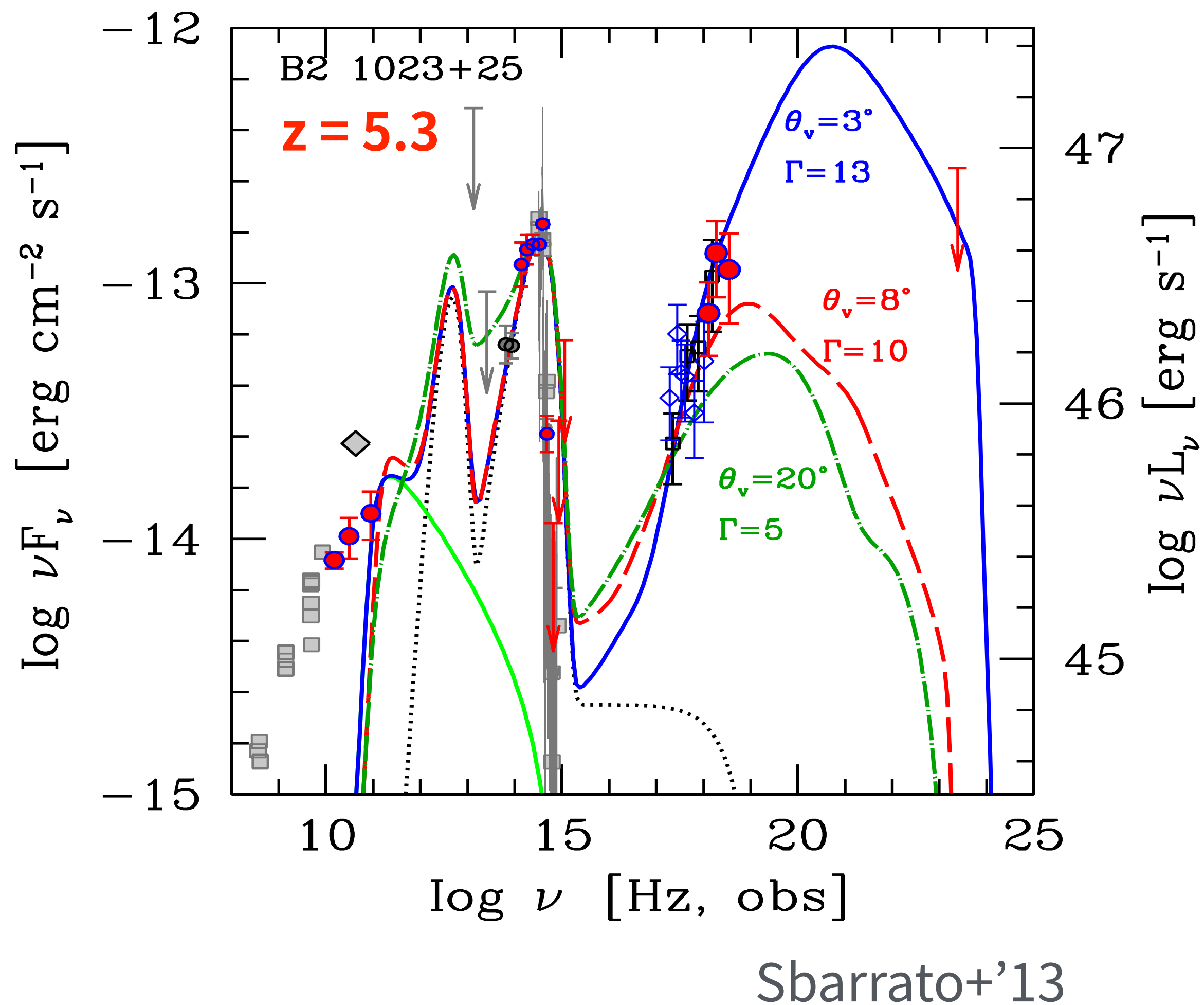
- Clear excess toward the direction of the Galactic Center
- Detailed morphology is still not clear

- Various origins are proposed
 - SNe Ia, LXMBs, Microquasars, RIAF,,, (e.g., Prantzos '06; Guessoum+'06; Totani '06)

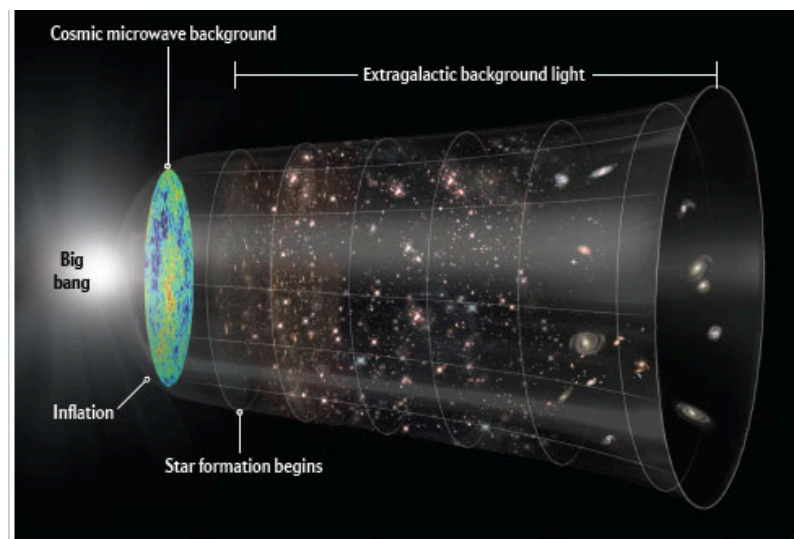


High Redshift Blazars

Probing the distant universe



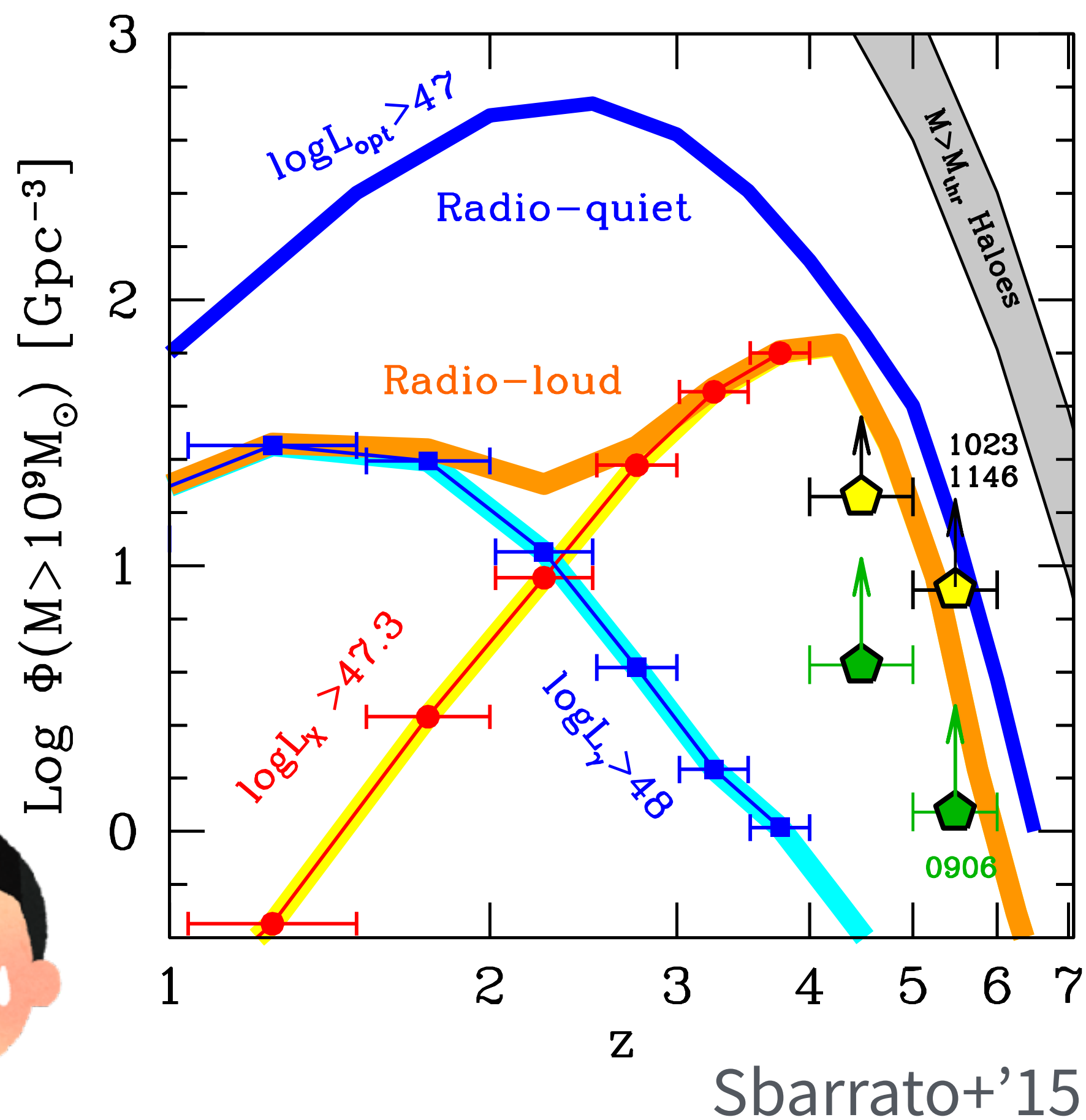
- Swift/BAT & NuSTAR report high redshift blazars, likely peaking at MeV
 - negative k-correction
- MeV gamma-ray can study high redshift universe.



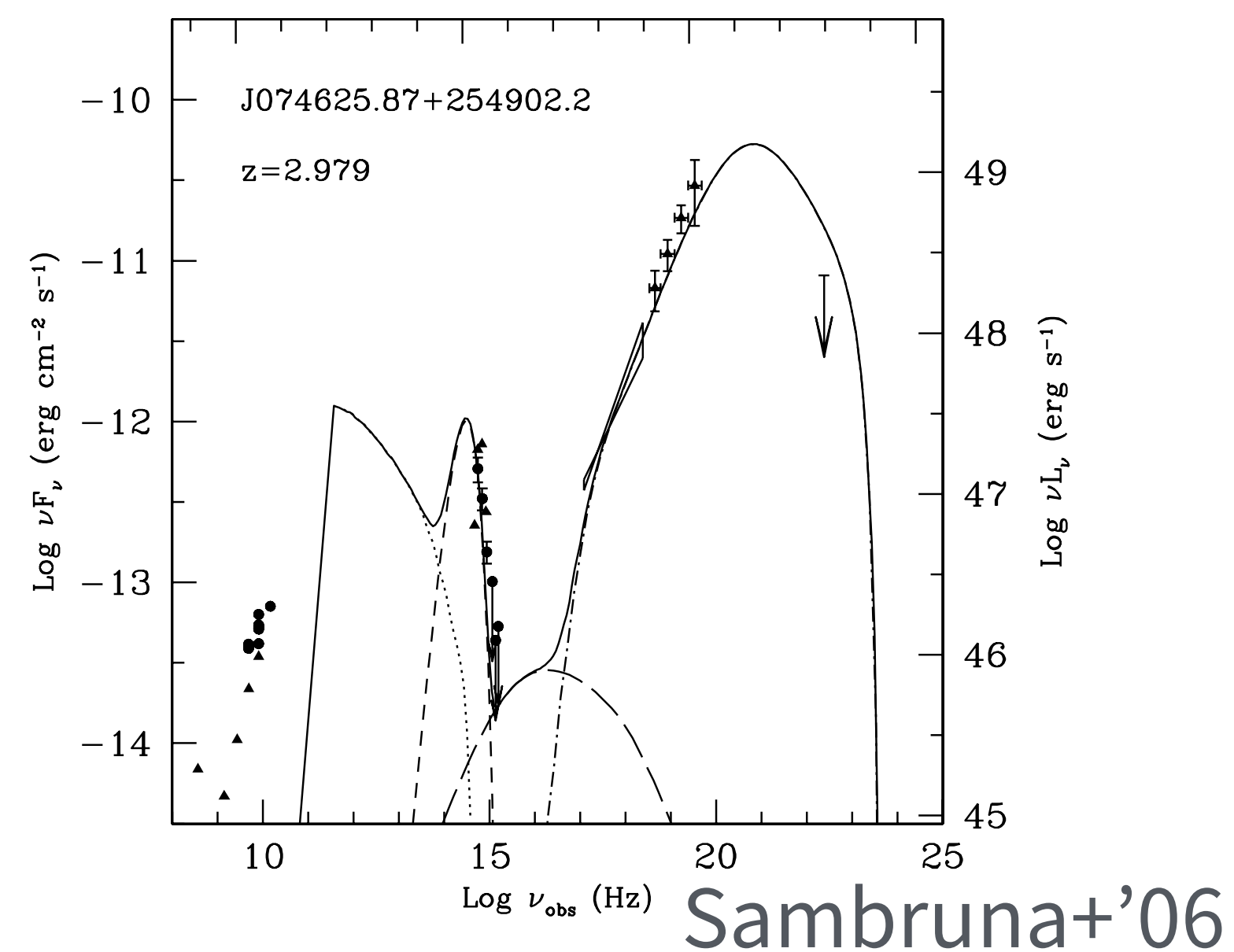
Evolution of Blazars

Inconsistency in X-ray and Gamma-ray?

- Gamma-ray blazars show evolutionary peak at $z \sim 1-2$ (e.g., YI & Totani'09; Ajello, YI+'15)
- But, it is at $z \sim 3-4$ for X-ray blazars (Ajello+'09, see also Toda, Fukazawa, YI'20).

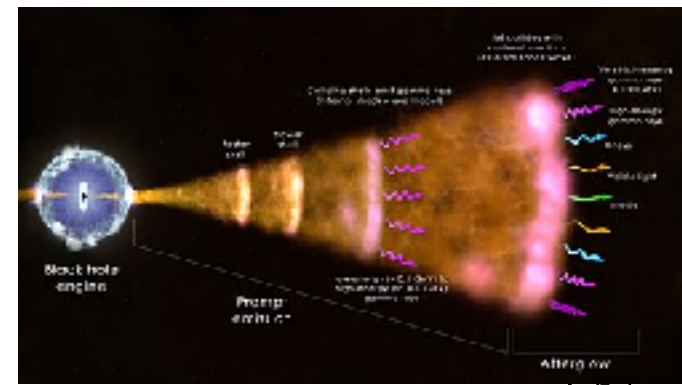


- More MeV blazars are needed (e.g., Blom+'96; Sambruna+'06).

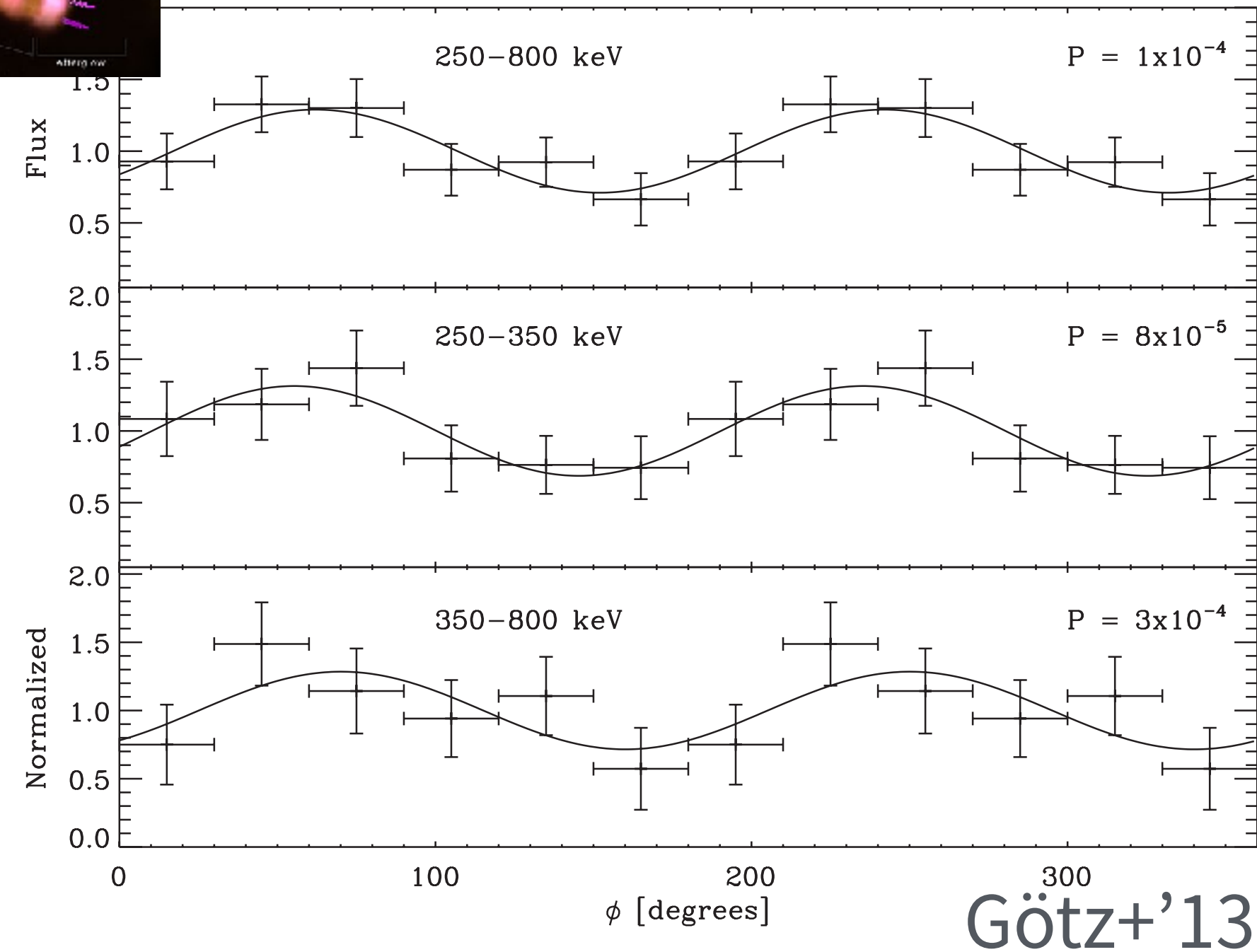


Gamma-ray Polarization

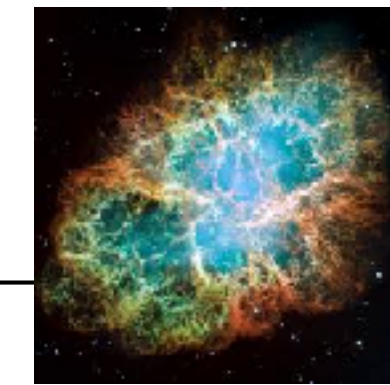
Probing the structure using Compton kinematics



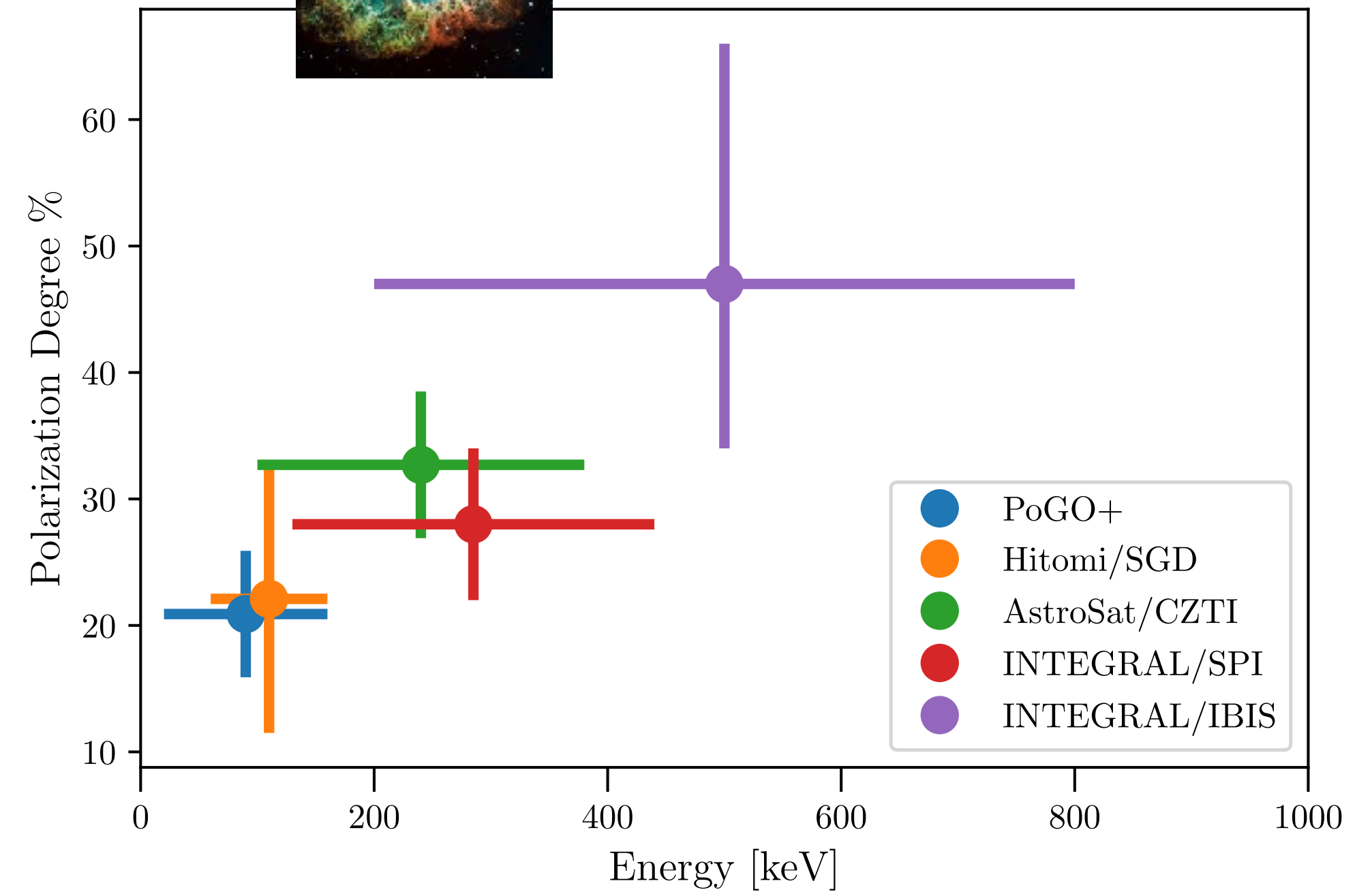
GRB 061122



- Linear polarization measurement of GRB prompt emission in 250-800 keV by INTEGRAL (Götz+'13)



Crab

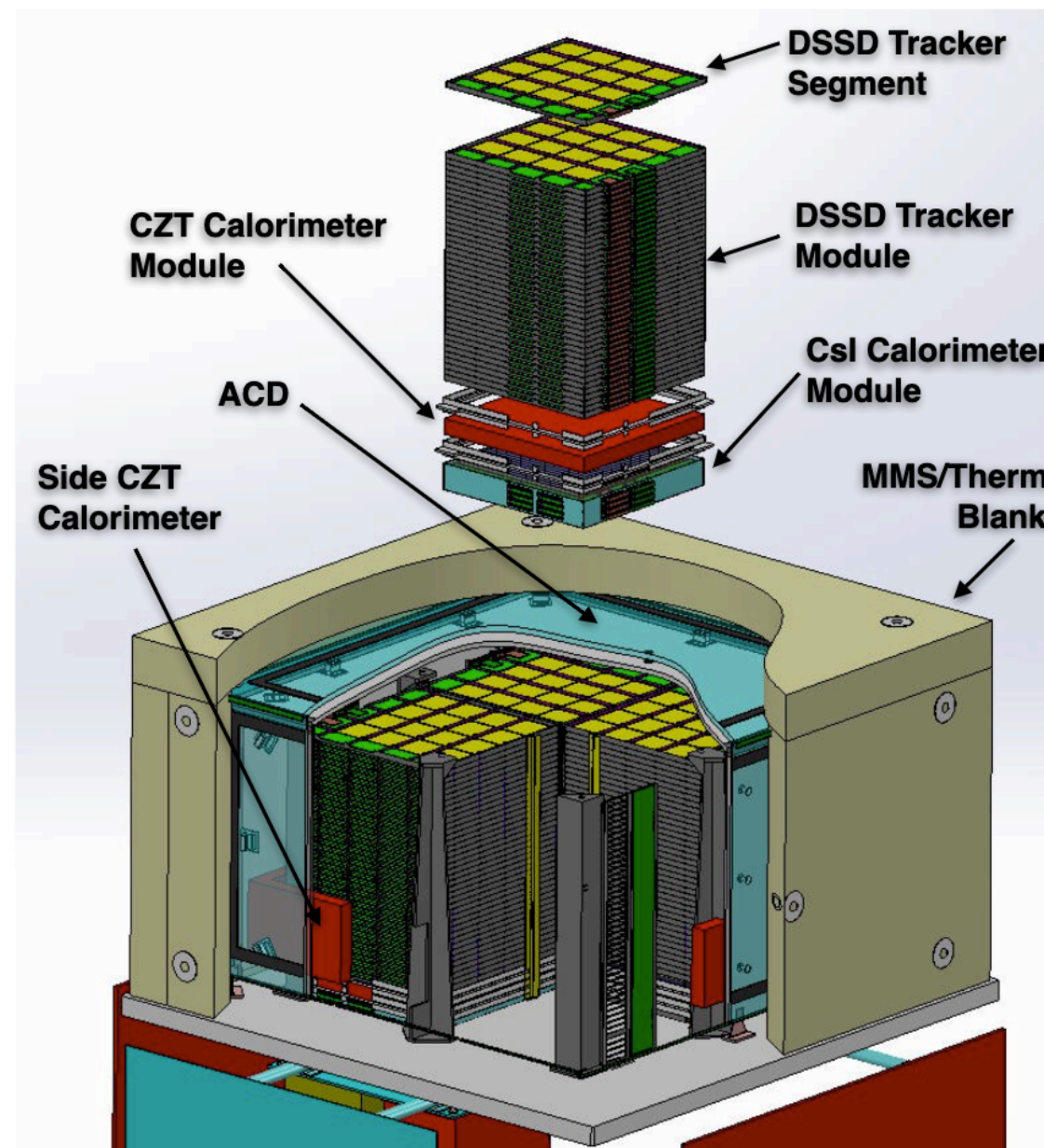


- Increase of polarization degree in Crab nebula (PoGo+, Hitomi, AstroSat, INTEGRAL)?

Proposed MeV Gamma-ray Missions

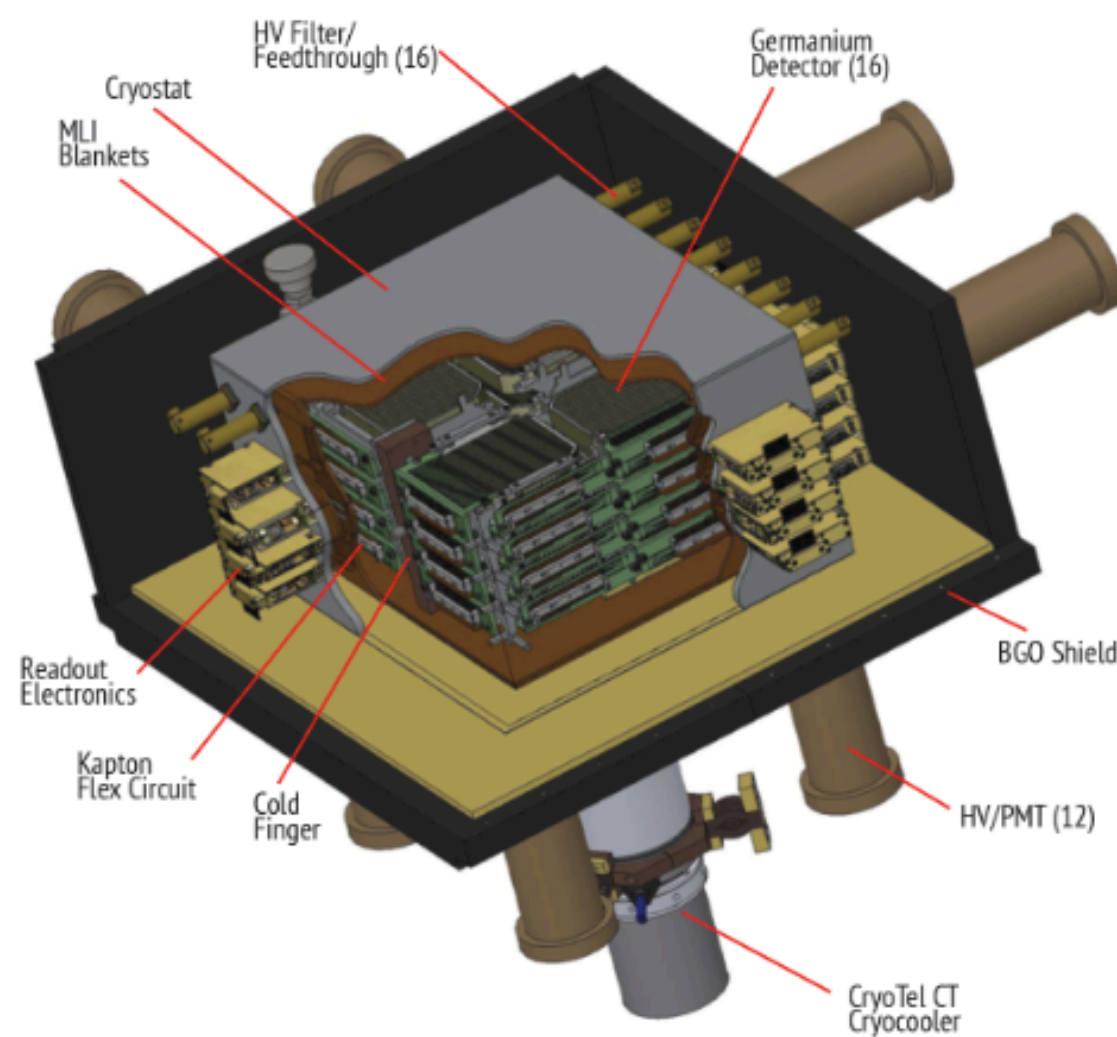
Not complete,,,,

Solid



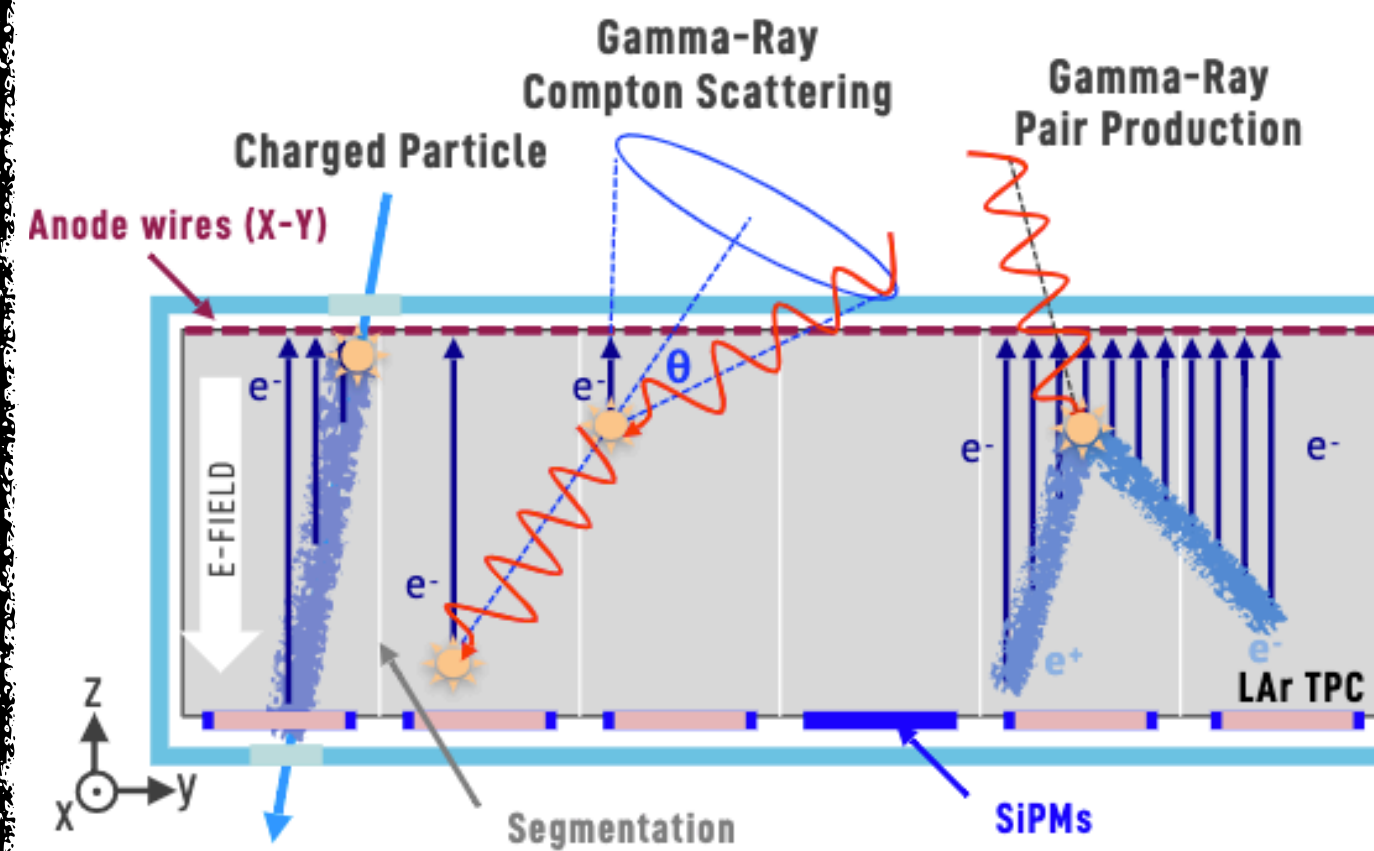
AMEGO

See talk by Zoglauer



COSI

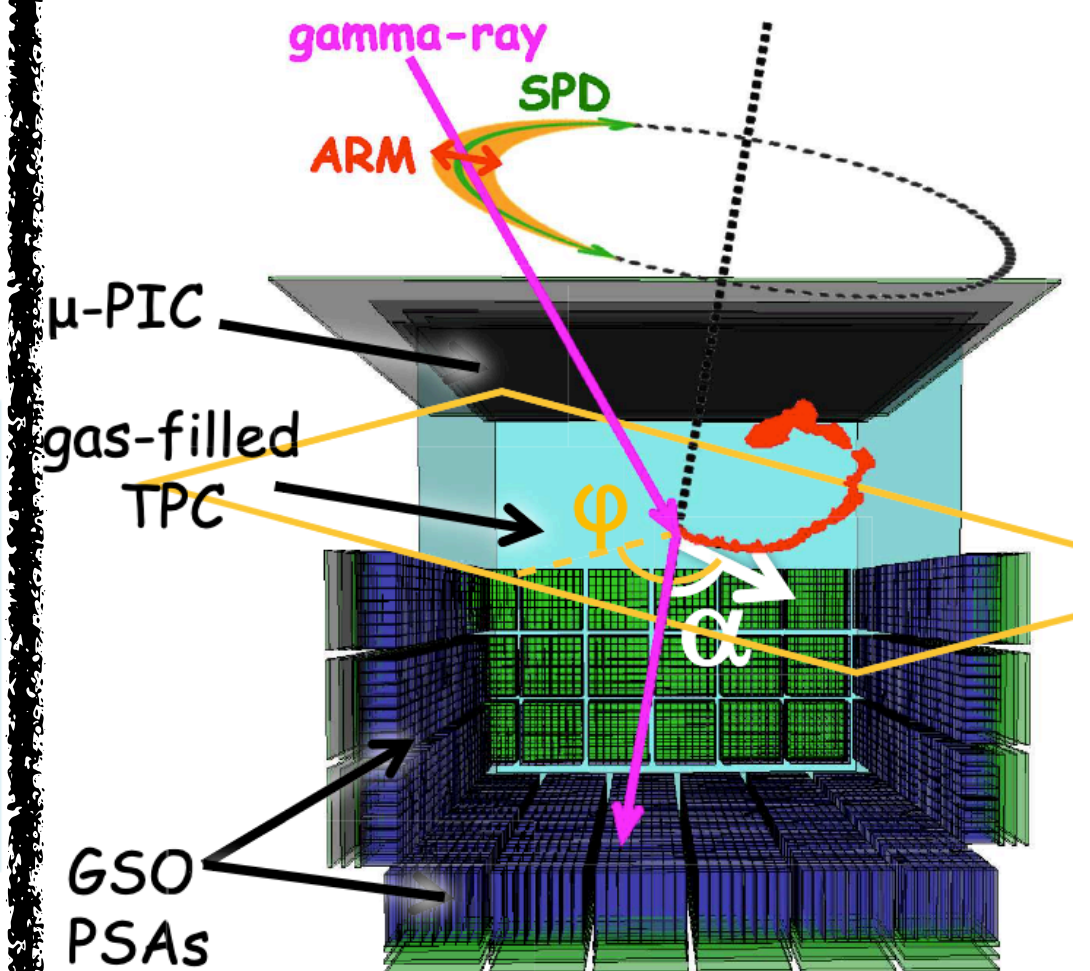
Liquid



GRAMS

See Poster by Takashima

Gas

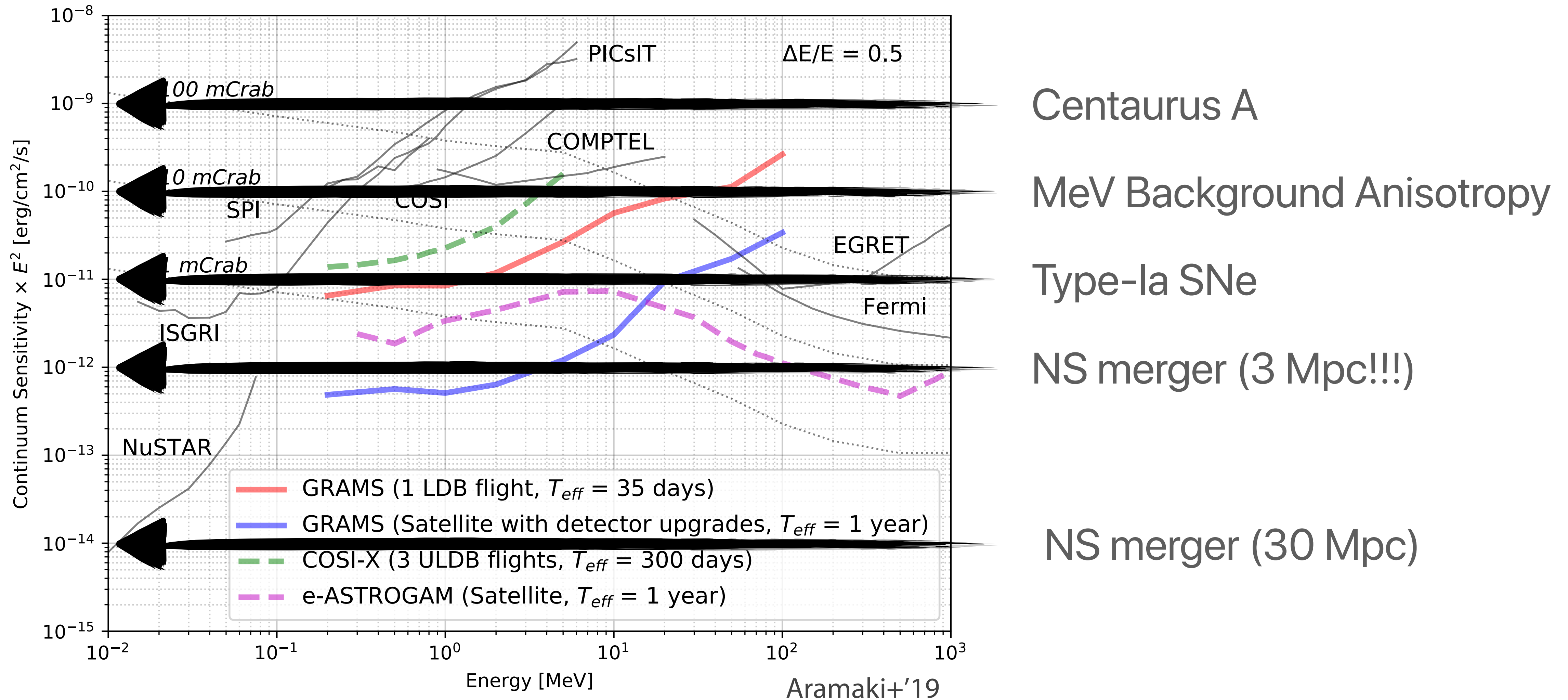


SMILE

See talk by Takada

Crude Estimates for MeV Science

What kind of sources can we see?

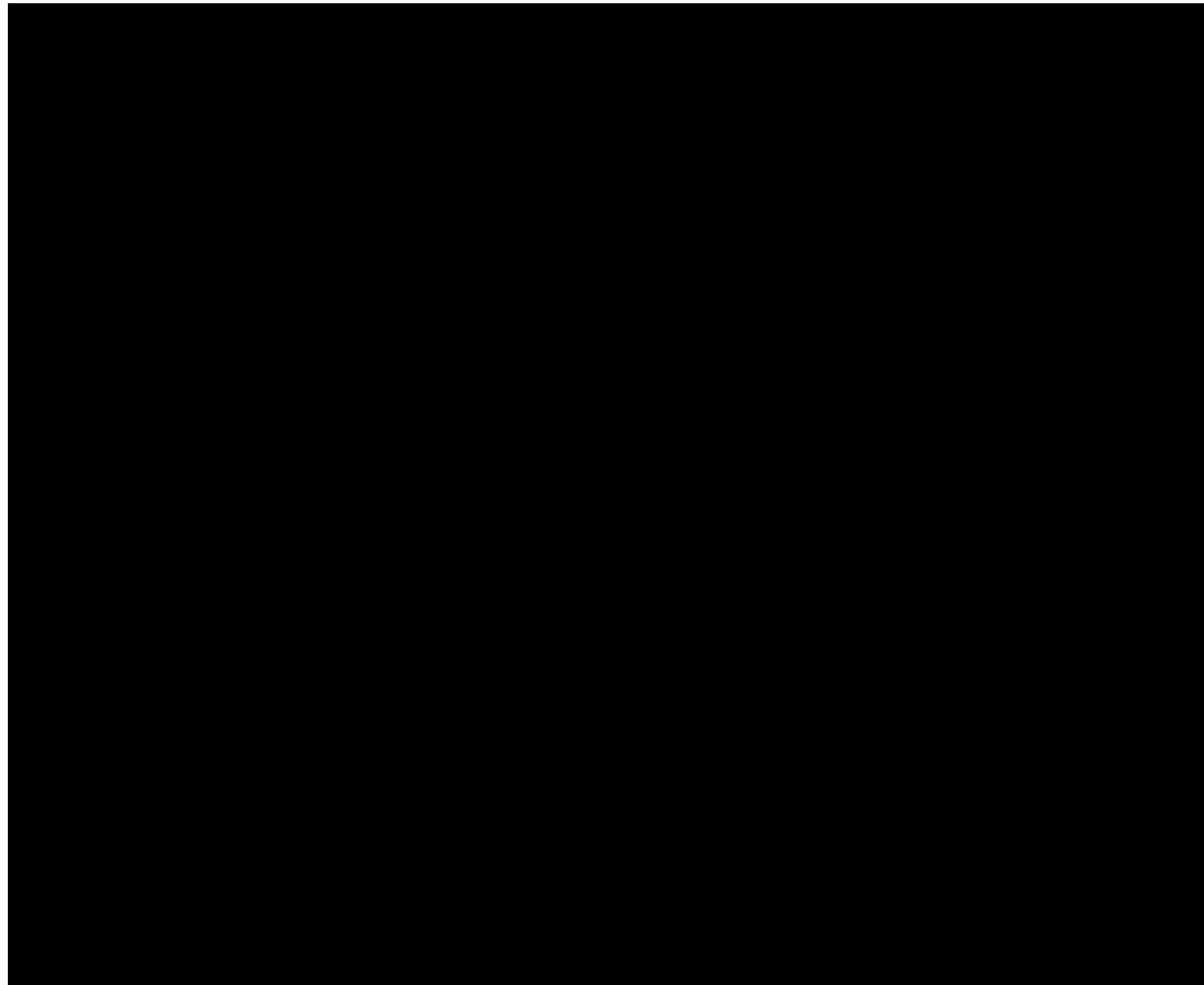


Expectation from Swift/BAT & Fermi/LAT

Realistic estimation for MeV Gamma-ray Astronomy in the next decade

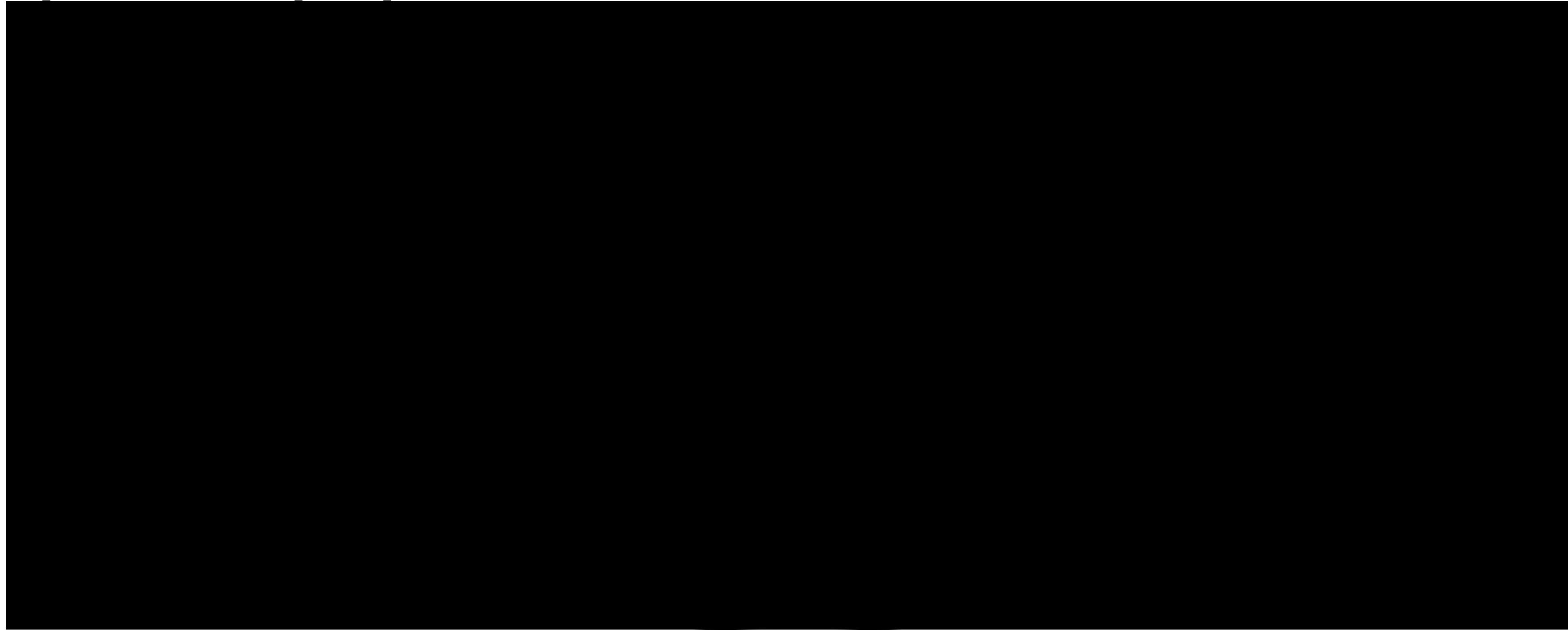
- Spatially matching Swift/BAT 105-month catalog and 4FGL-DR2 (10 year) catalog.
 - 0.05° (5% contamination)
- 135 matched objects
- Dominated by blazars: 89
 - Bimodal distribution in Photon index

BAT Flux



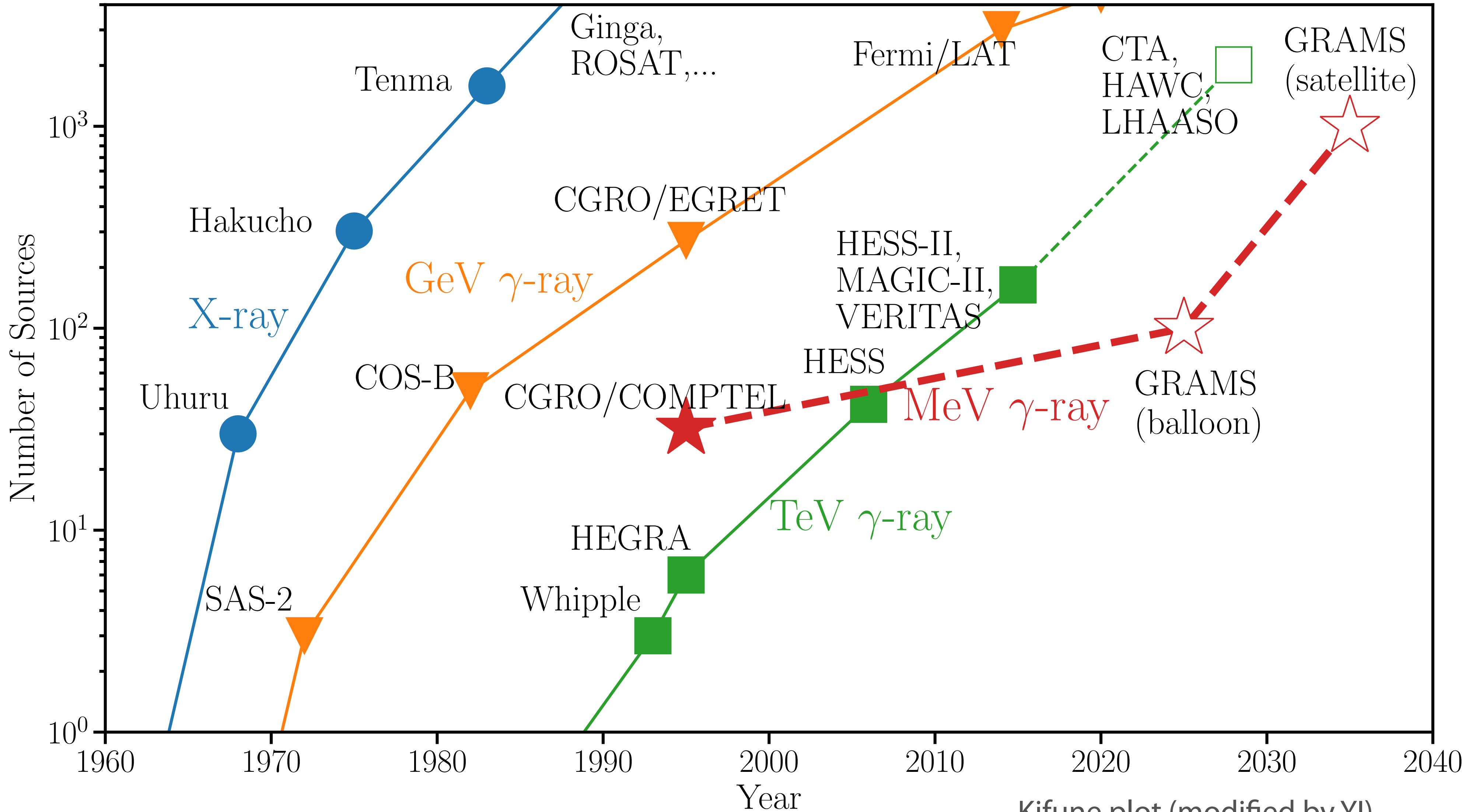
BAT-LAT MeV objects sky distribution

Naomi Tsuji et al. in prep.



- Toward the future observation plan.
- Interpolate MeV gamma-ray spectra of the Tsuji catalog
- Number of objects having MeV flux of
 - $> 10^{-10}$ erg/cm²/s : **23 sources**
 - $> 10^{-11}$ erg/cm²/s : **67 sources**

Number of Gamma-ray Objects



Kifune plot (modified by YI)

Summary

What's we need to accomplish? A: **Operation of MeV balloons/satellites.**

- A MeV gamma-ray observatory can bring various discoveries to us
 - nuclear astrophysics, cosmic evolution, high energy phenomena, dark matter particles
- Variety of Compton Cameras are proposed
 - Solid (AMEGO, COSI), Liquid (GRAMS), & Gas (SMILE)
- Latest Swift/BAT & Fermi/LAT catalogs tell us
 - @ $> 10^{-10}$ erg/cm²/s : 23 sources
 - @ $> 10^{-11}$ erg/cm²/s : 67 sources (Mostly blazars)