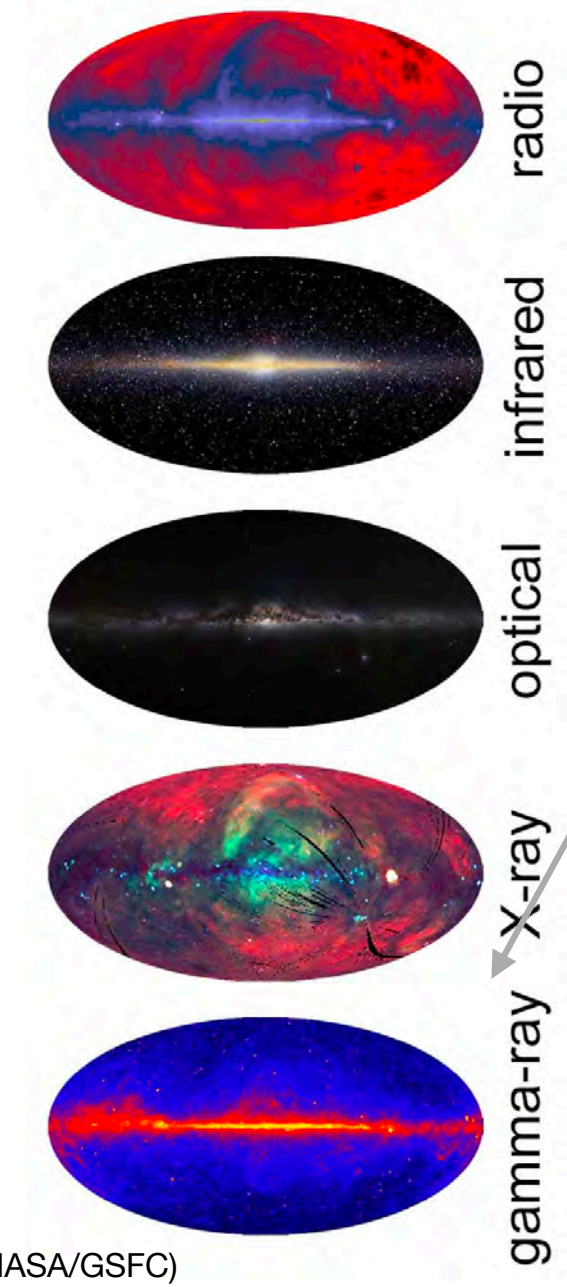
MeV gamma-ray mission mini-workshop / GRAMS collaboration meeting
June 20–22, 2021

MeV gamma-ray sources and all sky

Naomi Tsuji (Kanagawa University)

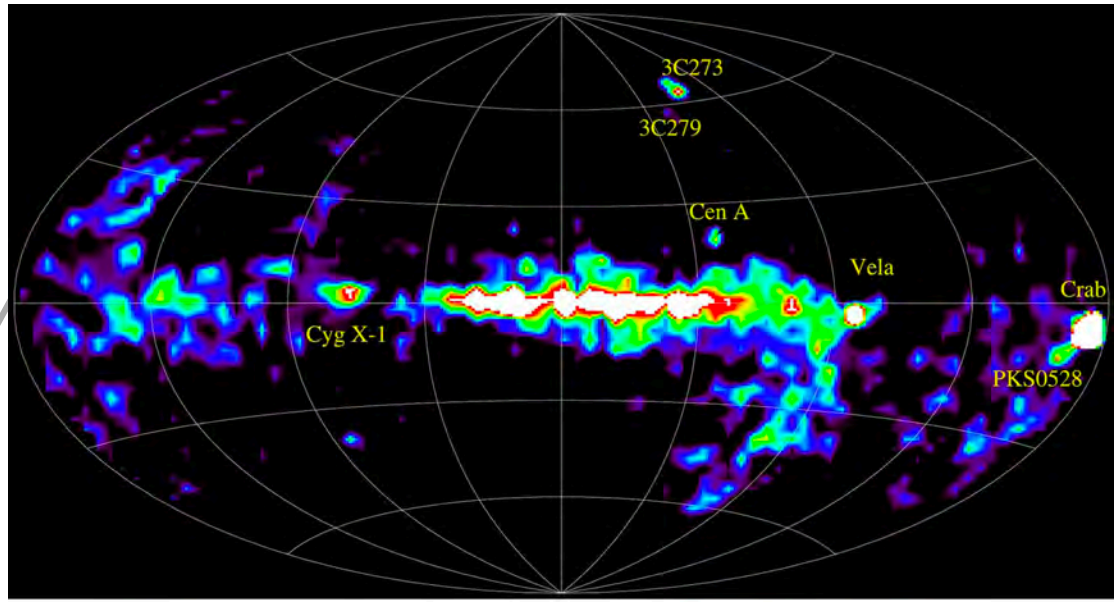
Yoshiyuki Inoue, Hiroki Yoneda, Reshmi Mukherjee, Hirokazu Odaka,
and GRAMS Collaboration

All-sky maps in multiwavelength



(NASA/GSFC)

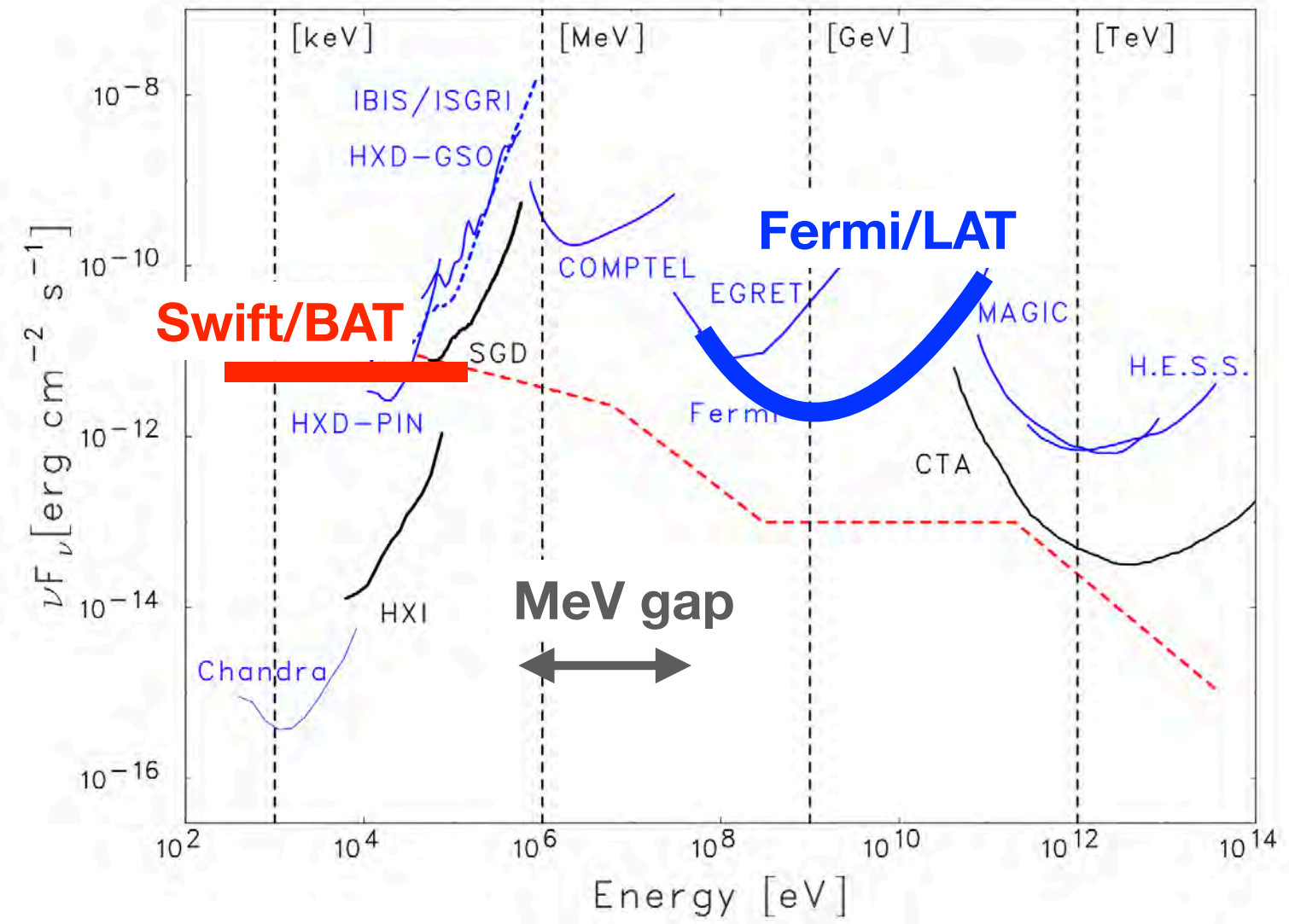
1–30 MeV all-sky survey by COMPTEL
(e.g., Strong et al. 1999)



MeV gamma-ray all sky

- 32 steady sources and 31 GRBs by COMPTEL
- But, still not well studied
- With future observatories,
  - What kind of sources can we observe?
  - What observational strategy is the best to maximize the outcome?

Sensitivity of X-ray and gamma-ray detectors



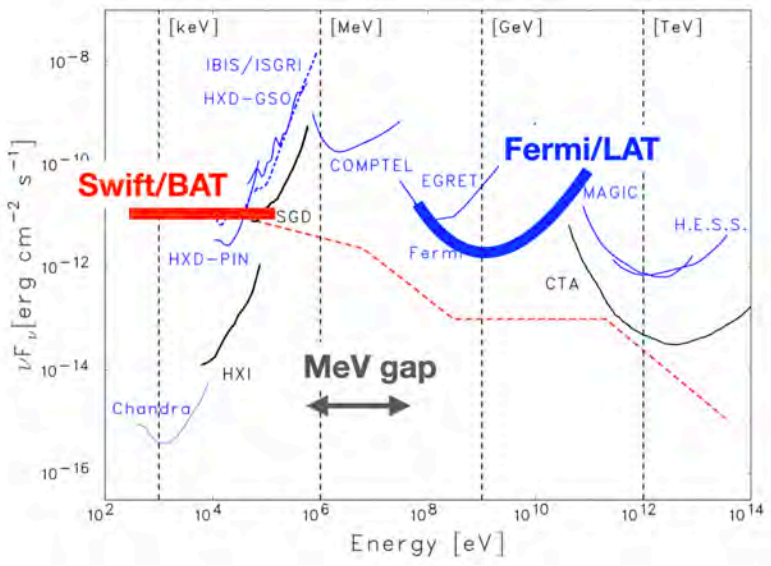
- ☑ Hard X-ray and GeV gamma-ray windows are well studied (e.g., Swift and Fermi)
- ☐ The gap (MeV gamma-ray sky) was covered by COMPTEL >20 years ago

MeV all-sky map: Plan

(1) MeV sources (→Tsuji+ 2021)

- BAT 105-month catalog (1632 sources) and 4FGL-DR2 (5788 sources) include:
  - Positional information
  - Spectral information

  →cross-match



(2) Others

- Diffuse galactic & extragalactic emission
- (Nuclear line emission)

(3) Simulate MeV all sky, including (1) and (2)

MeV gamma-ray all-sky

Weighted by detector response function → what can we observe?

MeV Gamma-ray Sources

Swift-BAT and Fermi-LAT catalog cross-match

(1) Spatial match of point-like sources
Use coordinates in the catalogs
Separation threshold of 0.08 degree is applied
→**132 sources (115 firmly matched)**

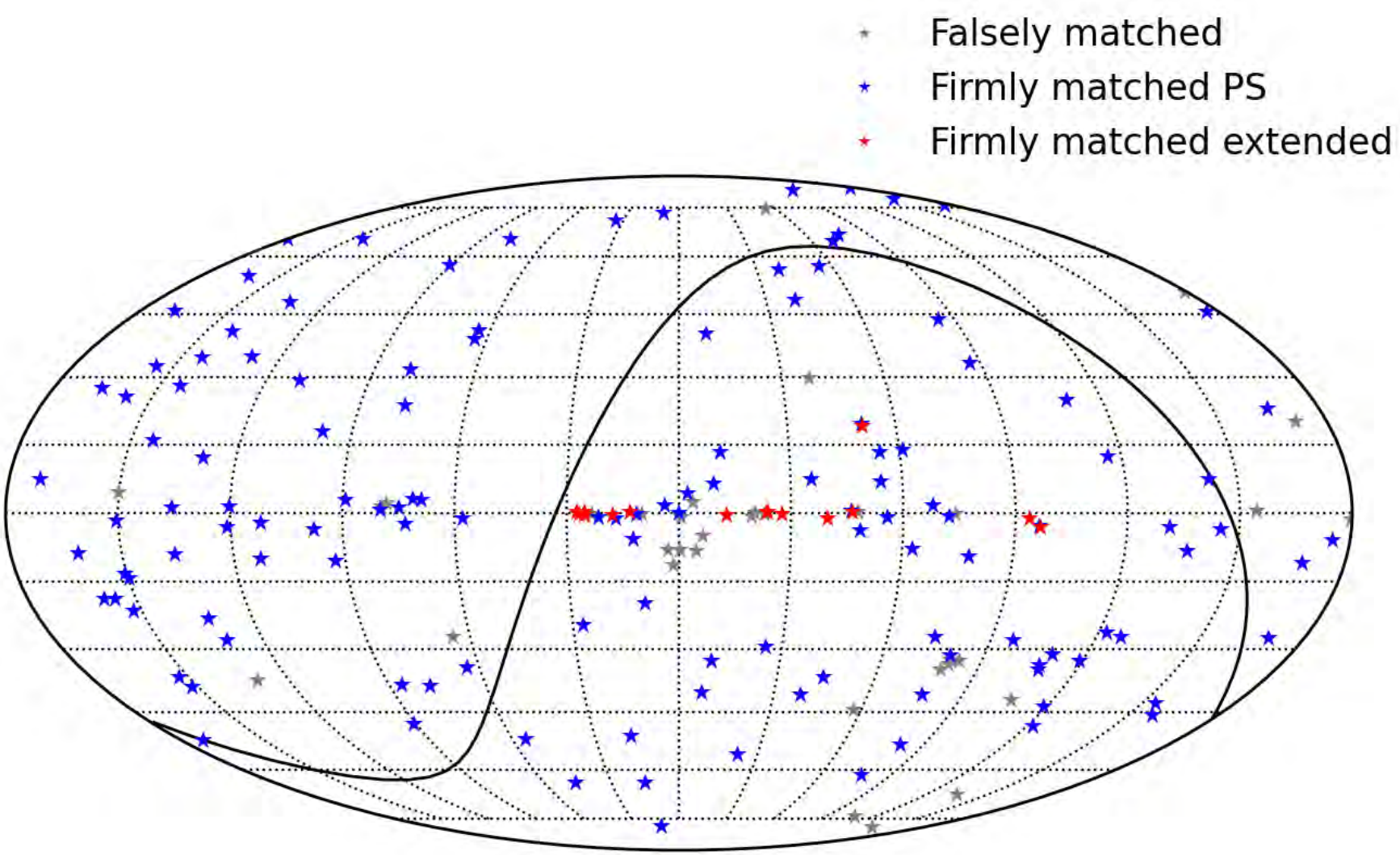
- Swift-BAT catalog: 1632 sources
- Fermi-LAT catalog: 5788 sources

(2) Spatial match of extended sources
4FGL-DR2 has 75 extended sources
Pick up BAT sources in the gamma-ray (Fermi) extent
→**31 sources (15 firmly matched)**

(3) Source identification (name) match
Pick up sources missed in (1) and (2)
→**18 sources (15 firmly matched)**

Summary:
181 sources in total
Firmly matched (source name and classification are same): 145 sources
Falsely matched and ambiguous: 23 sources
Unidentified: 13 sources

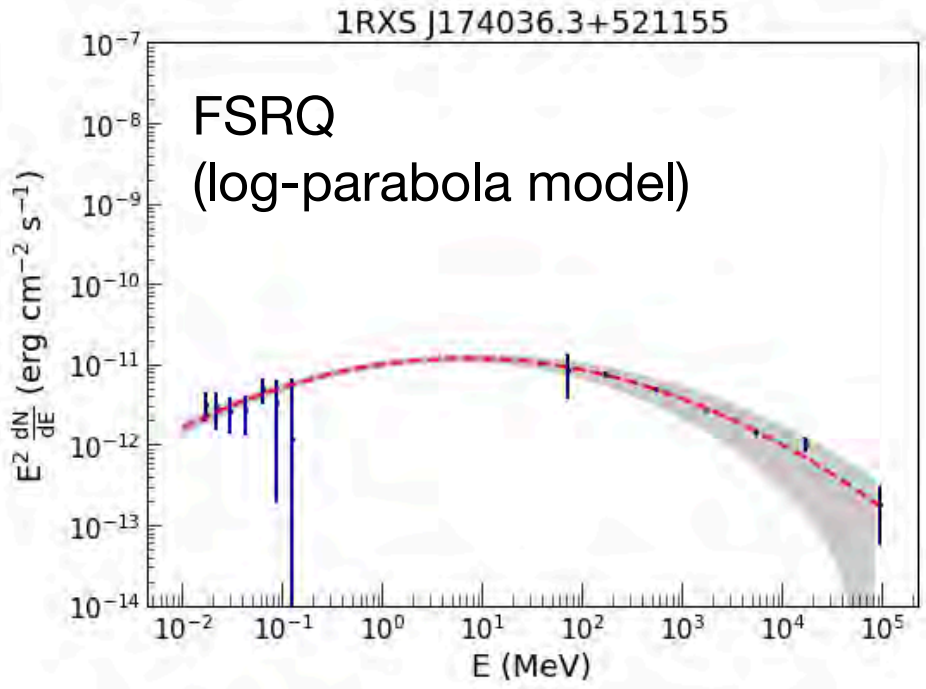
Swift-BAT and Fermi-LAT catalog cross-match

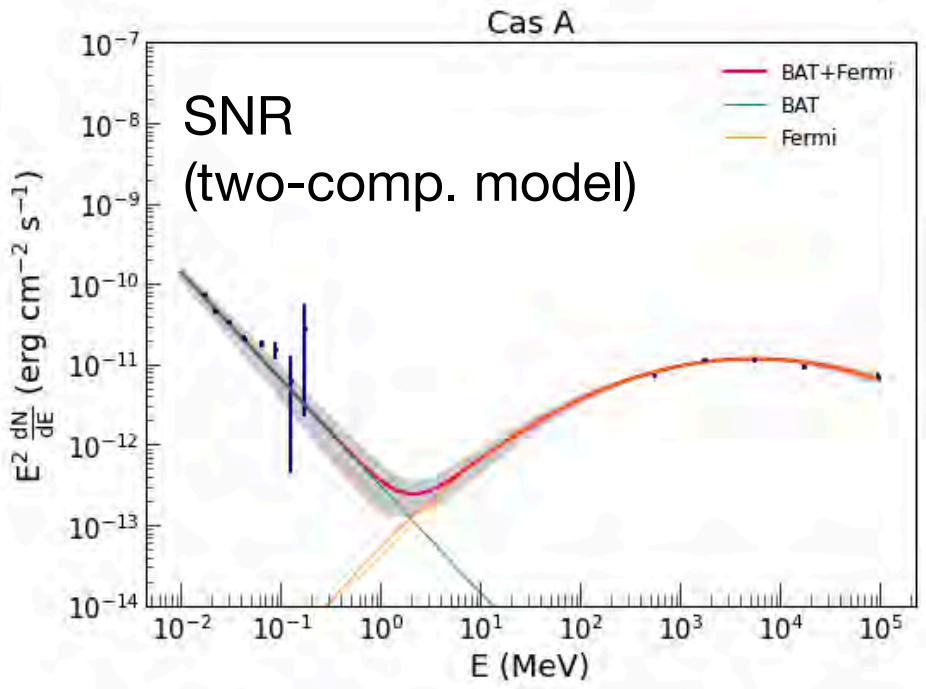


- Matched sources (i.e., hard X-ray and gamma-ray emitters)
- →“0th MeV source catalog”

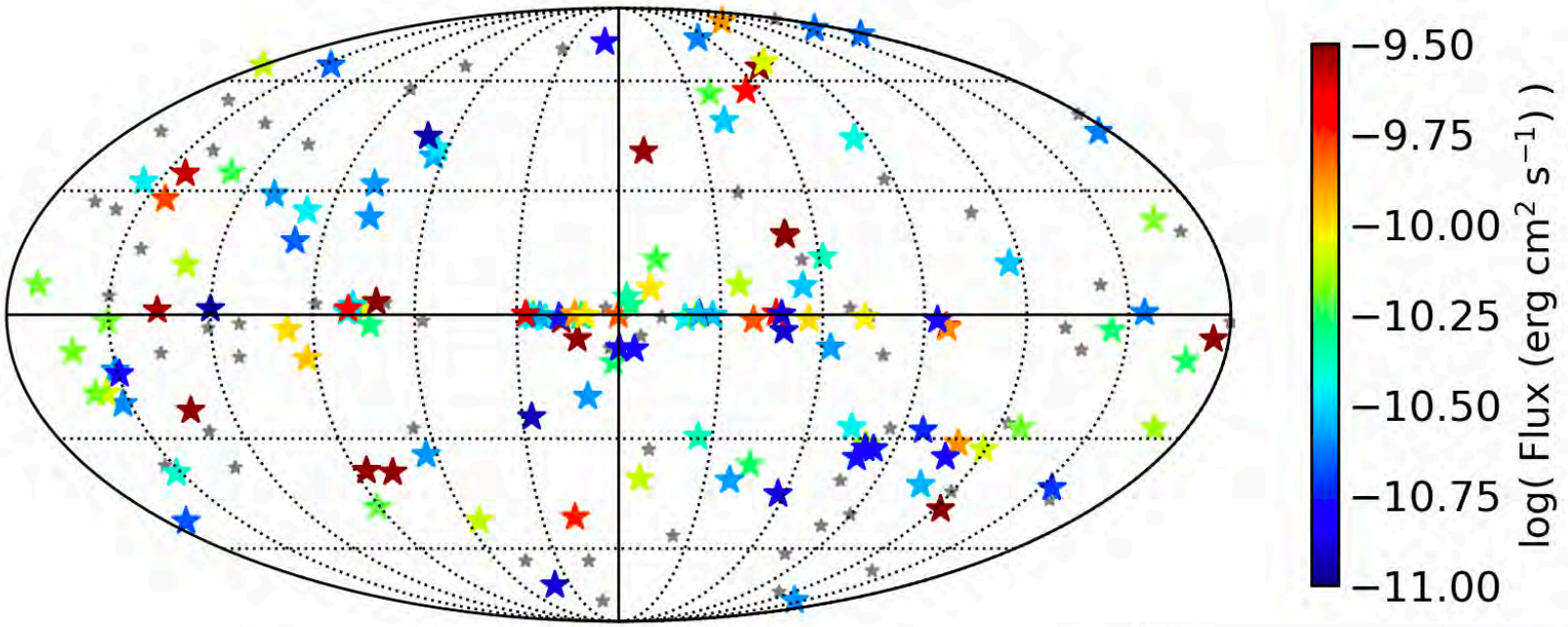
SED joint fit

- Fitting SED of cross-matched sources
- Model
  - Log parabola (as default)
  - Two-component (Swift-BAT + Fermi-LAT models)
- Estimate the 1–10 MeV flux from the best-fit model

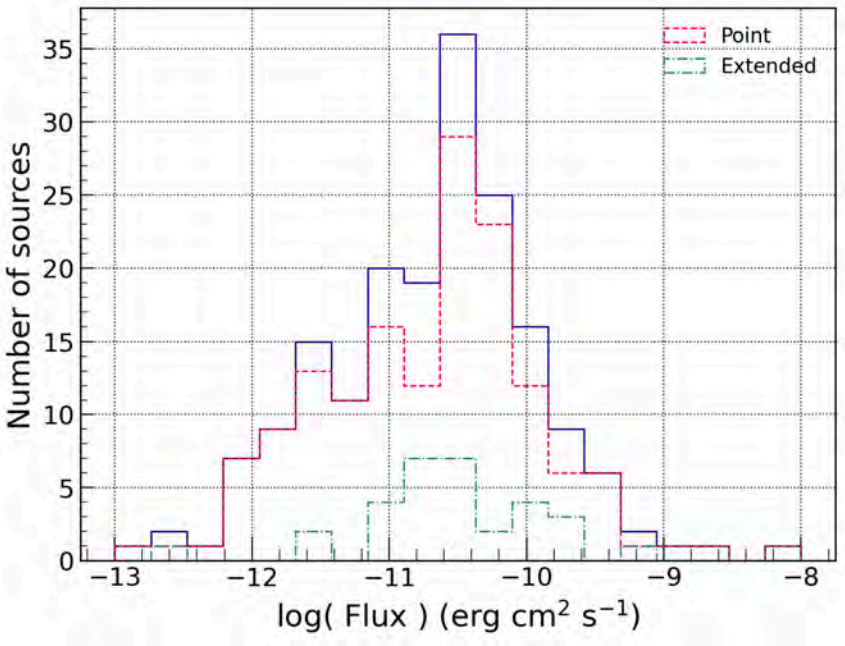




MeV source map



Color points with $F_{1-10\ MeV} > 10^{-11}$ erg/cm^2/s
Gray points with $F_{1-10\ MeV} < 10^{-11}$ erg/cm^2/s



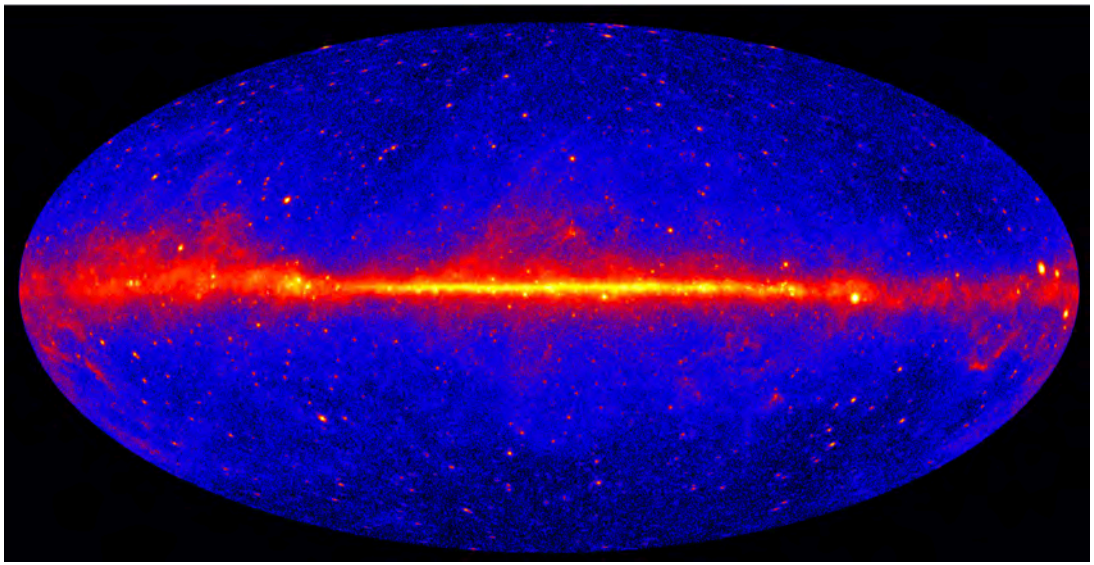
✓ Flux in 1–10 MeV > 10^{-10} erg/cm^2/s
→**30 sources**
(→Consistent with COMPTEL)

✓ Flux in 1–10 MeV > 10^{-11} erg/cm^2/s
→**125 sources**

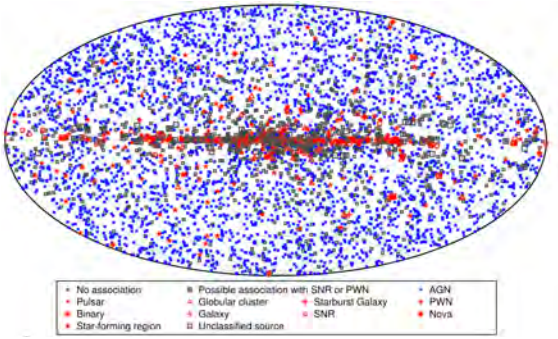
MeV Gamma-ray All-Sky

Emission components in all sky

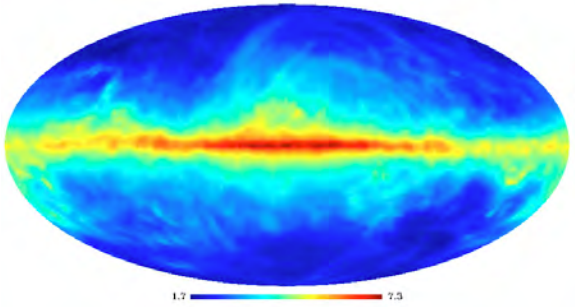
Femi LAT 5-yr sky



Sources ⊕ Galactic diffuse emission ⊕ Unresolved extragalactic (isotropic) emission



→Cross-match (Tsuji+ 2021)



→GALPROP

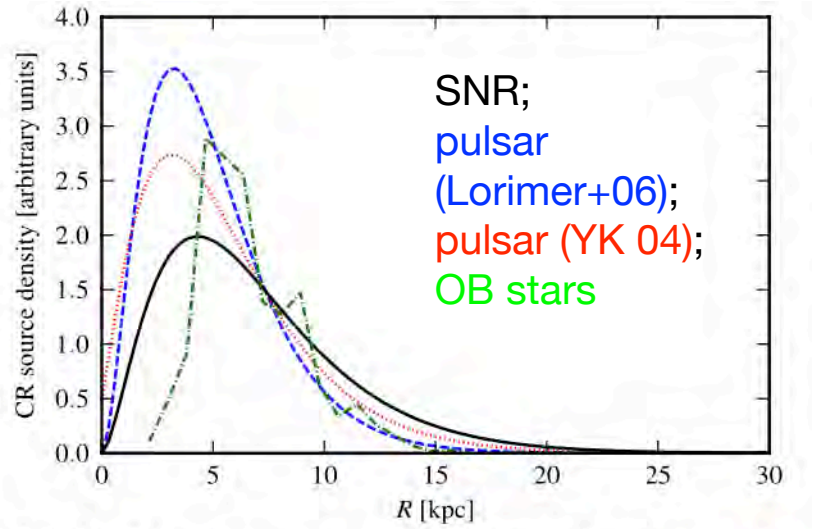
Isotropic component

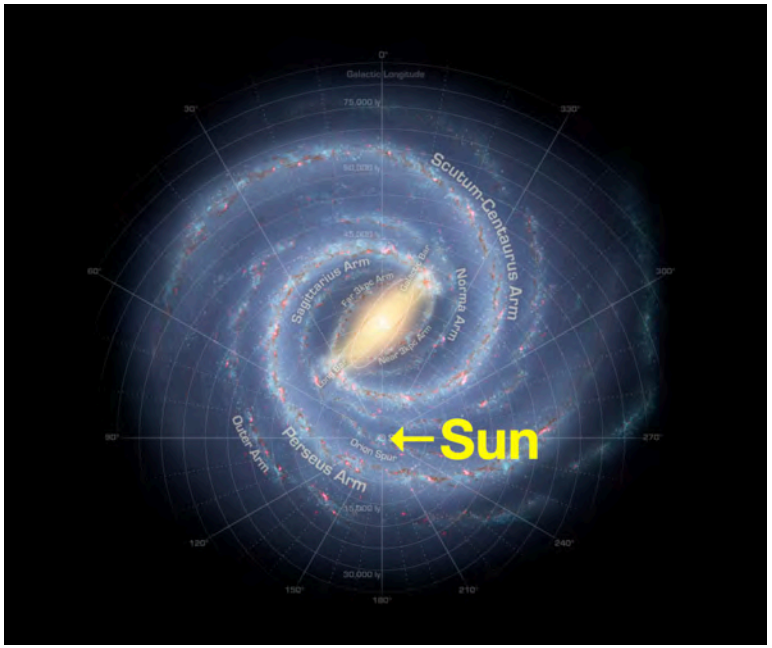
→COMPTEL (and SMM) results

Galactic diffuse emission: GALPROP

GALPROP: calculate cosmic-ray propagation and its radiation
(e.g., Strong+, GALPROP version 54 explanatory supplement)

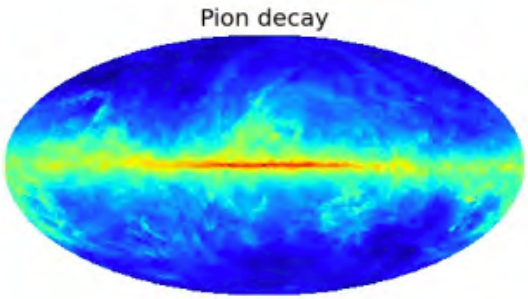
1. CR source distribution



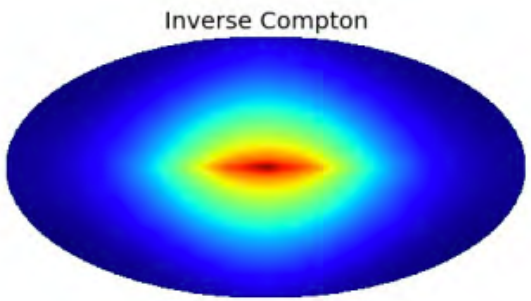


2. Propagation in our Galaxy

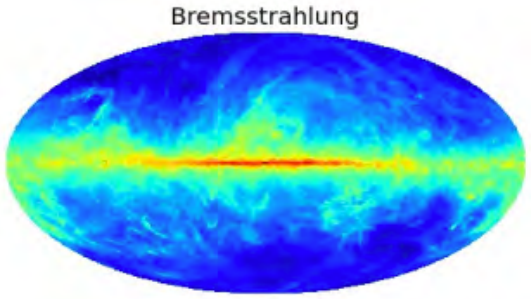
3. Radiation



CR proton + ISM



CR electron + photons

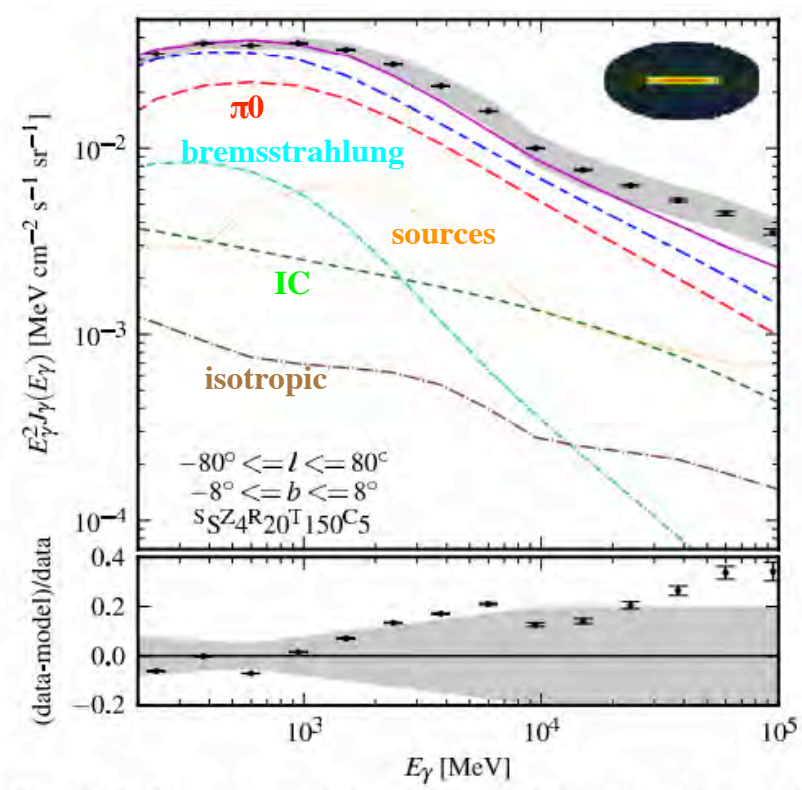


CR electron + ISM

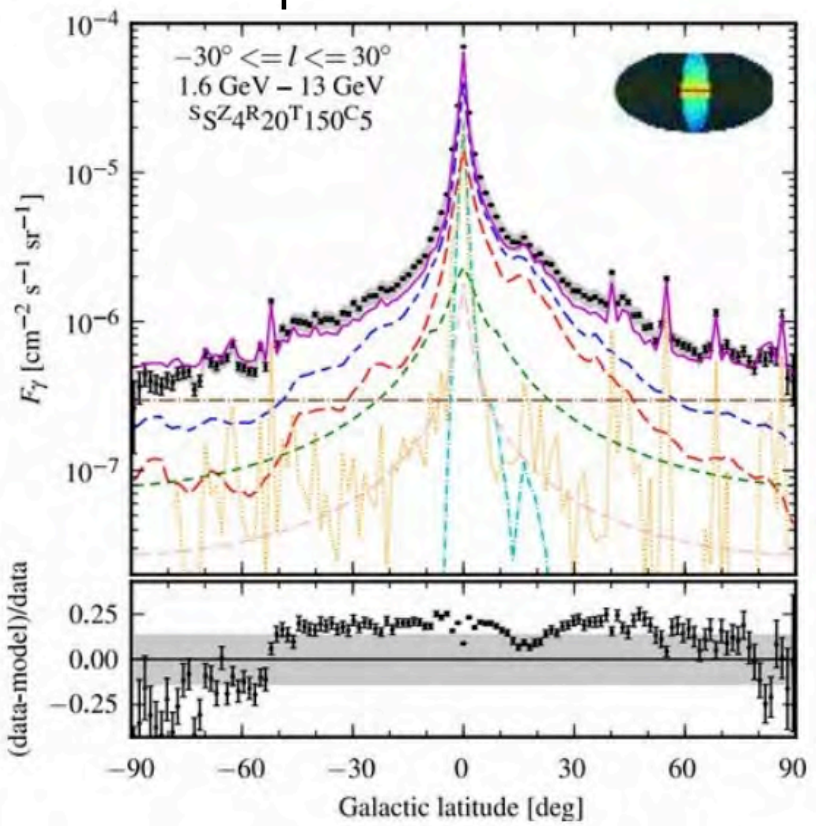
Galactic diffuse emission: Fermi-LAT data

(Ackermann+ 2012)

Spectral distribution



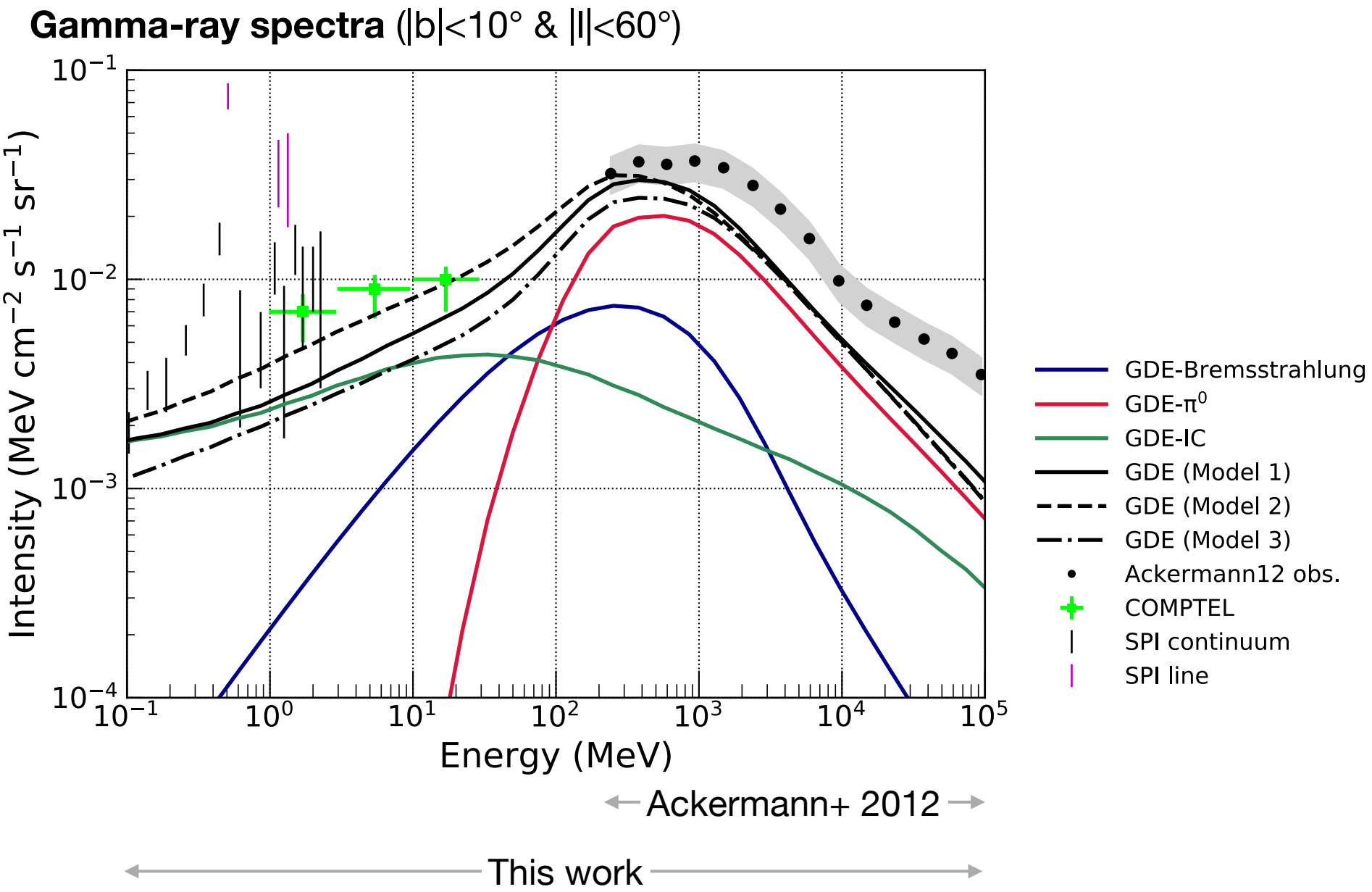
Spatial distribution



Fermi-LAT observation (both spectrum and morphology) in 0.2–100 GeV is well reproduced by the models

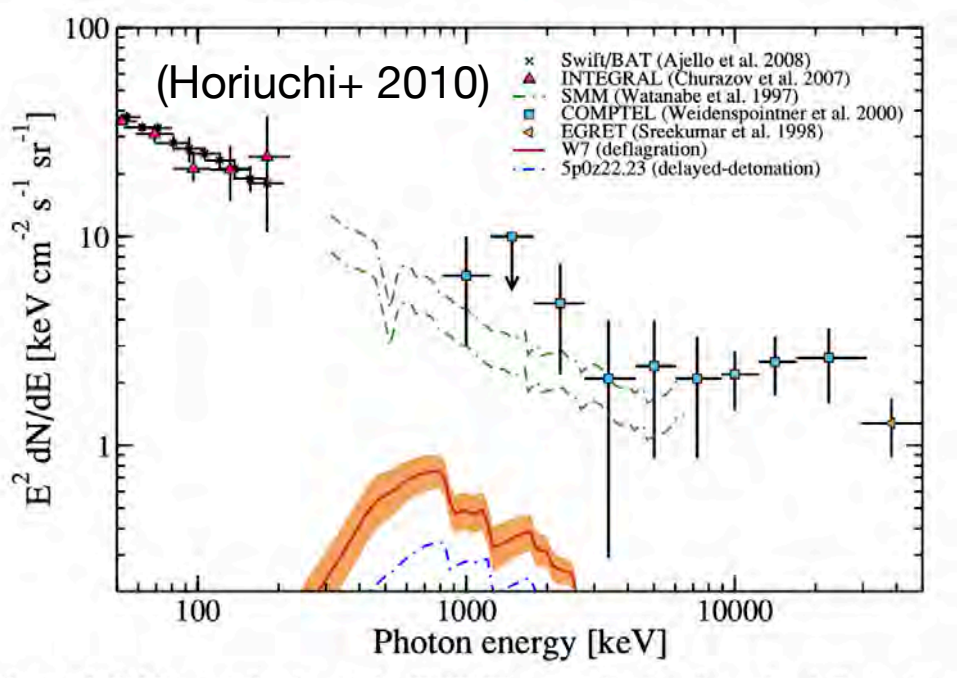
→ Extrapolate this study to ***0.1–100 MeV***

Galactic diffuse emission in MeV range



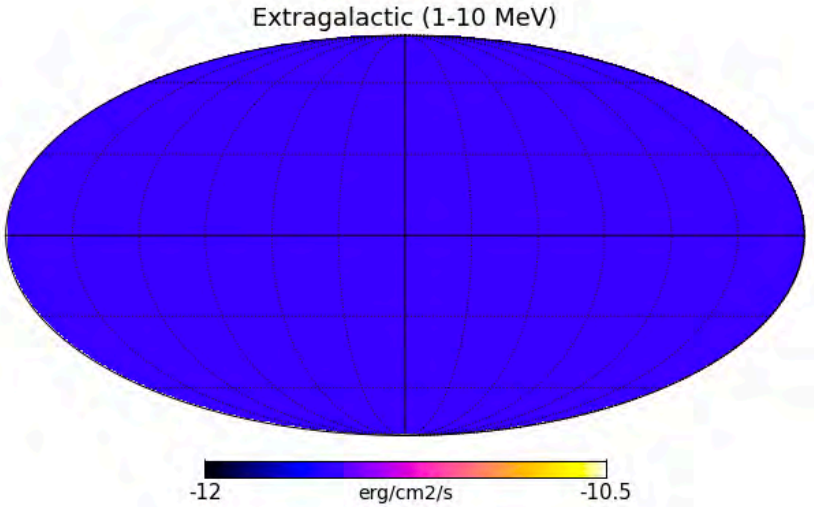
Extragalactic emission in MeV range

CGB (Cosmic gamma-ray background)



COMPTEL (Weidenspointner+ 2000)
0.8–30 MeV and | b | >30 degree

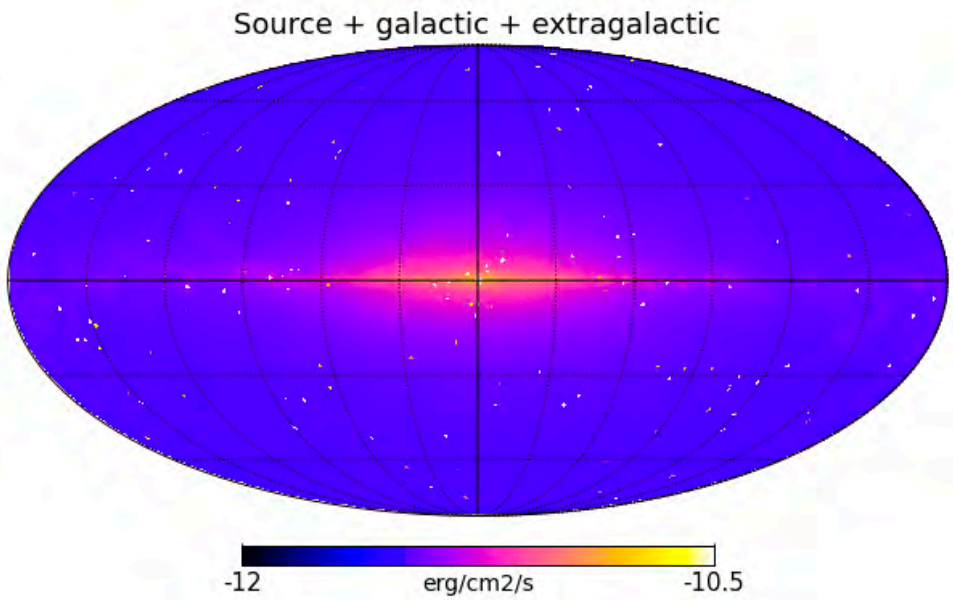
MeV Extragalactic (isotropic) map



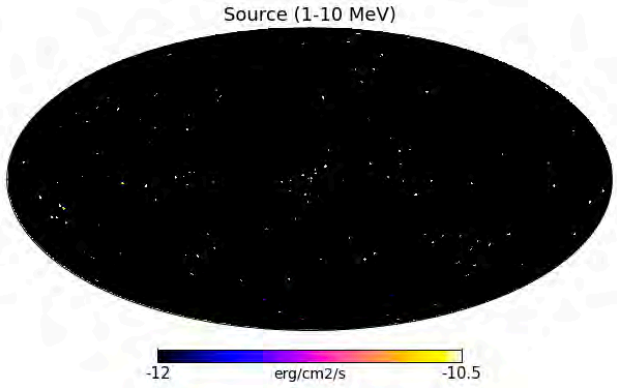
- Produced based on the COMPTEL result
- Assume the isotropic distribution

MeV gamma-ray all-sky map

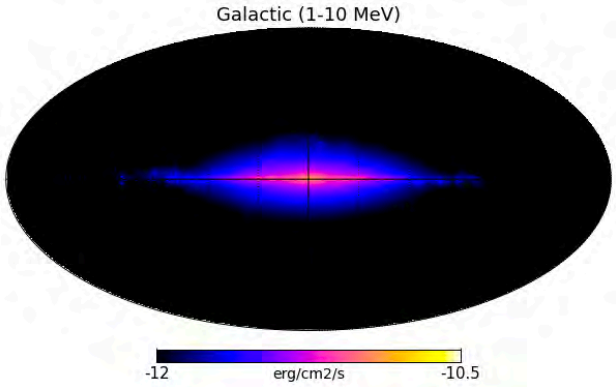
All-sky map in 1–10 MeV (preliminary)



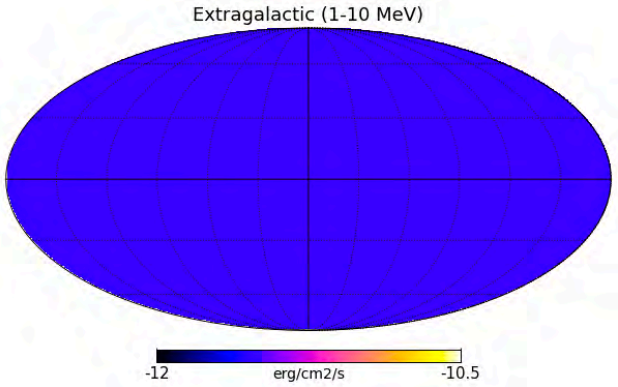
Sources



Galactic diffuse emission



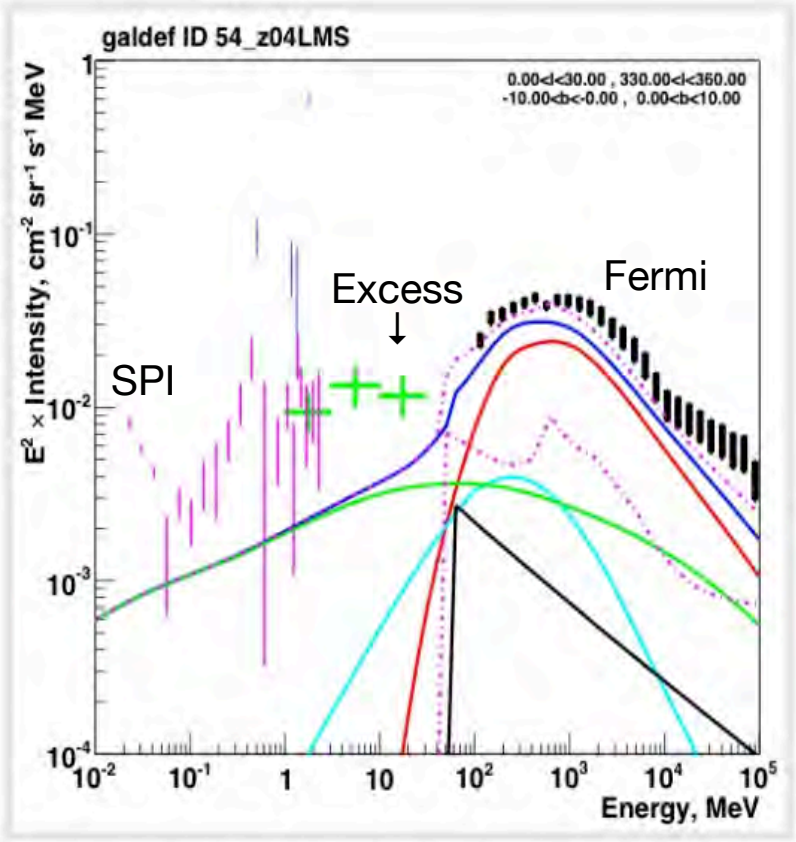
Unresolved extragalactic (isotropic) emission



Cross-matched (only *point)* sources (Tsuji+ 2021)

The origin of Inner Galactic diffuse emission

COMPTEL excess



1–30 MeV diffuse emission from the inner Galactic region ($|l| < 60°$ and $|b| < 10°$)

- CGRO/COMPTEL (Strong+ 1994; 1996; 2004)

Cannot be reproduced by standard GDE
→"COMPTEL excess"

Also confirmed by

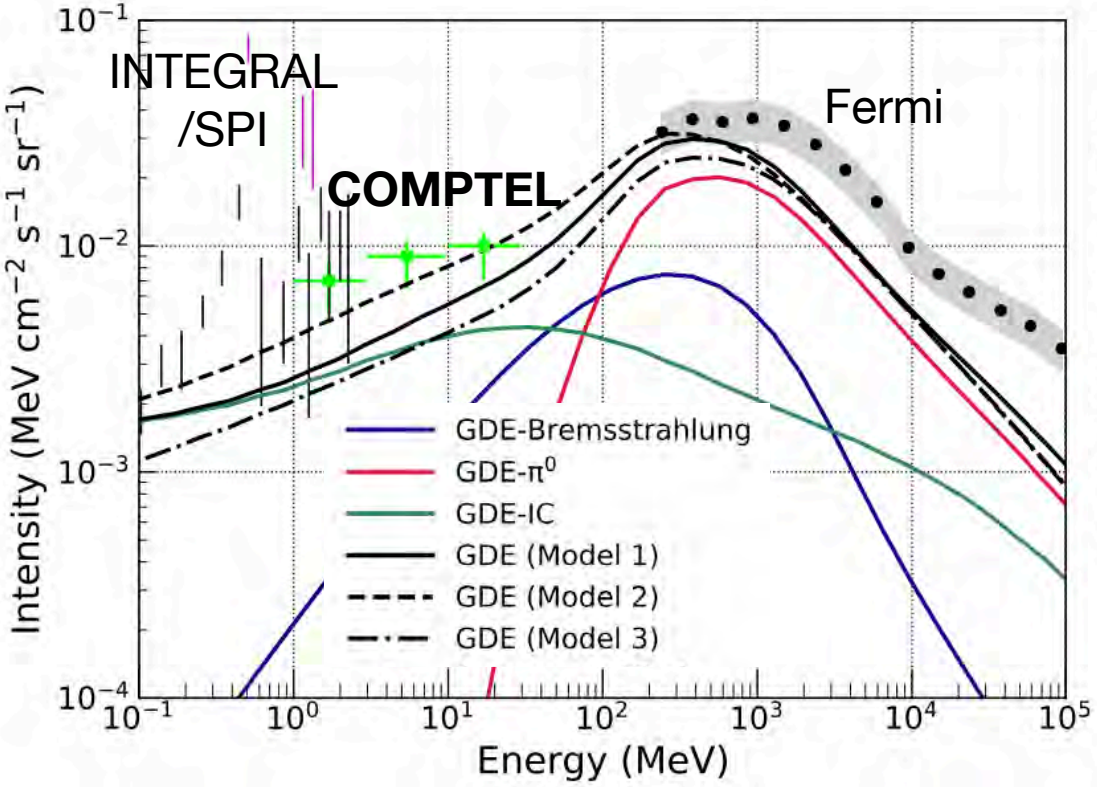
- INTEGRAL/SPI (Bouchet+ 2011; Siegert+ 2022)
- SMILE-2/ETCC (Takada+ 2022)

This work (Tsuji+ in prep.)
Investigation of COMPTEL excess by a combination of:

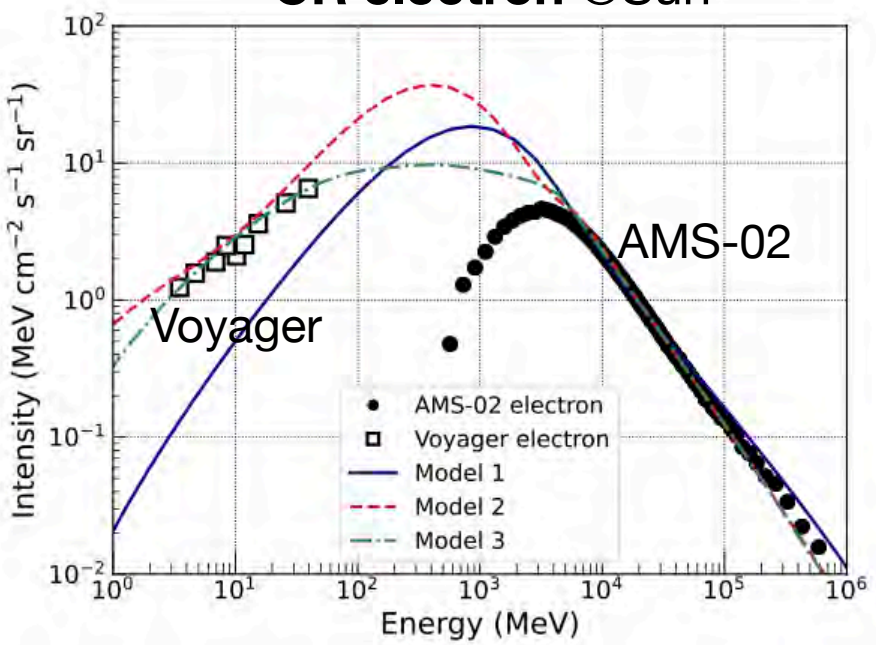
1. Galactic diffuse emission
2. MeV gamma-ray sources
(3. Cosmic Gamma-ray background; CGB)

Galactic diffuse emission

Gamma-ray spectra (|b|<10° & |l|<60°)



CR electron @Sun



Model 1. Ackermann+12
Model 2. Orlando 18-DRE
Model 3. Orlando 18-DRELowV

Model uncertainty in MeV gamma ray
→~a factor of 2–3, arising from CR electron in 100–1000 MeV

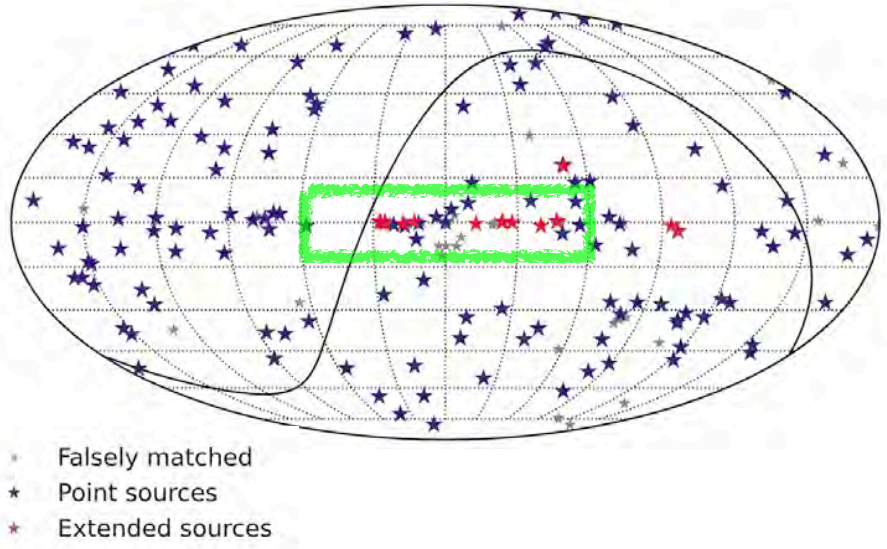
Source contribution

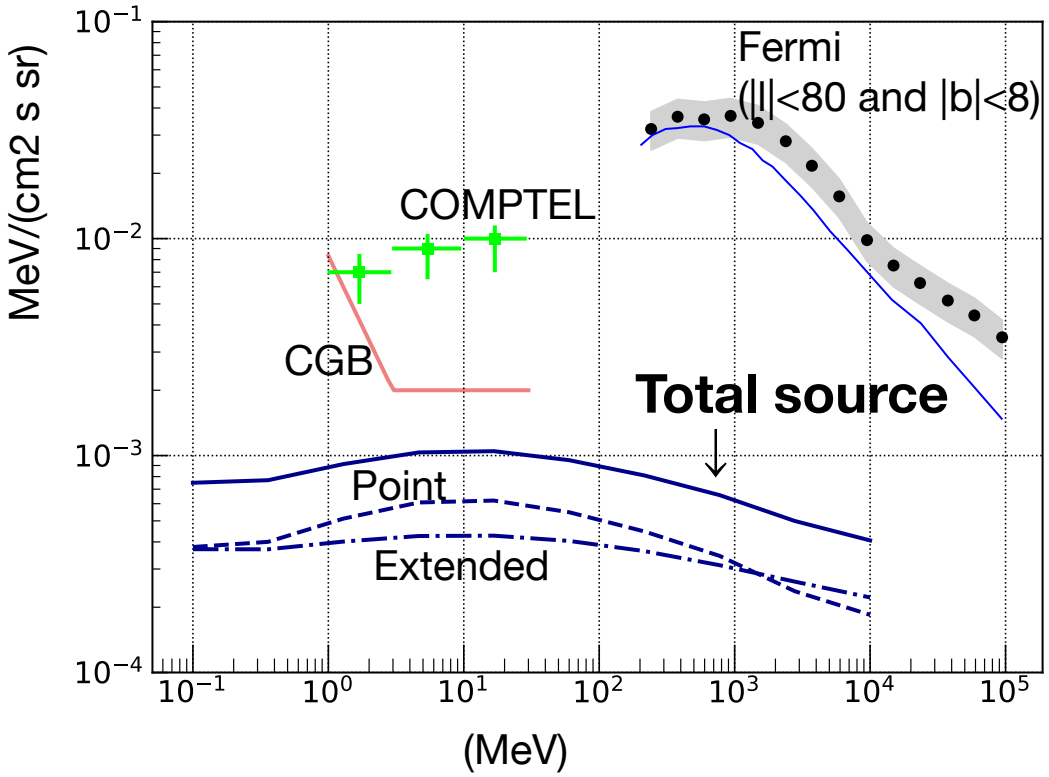
(1) Point sources

- 23 sources in the inner Galactic region (|l|<60 and |b| <10)
- 5 Blazars, 1 Galactic center, 1 Seyfert, 1 SNR-PSR, 4 X-ray binaries, 3 PSR, 1 Globular cluster, 3 False match, 4 Unk

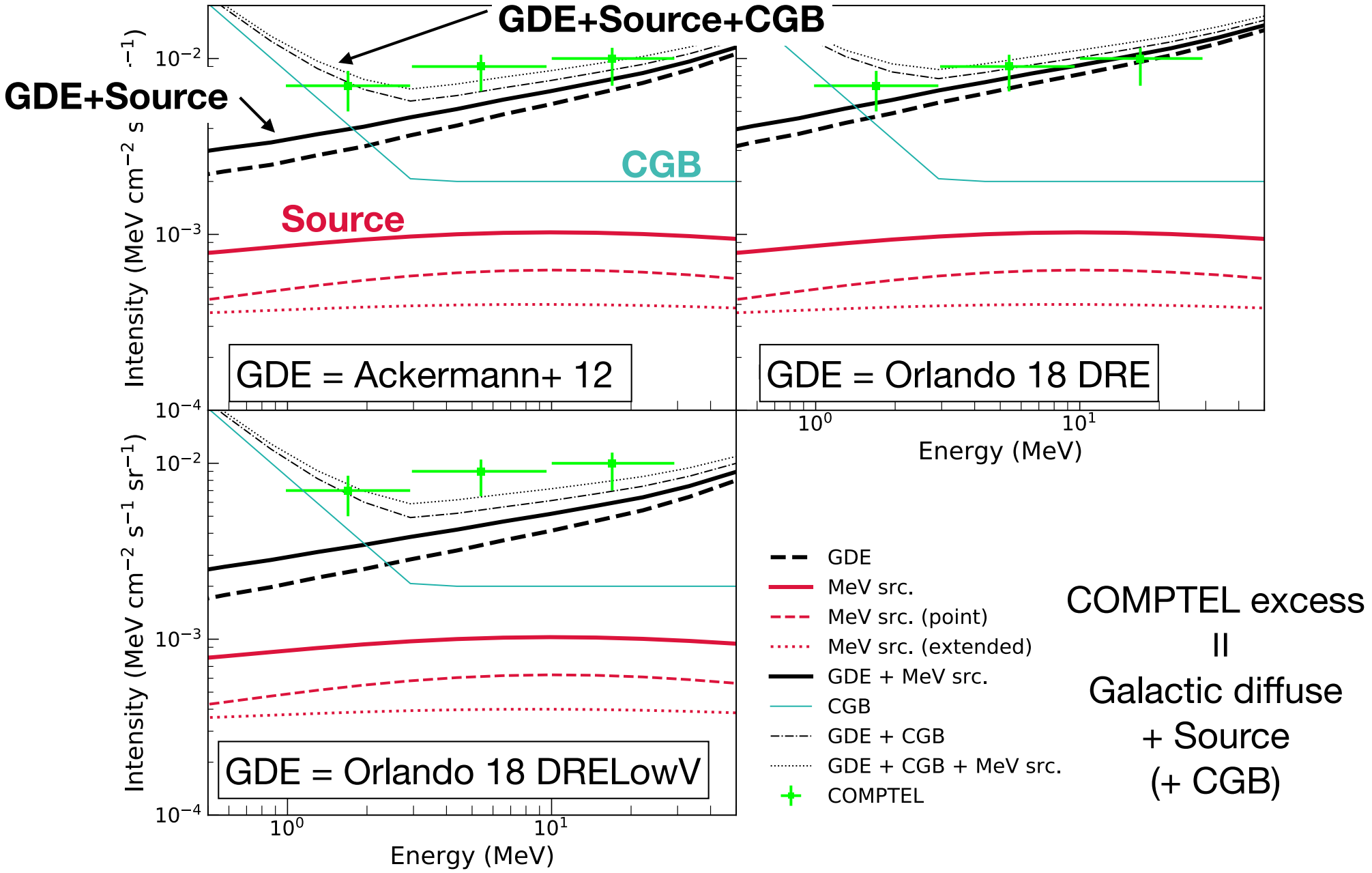
(2) Extended sources

- 17 sources in the inner Galactic region (|l|<60 and |b| <10)
- 8 PWN, 2 SNR, 5 Spp, 2 Unk





COMPTEL excess



COMPTEL excess
||
Galactic diffuse
+ Source
(+ CGB)

Summary

MeV gamma-ray sources

Cross-match between Swift-BAT and Fermi-LAT catalogs (Tsuji+ 2021)

MeV gamma-ray all sky

Galactic diffuse + Sources + CGB (work in progress)

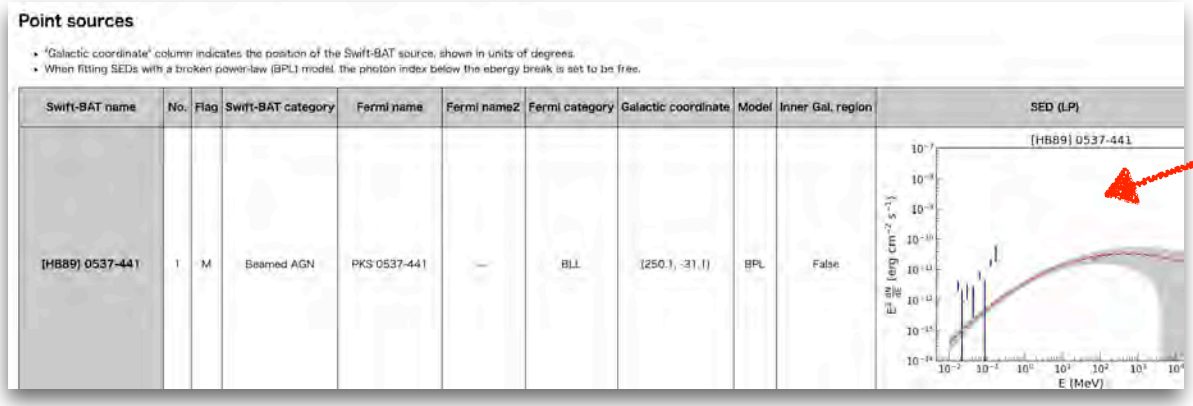
COMPTEL excess

Galactic diffuse + Sources (+ CGB) (Tsuji+ in prep.)

Data release (*very preliminary*; link)

Source catalog

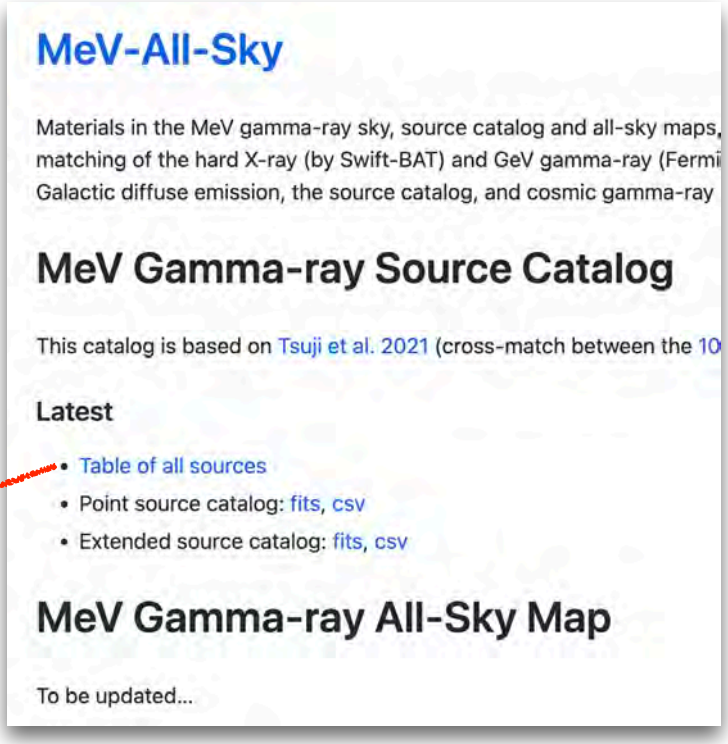
+ all-sky map (to be updated)



Point sources

- 'Galactic coordinate' column indicates the position of the Swift-BAT source, shown in units of degrees.
- When fitting SEDs with a broken power-law (BPL) model, the photon index below the ebergy break is set to be free.

Swift-BAT name	No.	Flag	Swift-BAT category	Fermi name	Fermi name2	Fermi category	Galactic coordinate	Model	Inner Gal. region	SED (LP)
[HB89] 0537-441	1	M	Beamed AGN	PKS 0537-441	—	BLL	(250.1, -31.1)	BPL	False	



MeV-All-Sky

Materials in the MeV gamma-ray sky, source catalog and all-sky maps, matching of the hard X-ray (by Swift-BAT) and GeV gamma-ray (Fermi Galactic diffuse emission, the source catalog, and cosmic gamma-ray

MeV Gamma-ray Source Catalog

This catalog is based on Tsuji et al. 2021 (cross-match between the 10

Latest

- Table of all sources
- Point source catalog: fits, csv
- Extended source catalog: fits, csv

MeV Gamma-ray All-Sky Map

To be updated...