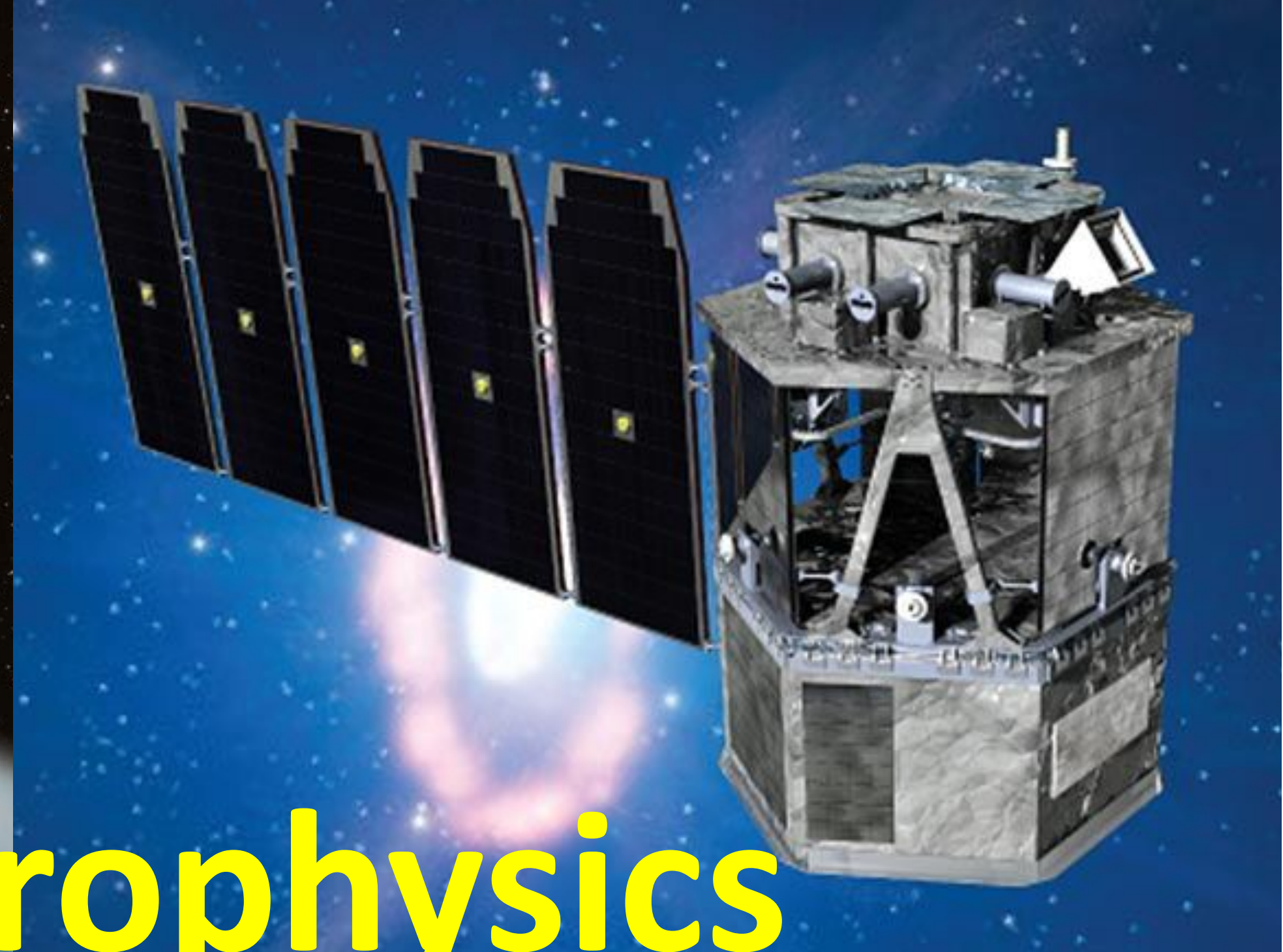




MeV Astrophysics

Matterhorn



Antimatterhorn



Laura Eisenberger

Julius-Maximilians-Universität Würzburg

20.07.2026, FRANCI, Würzburg, Germany

Nuclear Astrophysics in Würzburg

estd. August 2022



**Thomas
Siegert**

**Hiroki
Yoneda**

**Tomohiko
Oka**

**Tristan
Bouchet**

**Maura
Quezada**

**Saurabh
Mittal**

**Laura
Eisenberger**

**Dimitris
Tsatsis**

**Rudi
Reinhardt**

**Manuel
Skalka**

**Anastasia
Kirichenko**

**Manja
Zimmerer**

**Mika
Gelowicz**

**AG
Supervisor**

**now Prof.
in Japan**

Postdoc

Postdoc

**Postdoc
soon**

**PhD

final yr**

**PhD

2nd yr**

**PhD

2nd yr**

**PhD

1st yr**

**PhD

1st yr**

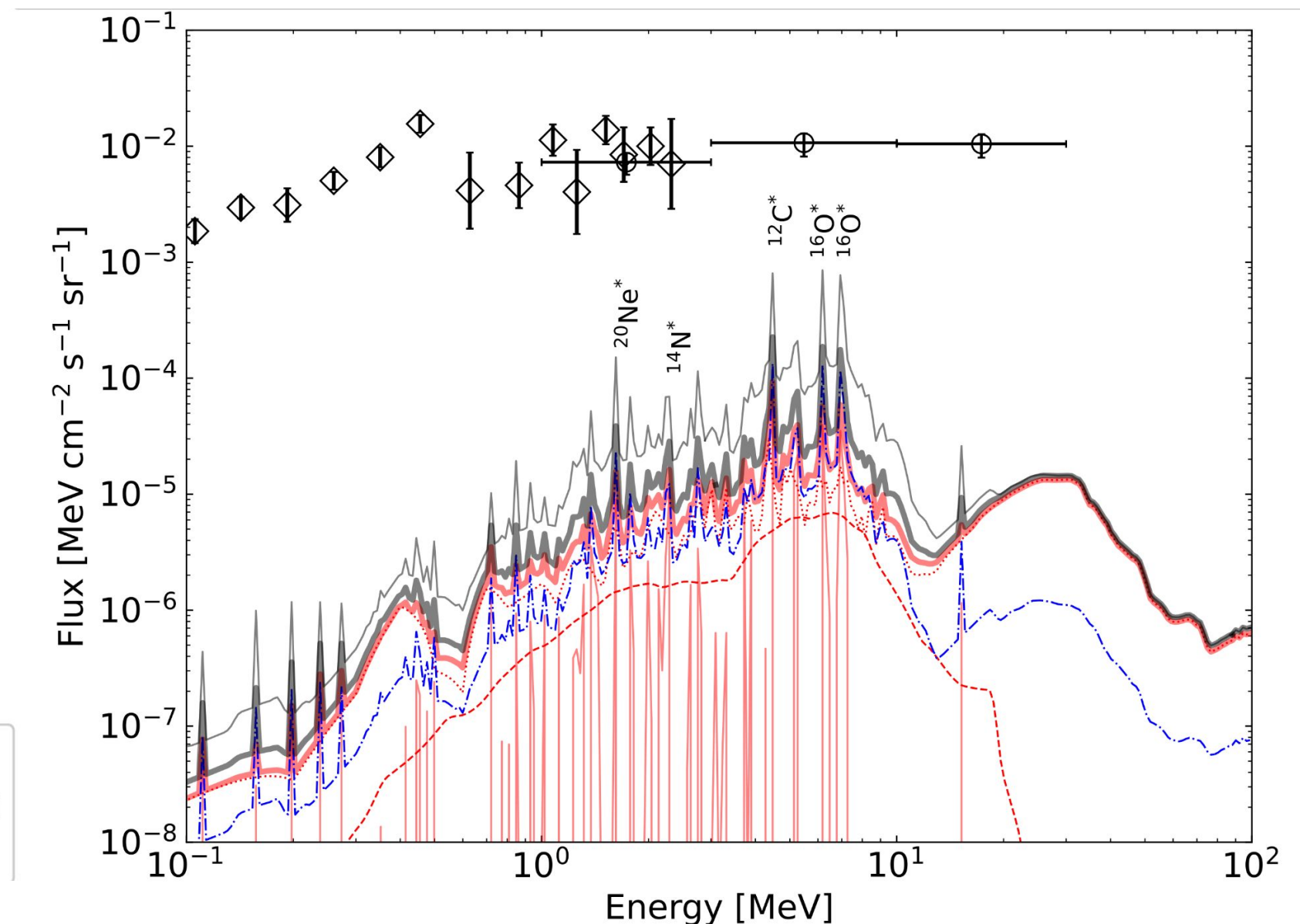
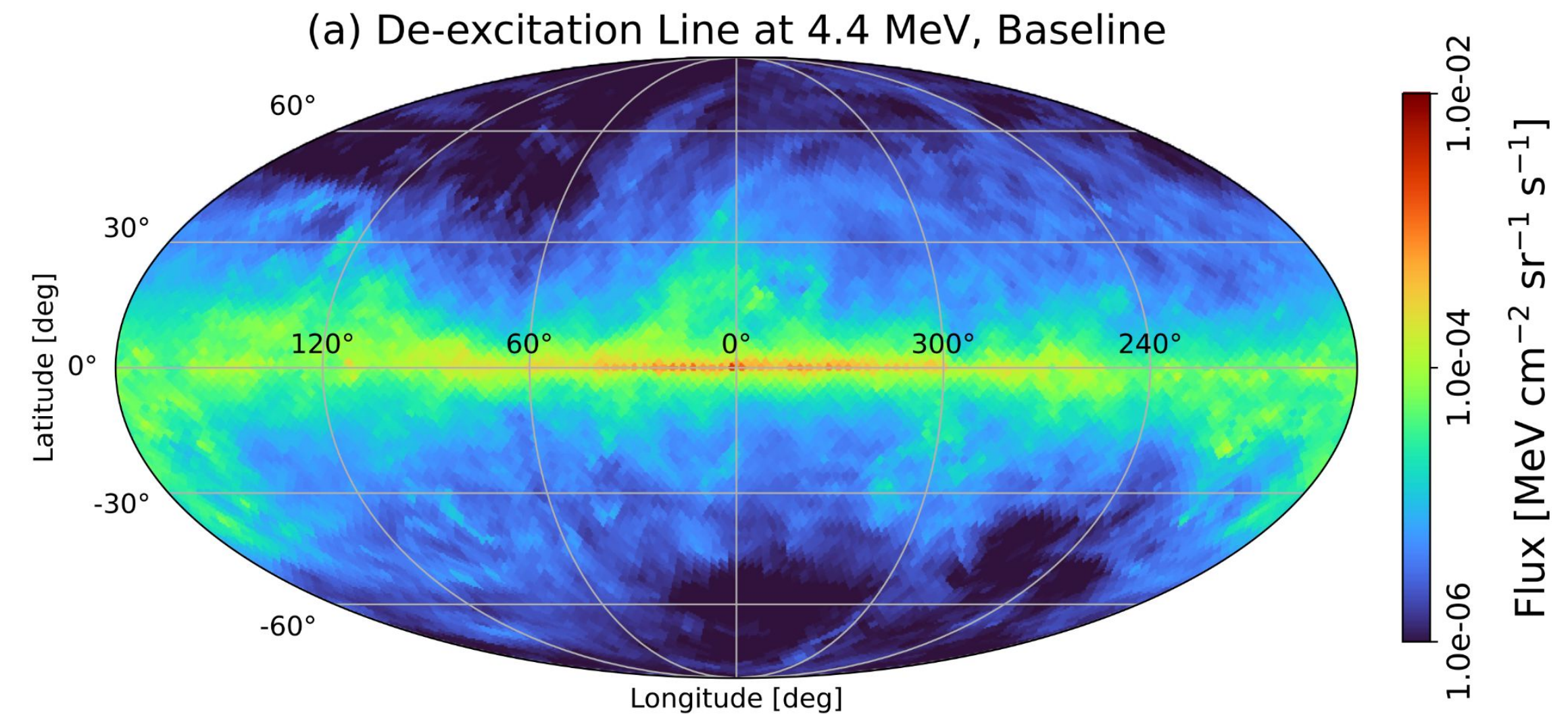
**PhD
soon**

**BSc
now MSc**

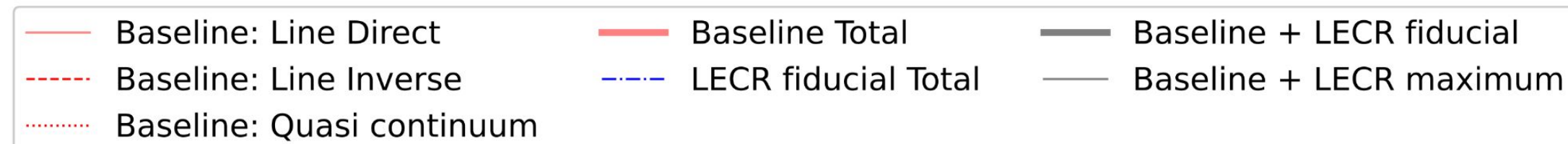
**BSc
now MSc
in Bonn**

Cosmic-Ray-Induced Nuclear De-excitation Lines

- The origin of cosmic rays (CRs) remains unknown.
- Nuclear de-excitation lines produced by CR interactions with molecular clouds provide one of the most reliable probes of CR ions, enabling us to identify CR acceleration sites and constrain their density.
- Construct all-sky models of the inner Galaxy by combining the CR propagation code GALPROP & the nuclear reaction code TALYS
- Assess the detectability of these lines with current and future MeV missions, including INTEGRAL/SPI and COSI



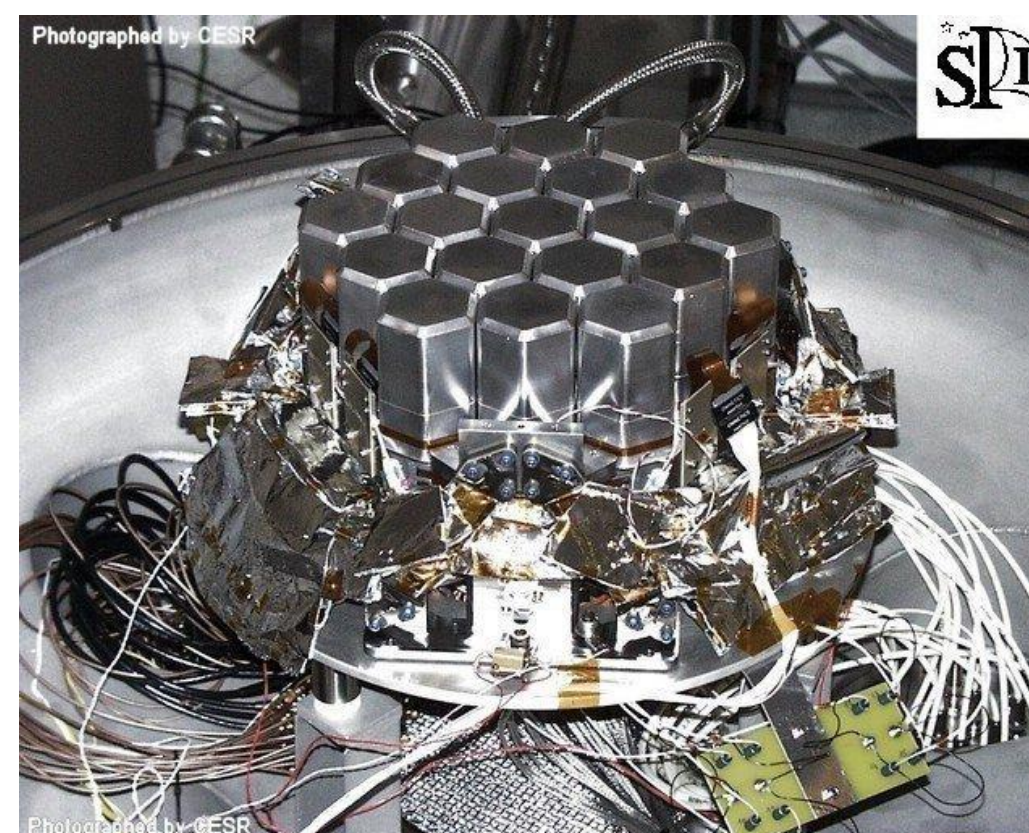
De-excitation gamma-ray spectra integrated over the large-scale GC region, $|l| \leq 30^\circ$ & $|b| \leq 15^\circ$



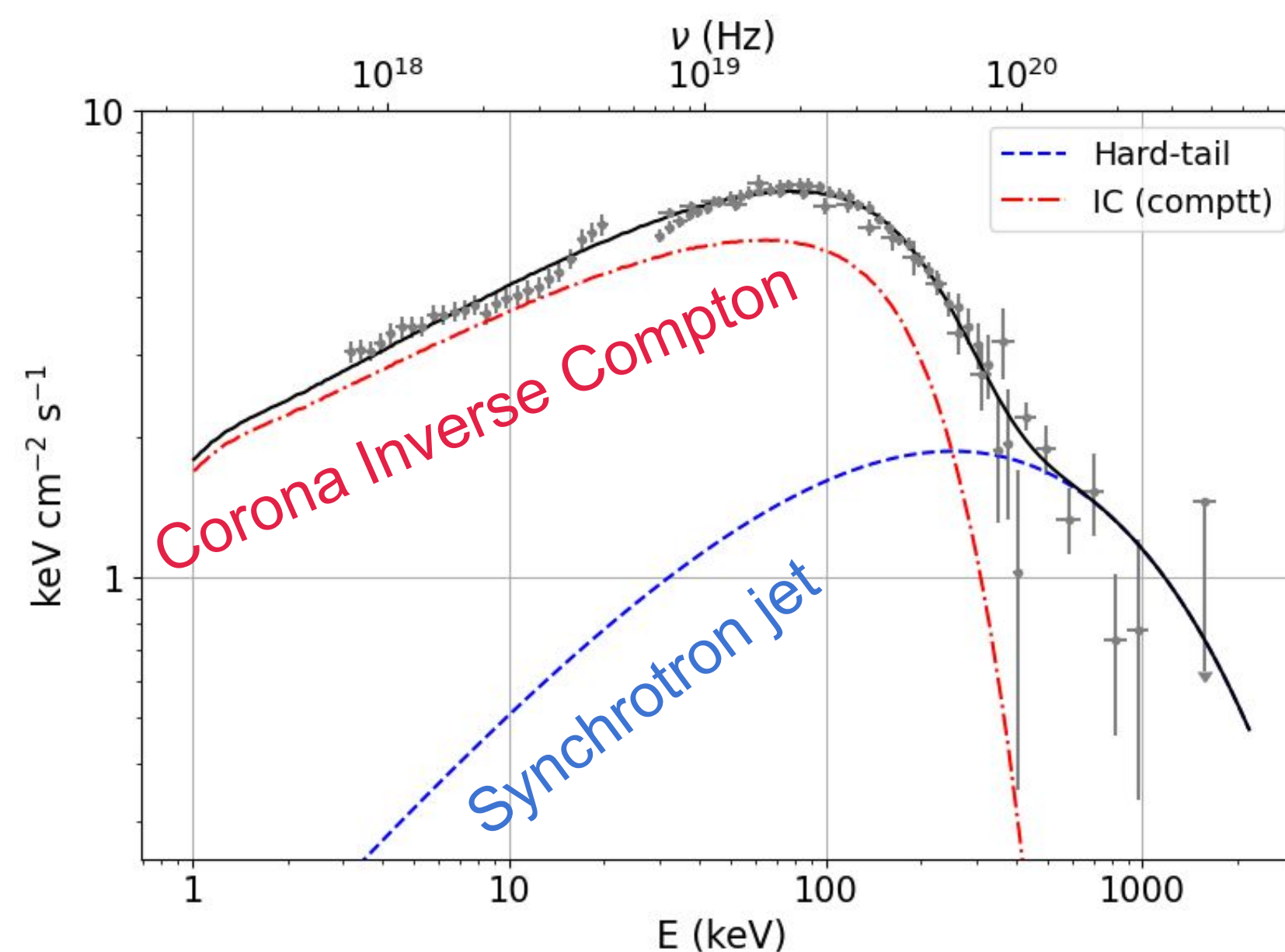
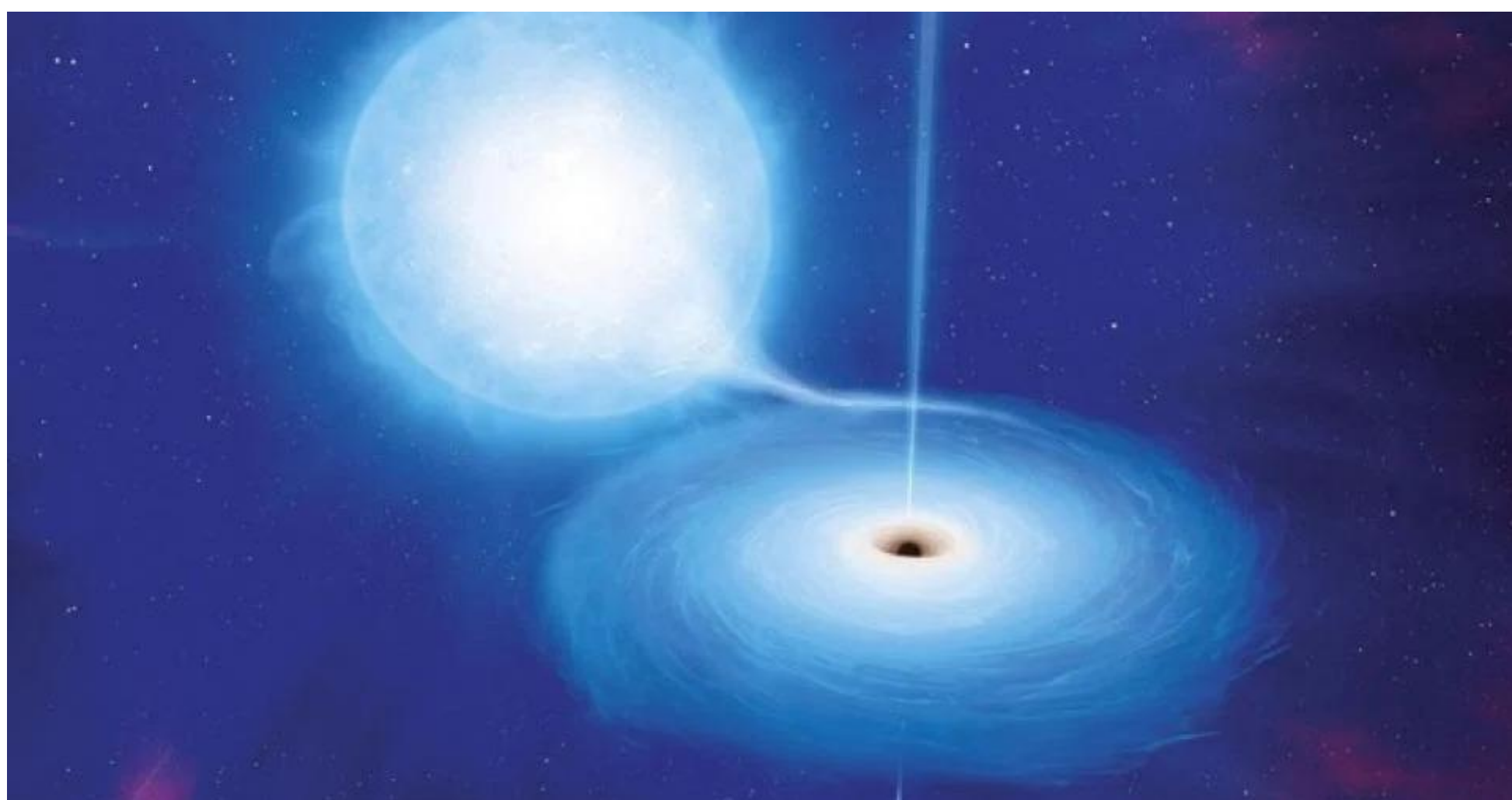


High-energy spectro-polarization

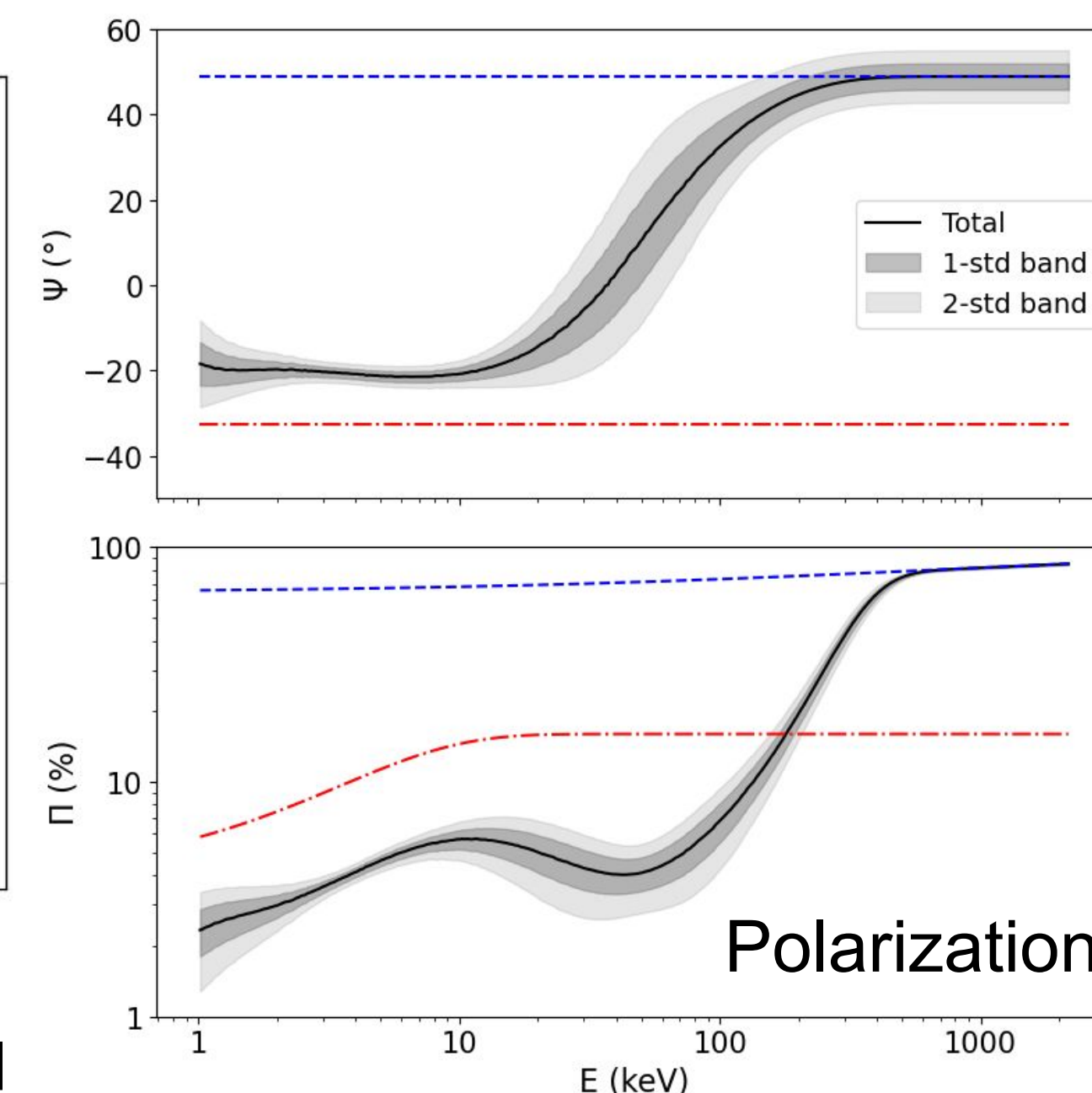
- Instrumental analysis in hard X-rays
- Transient sources catalog with INTEGRAL/SPI
- Main topic: X-ray binaries
- Understand acceleration process and source geometry
- Developing new methods to model spectro-polarization at high-energies



SPI Ge detectors
(20 keV - 8 MeV)



Spectro-polarization model of Cygnus X-1

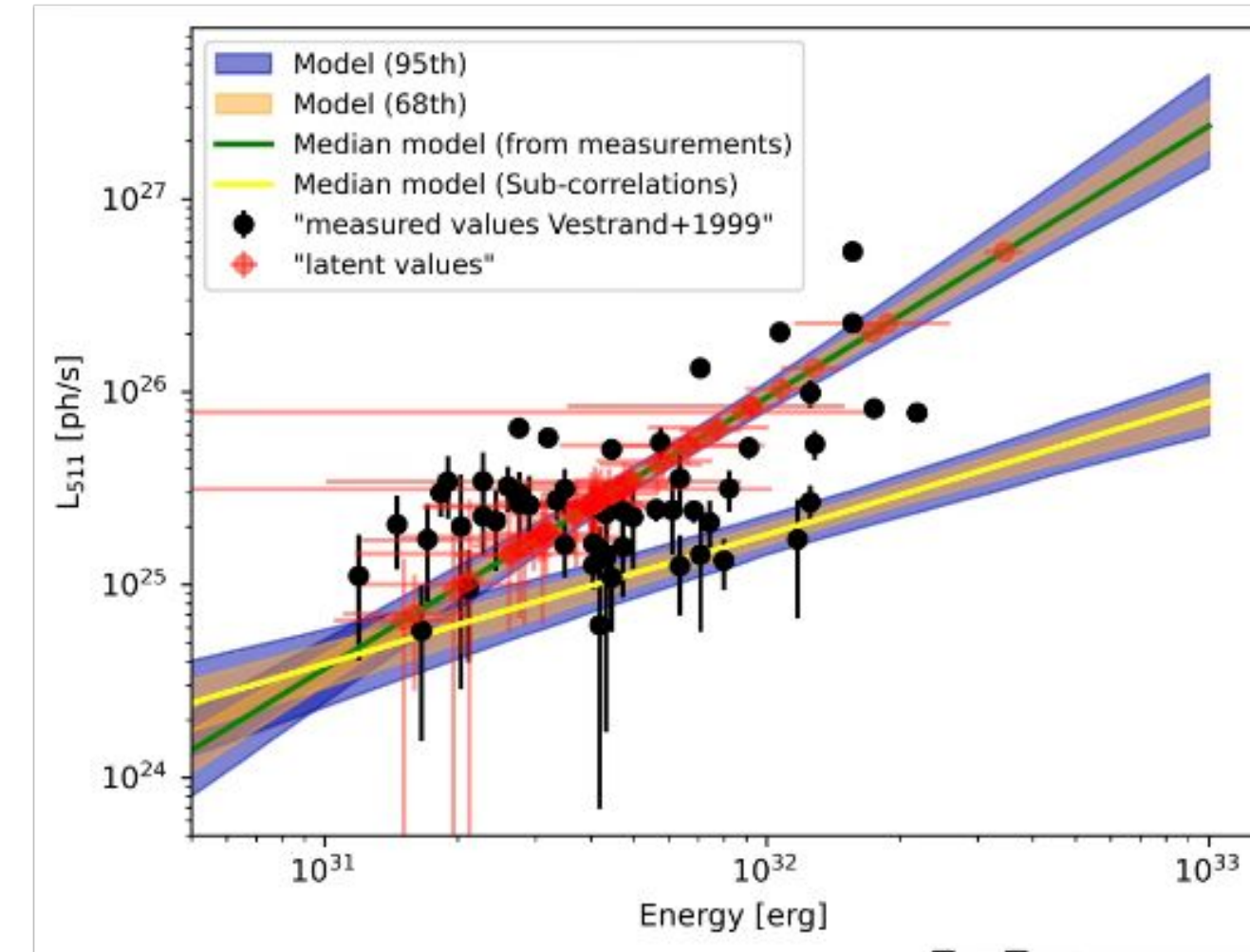


Stellar Flare contribution to 511 keV sky

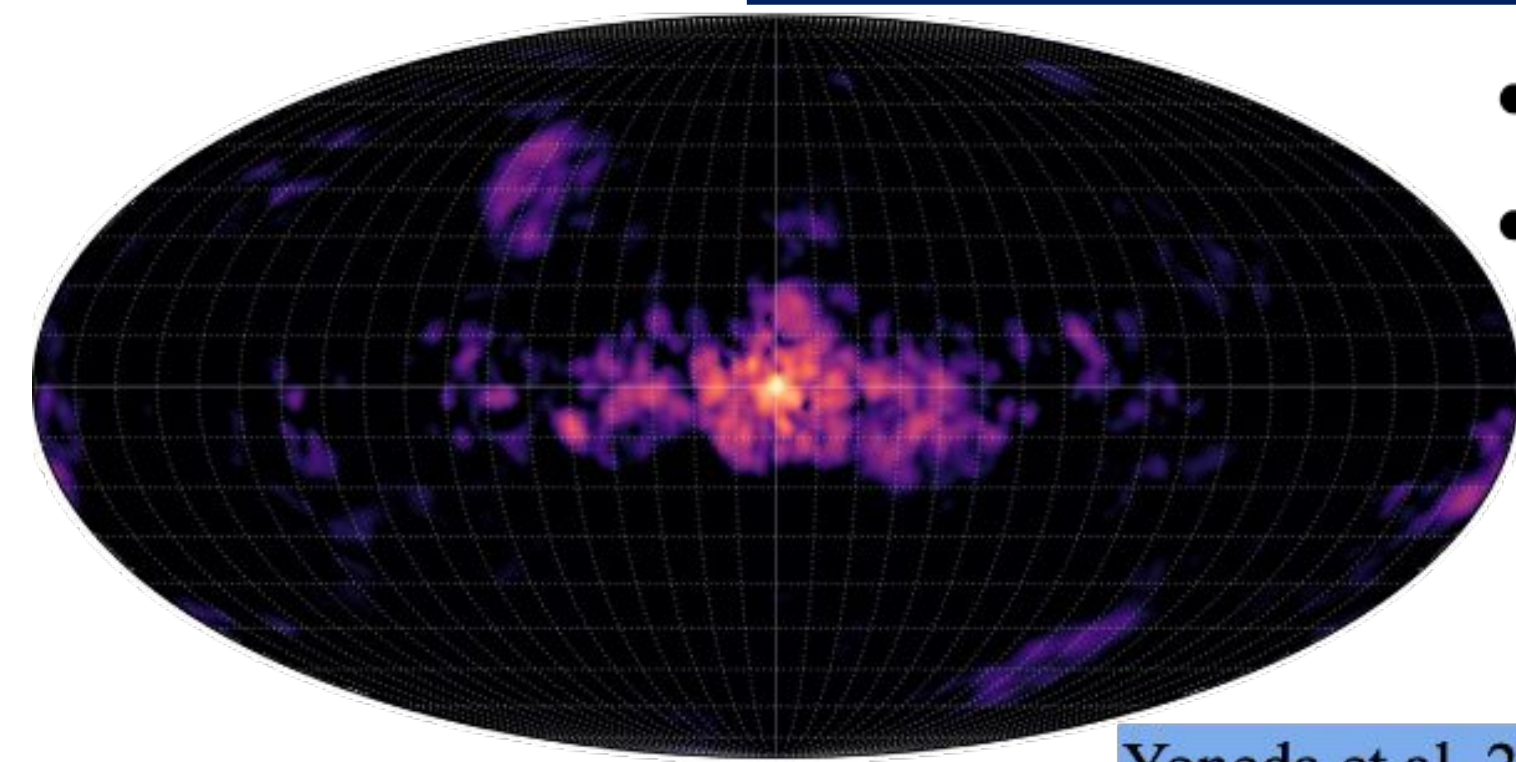


Mittal+2026,
Accepted A&A

511 Luminosity as
a function of flare
energy



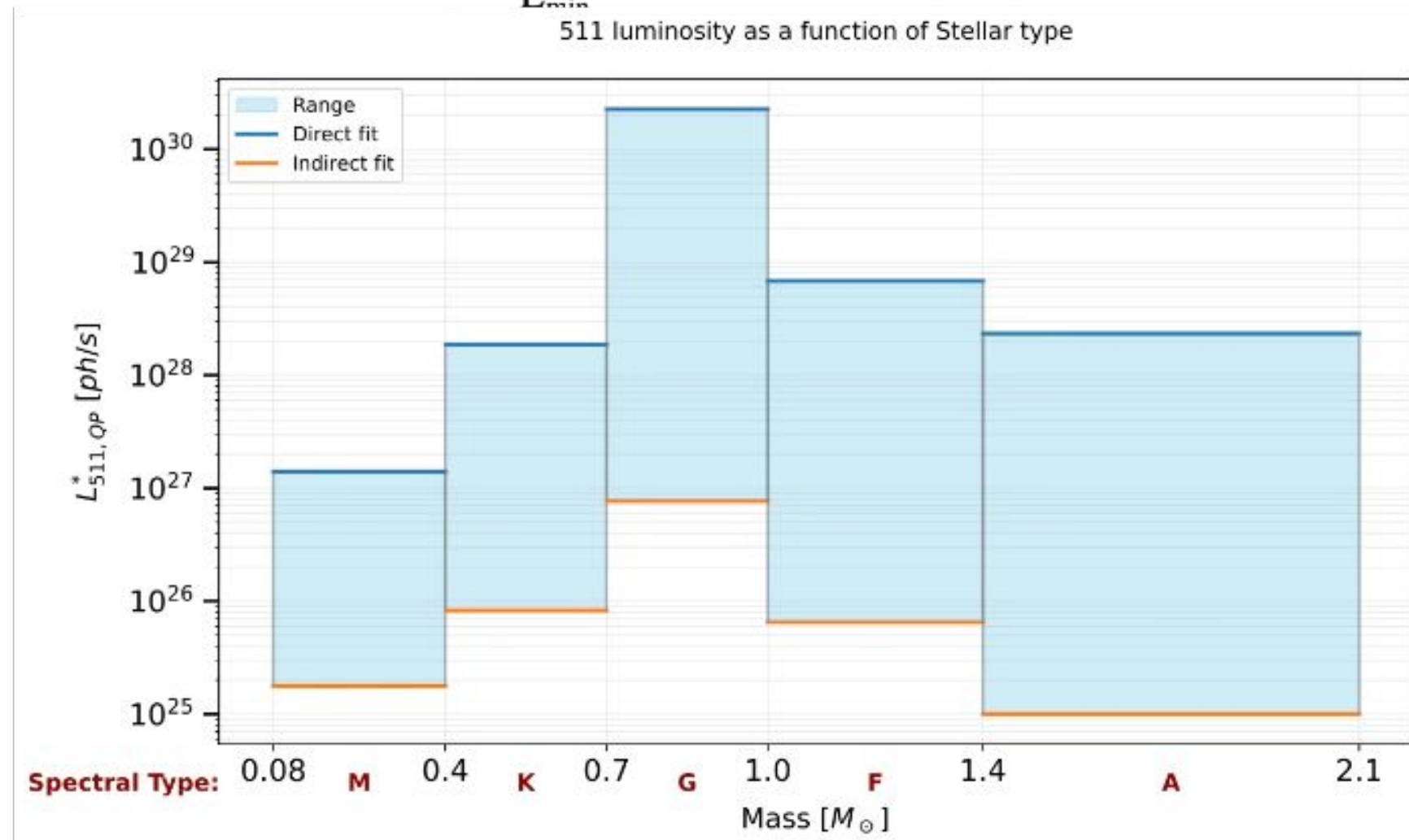
- Galactic bulge as bright as the disk
- Multiple possible contributing sources
 - CCSNe / Massive stars
 - Pulsars
 - **Stellar flares**



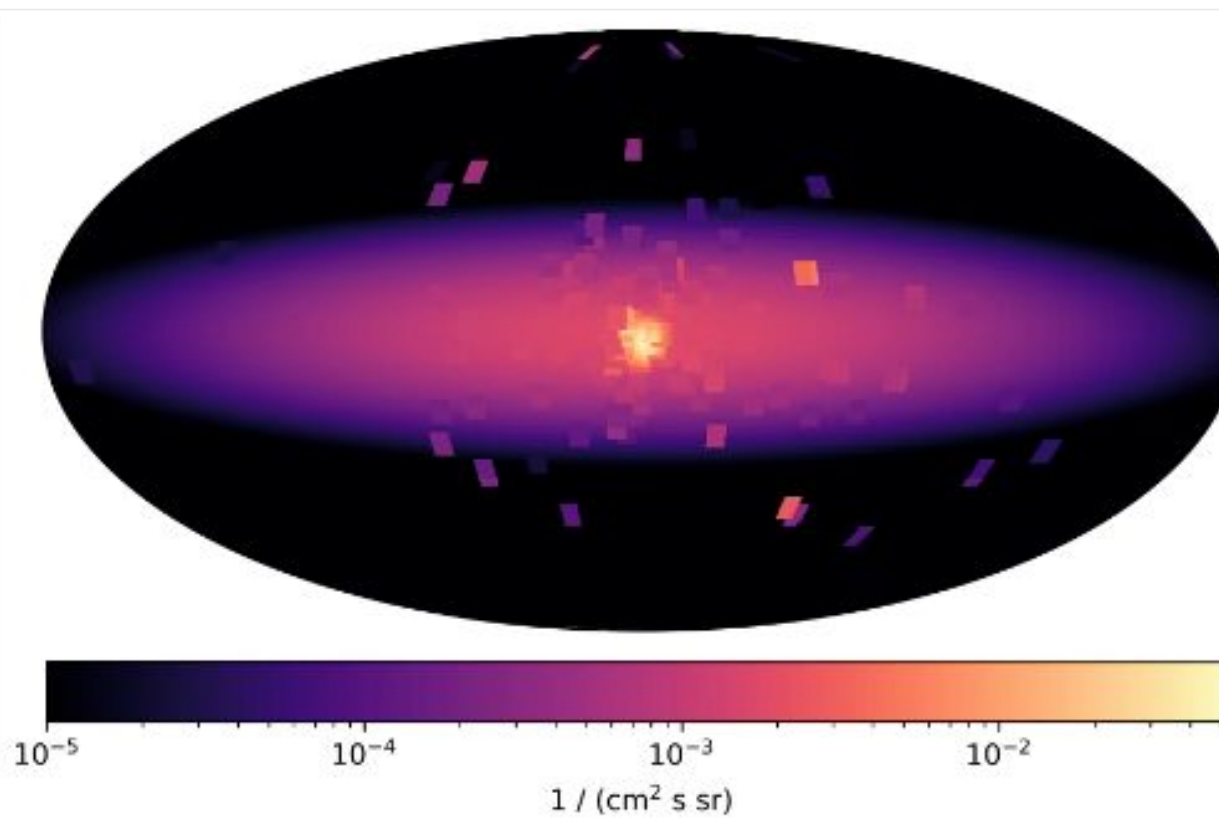
Yoneda et al. 2025

$$L_{511,QP}^*(E_F, M^*) = \int_{E_{min}}^{E_{max}} \nu(E_F, M^*) L_{511,\odot}(E_F) \Delta t(E_F, M^*) dE_F$$

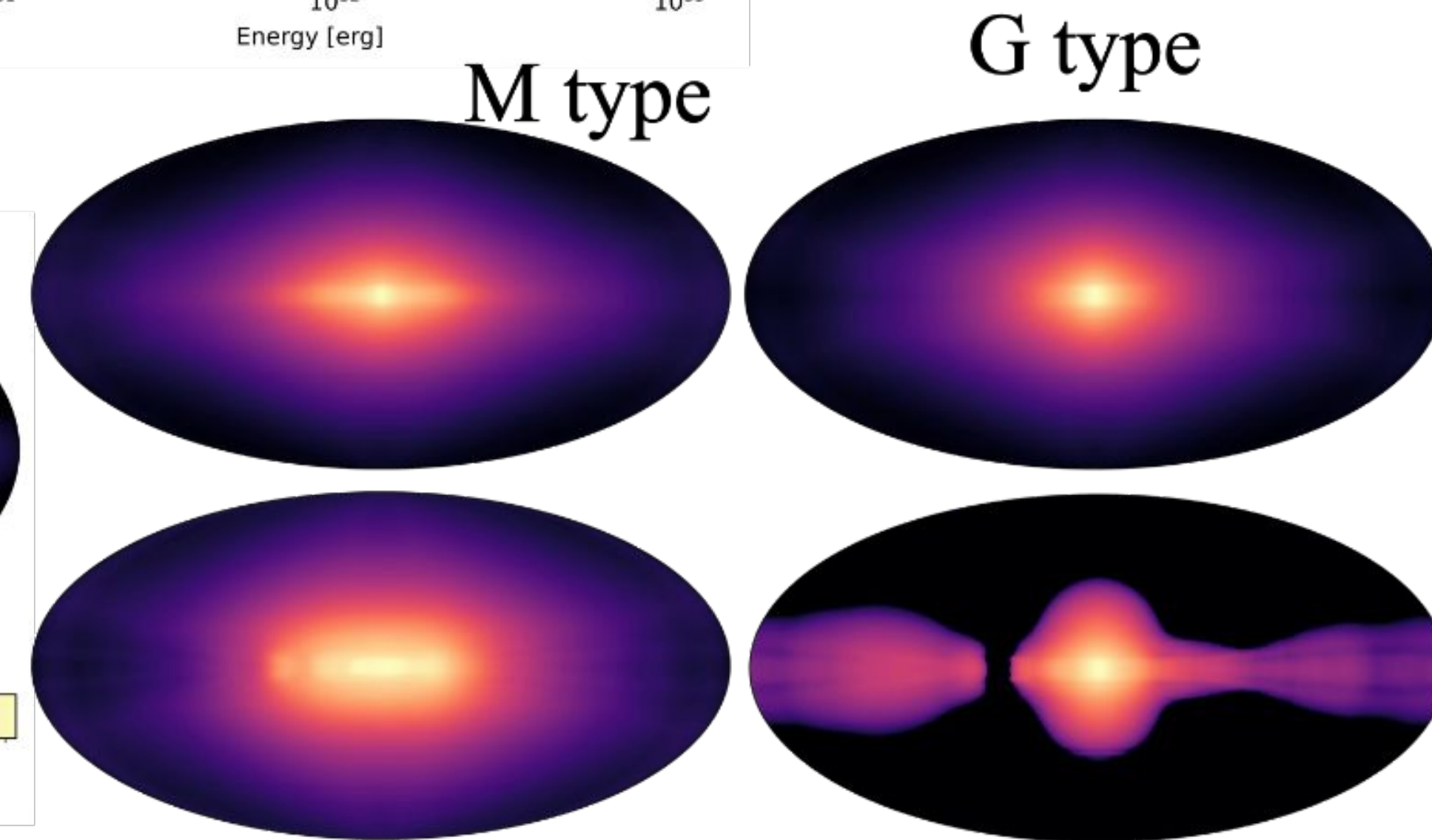
511 luminosity as a function of Stellar type



Quasi persistent 511 keV
luminosity of different stellar types



Disk + NB + clusters



B type

M, G, B fit

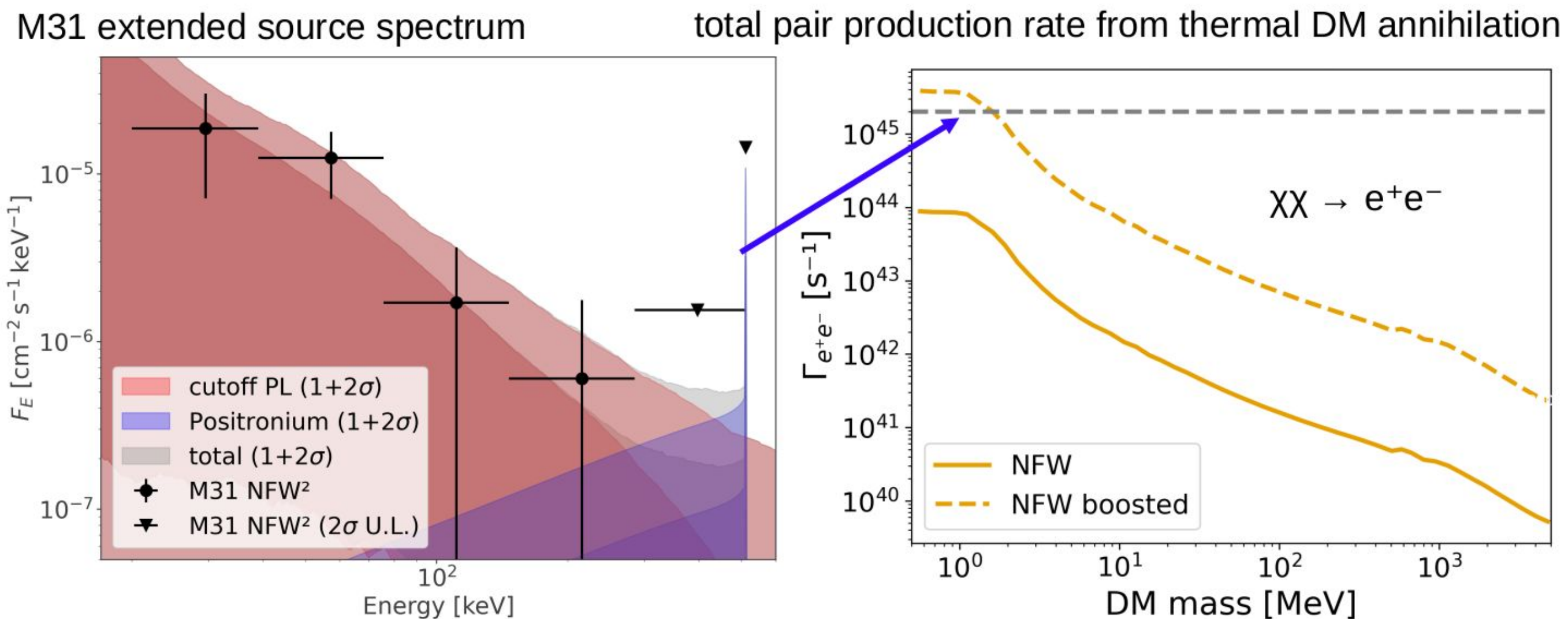
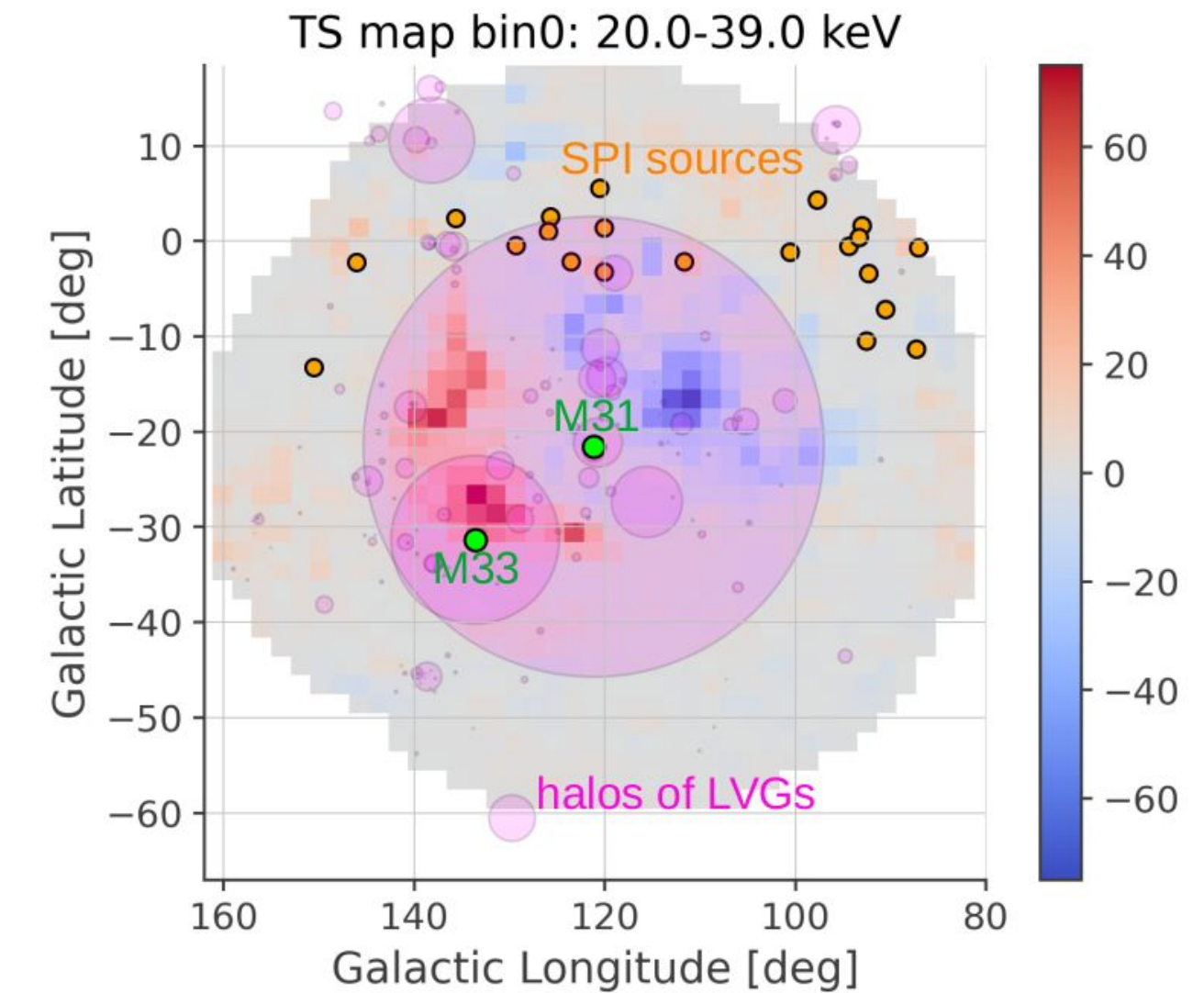
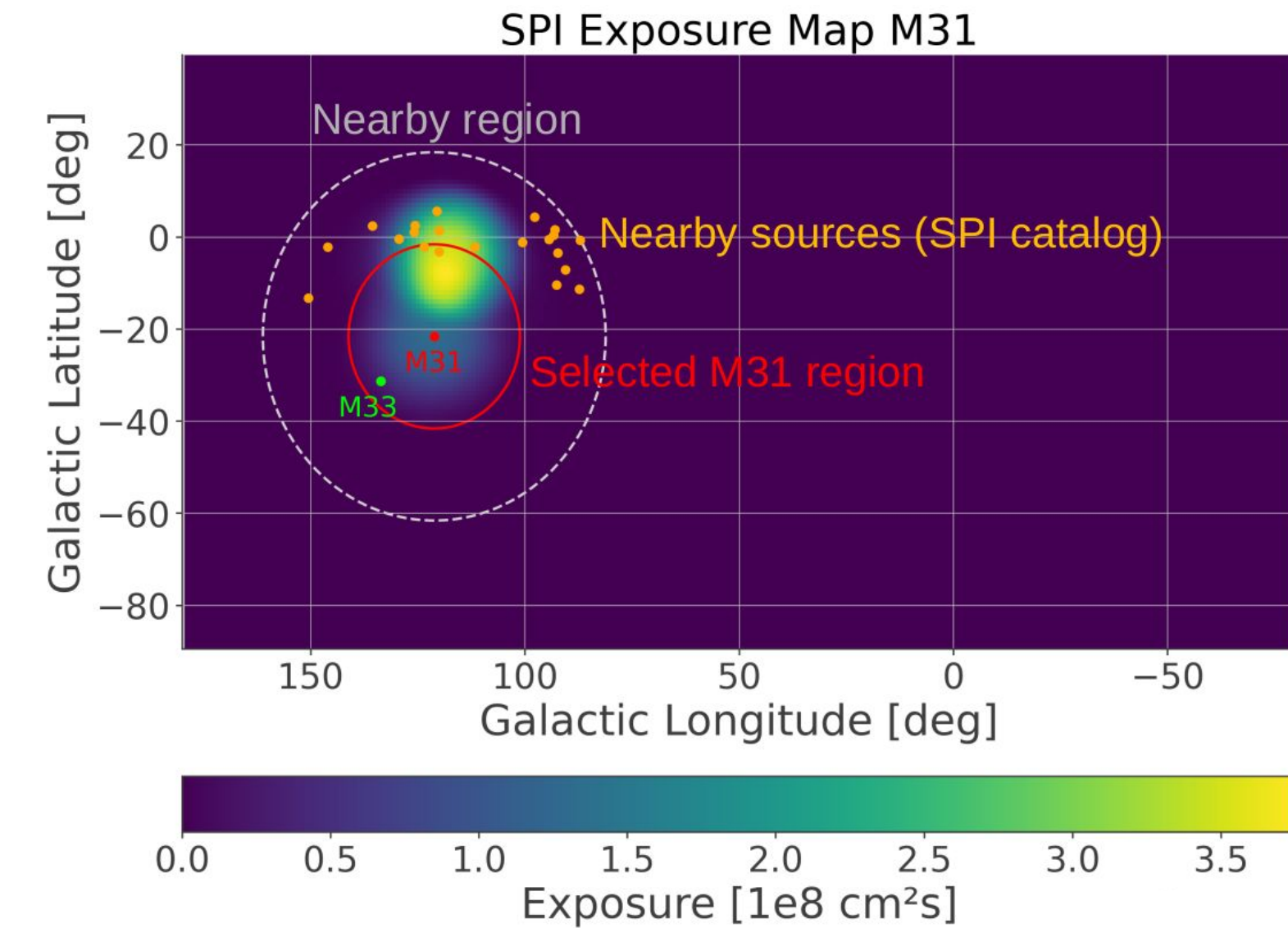
Stellar distribution MW

X



INTEGRAL/SPI observations of M31 DM Halo

- 6 Ms of SPI observations
- positive TS excess towards M33 and M31 halo
- robust extended source spectrum for M31 halo
- > positive flux below 100 keV

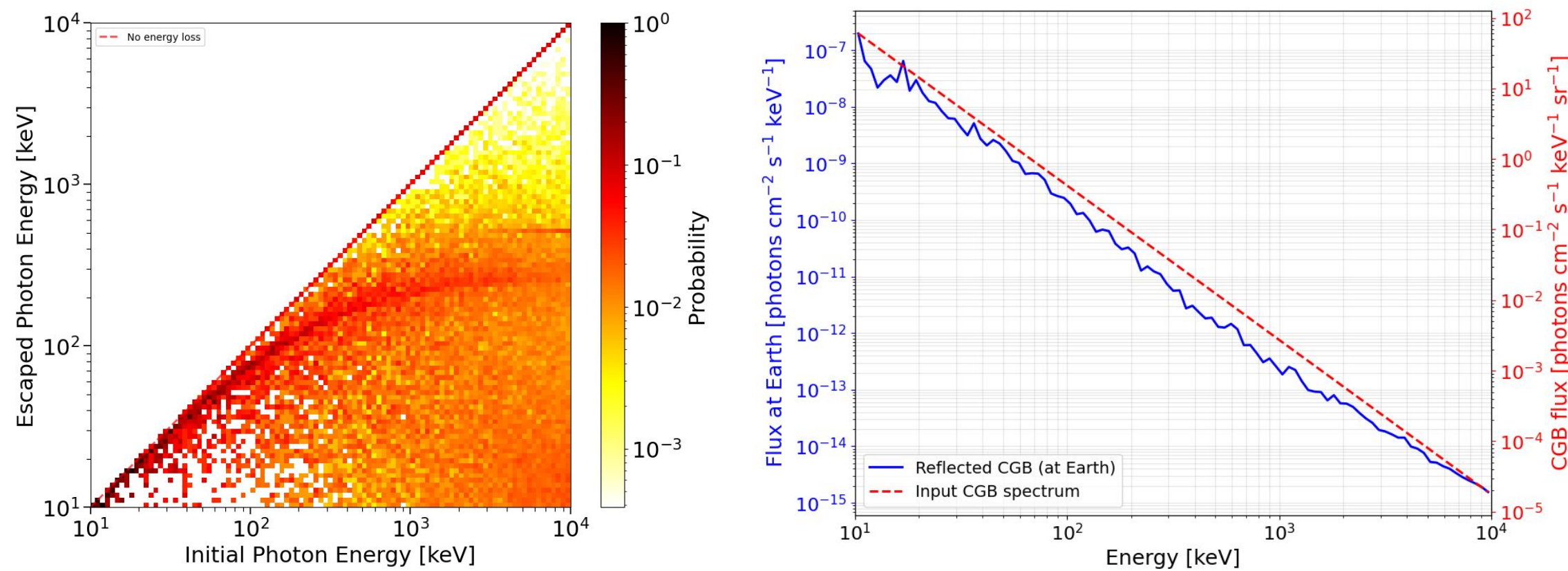


- use M31 data to constrain different dark matter (DM) models:
 - final state γ radiation of DM annihilation/decay into e^+e^-
 - evaporation of primordial black holes including e^+e^- annihilation components
 - thermal DM annihilation into e^+e^- from 511 keV upper limit

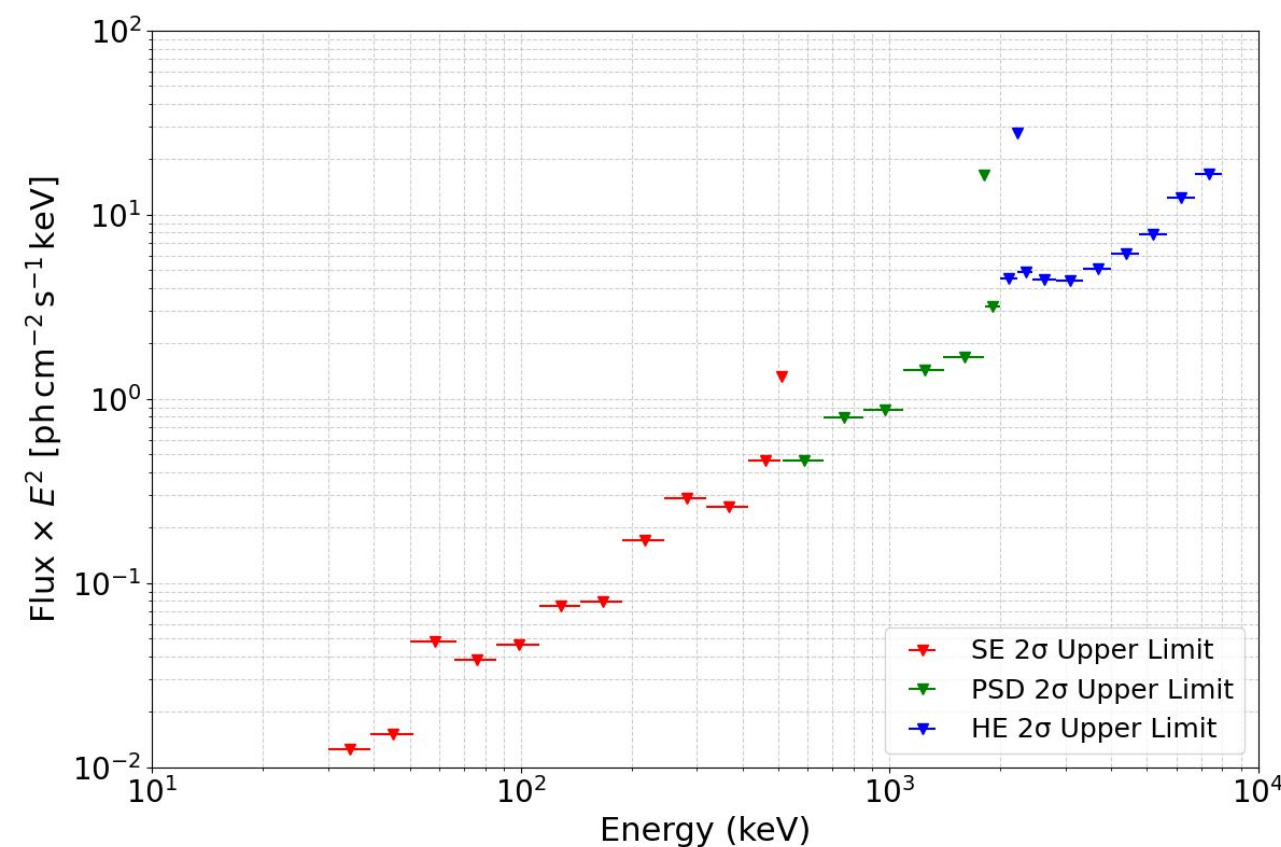


MeV Emission from Jupiter/ Source catalogue SPI

Reflection of the Cosmic Gamma-ray Background Cosmic-Ray Particle Interactions

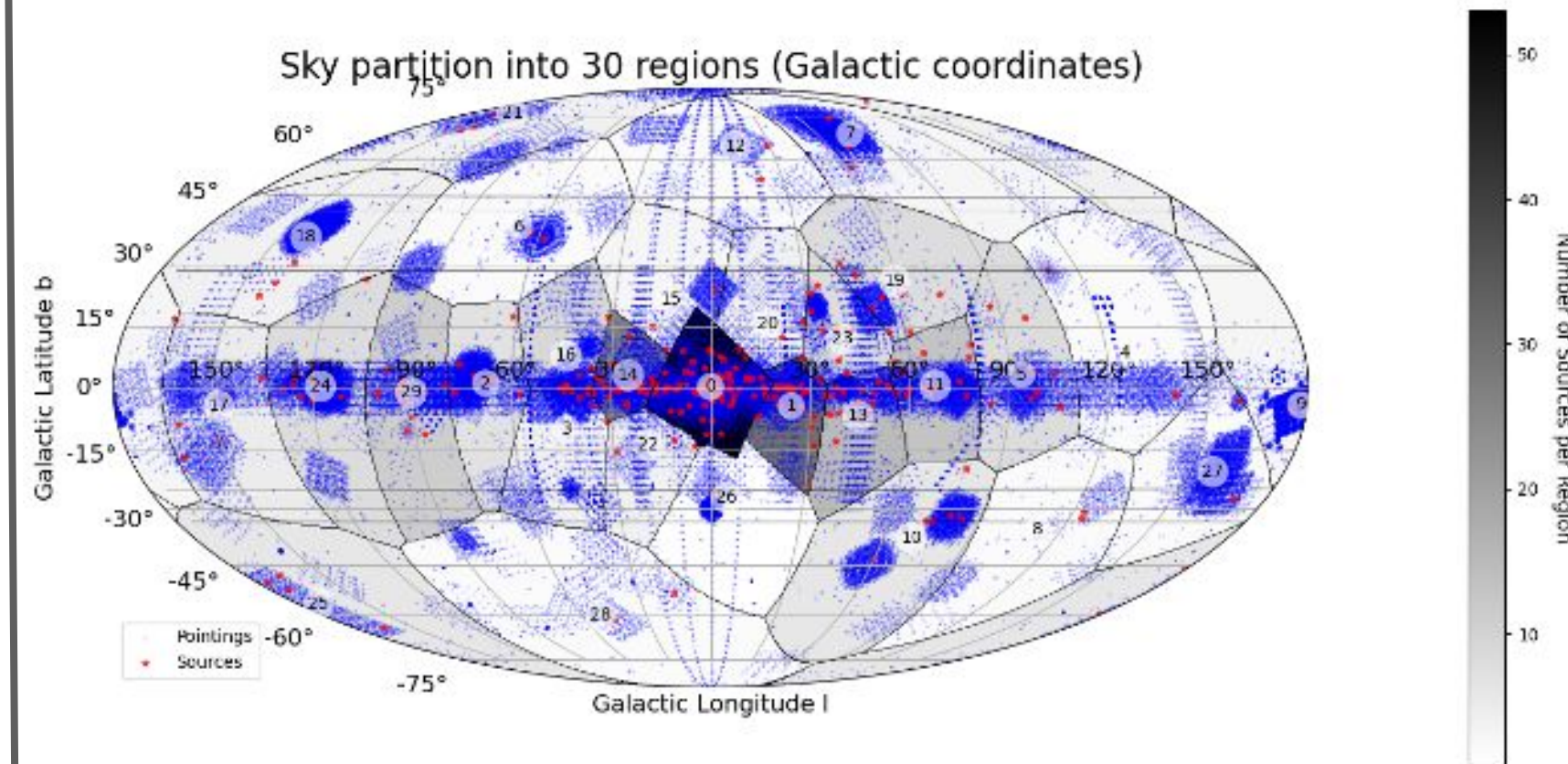


Data Analysis with INTEGRAL/SPI

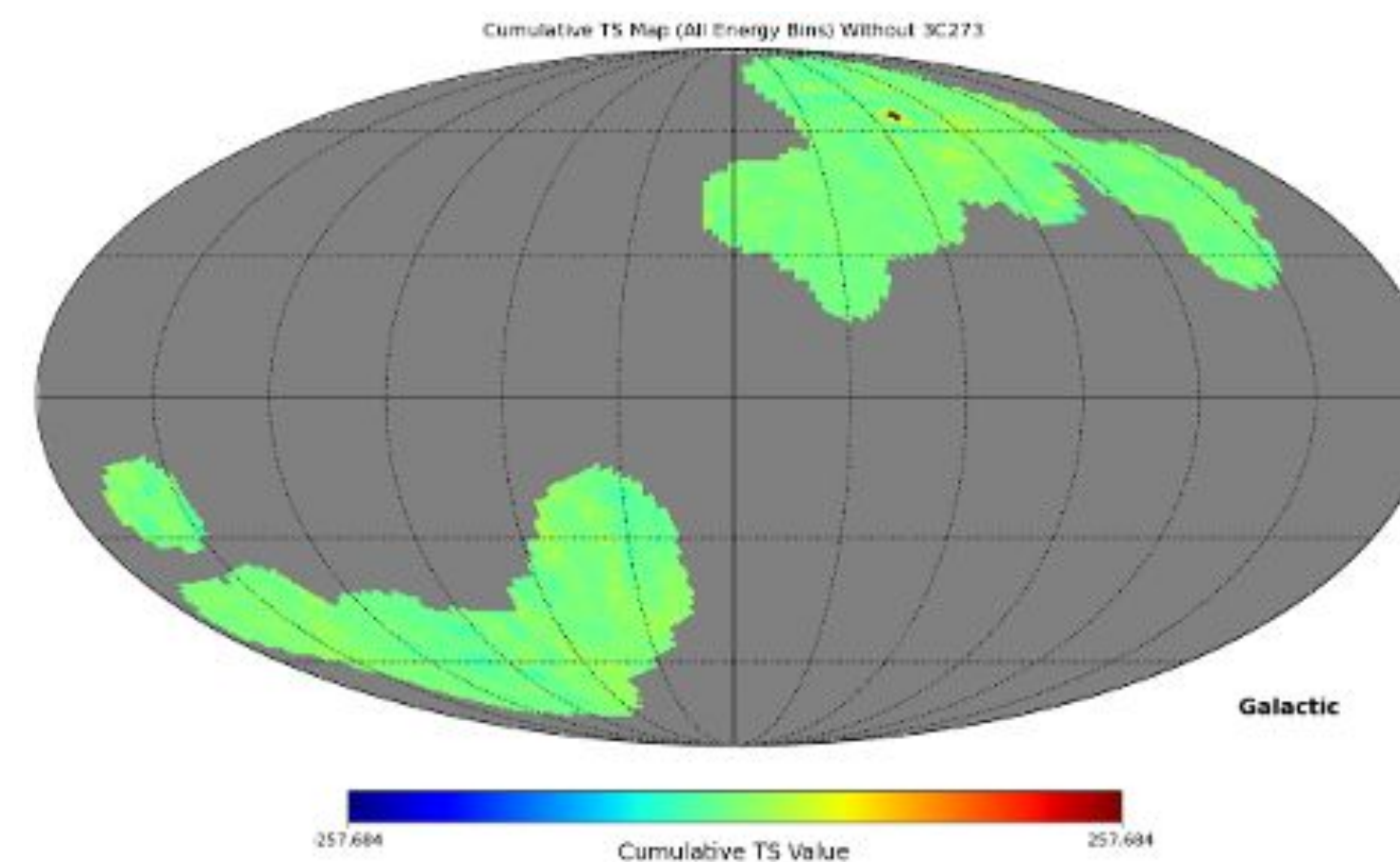


- ULs in the 30 keV to 8 MeV range
- Future:
 - Solar cycle modulation

Expansion of SPI catalogue with 22 years of data

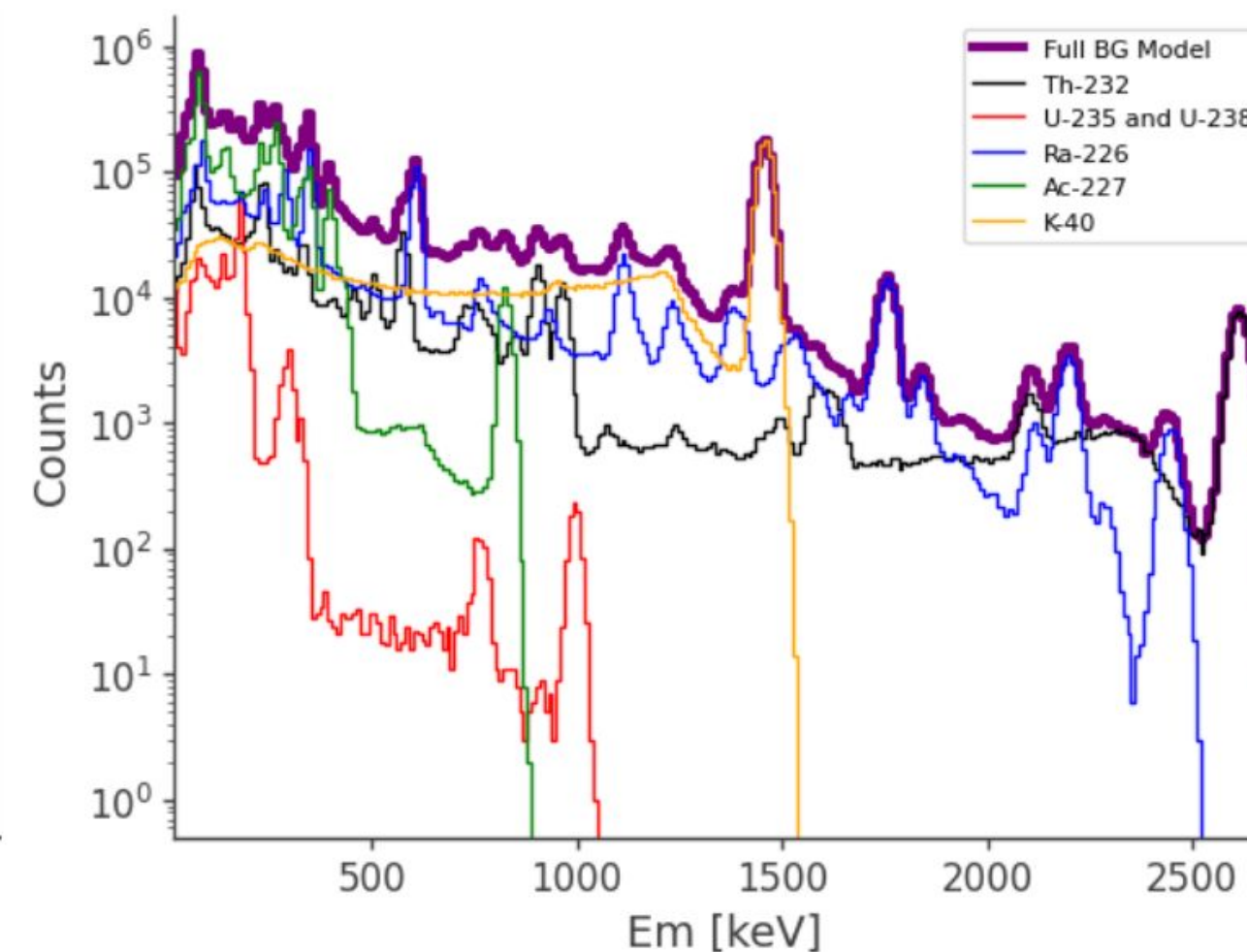
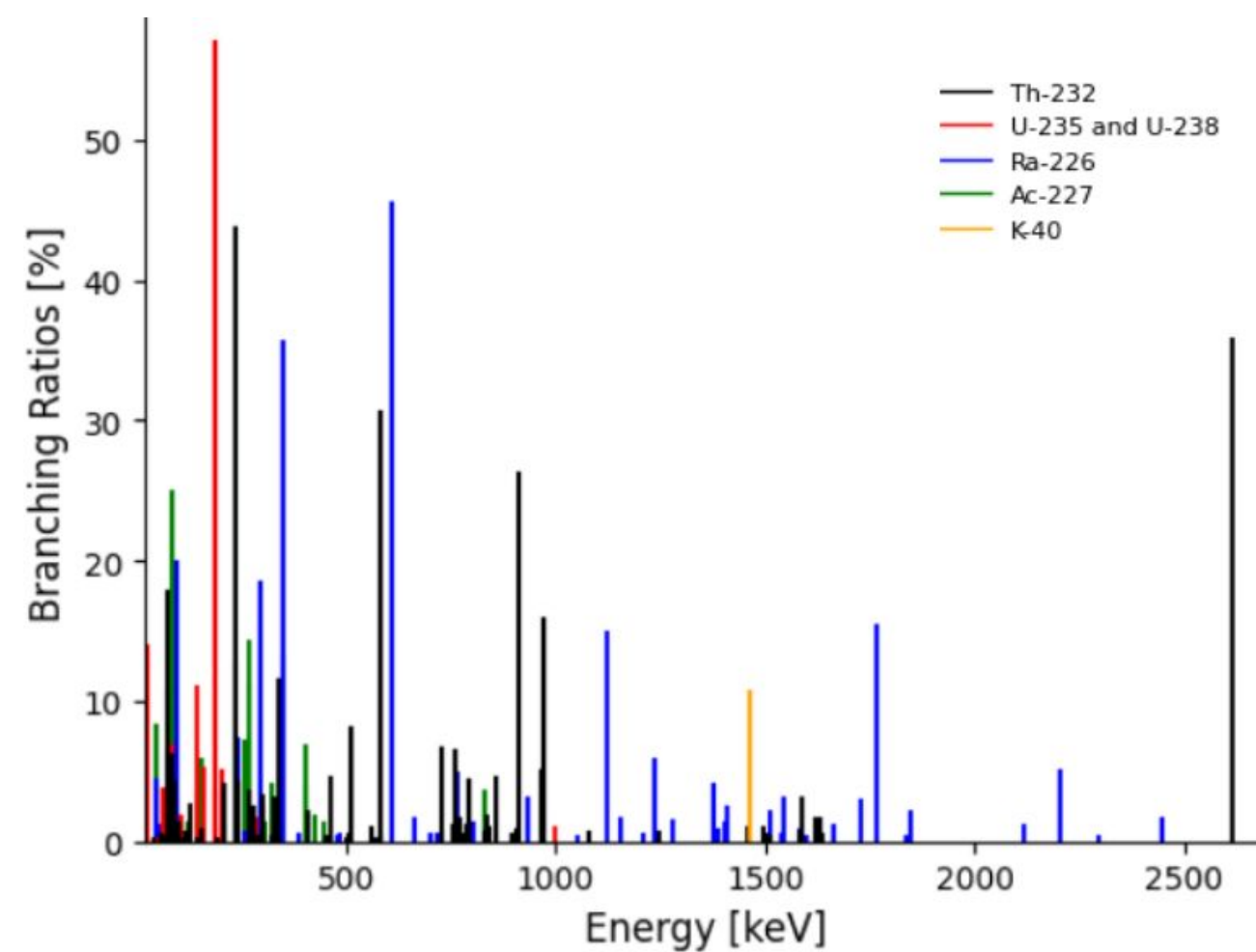
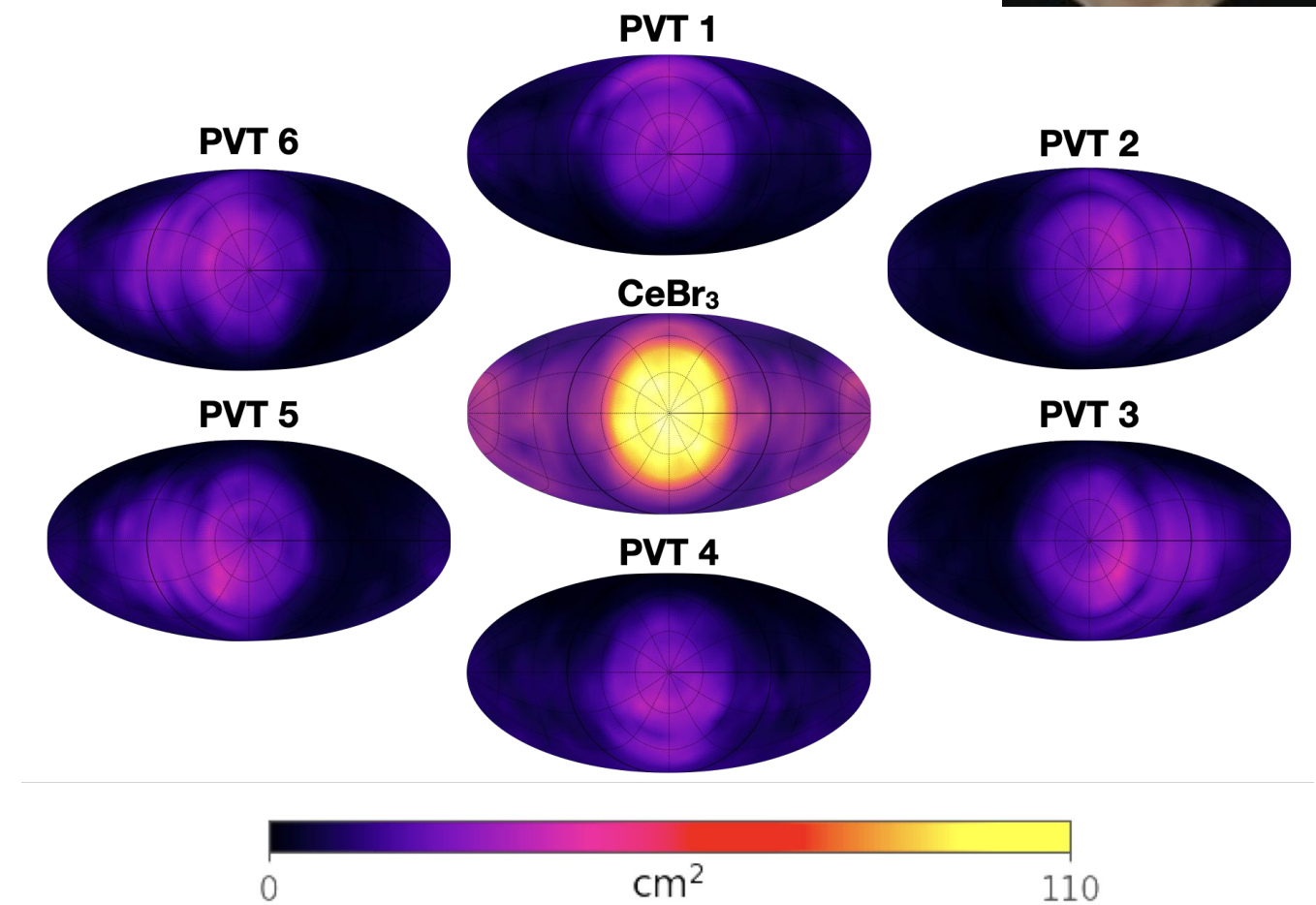
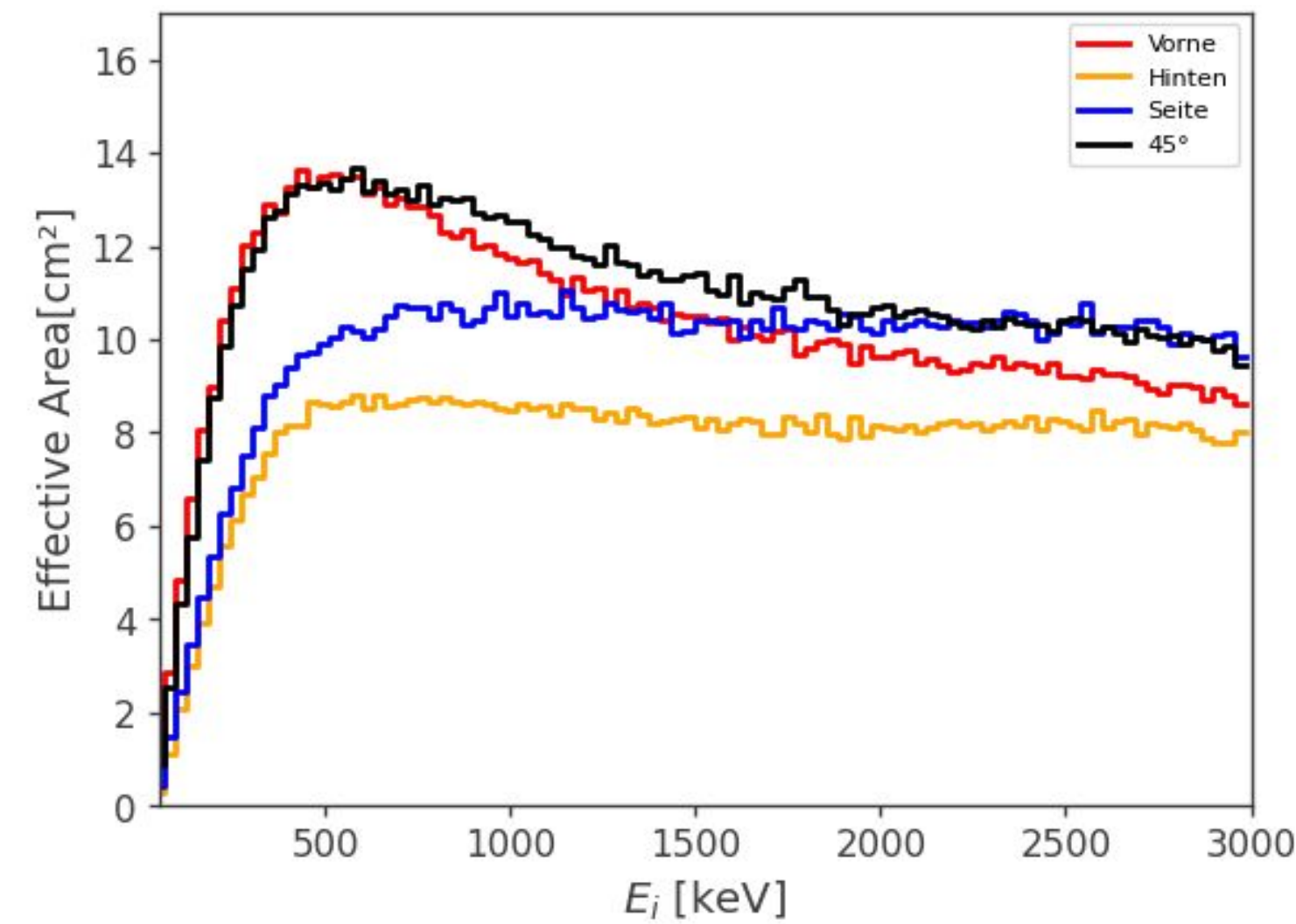
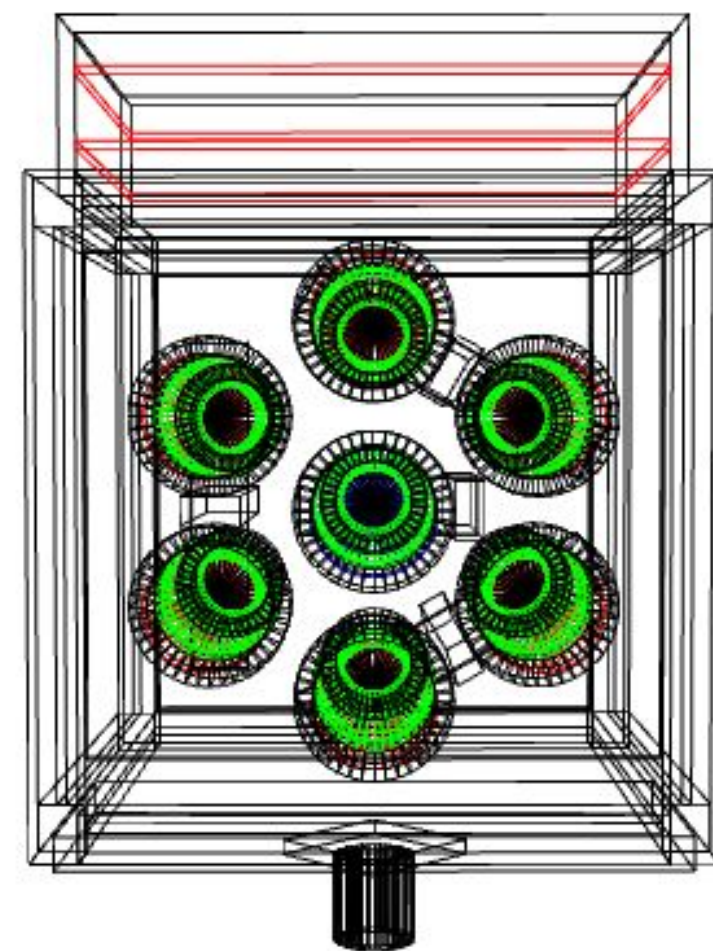
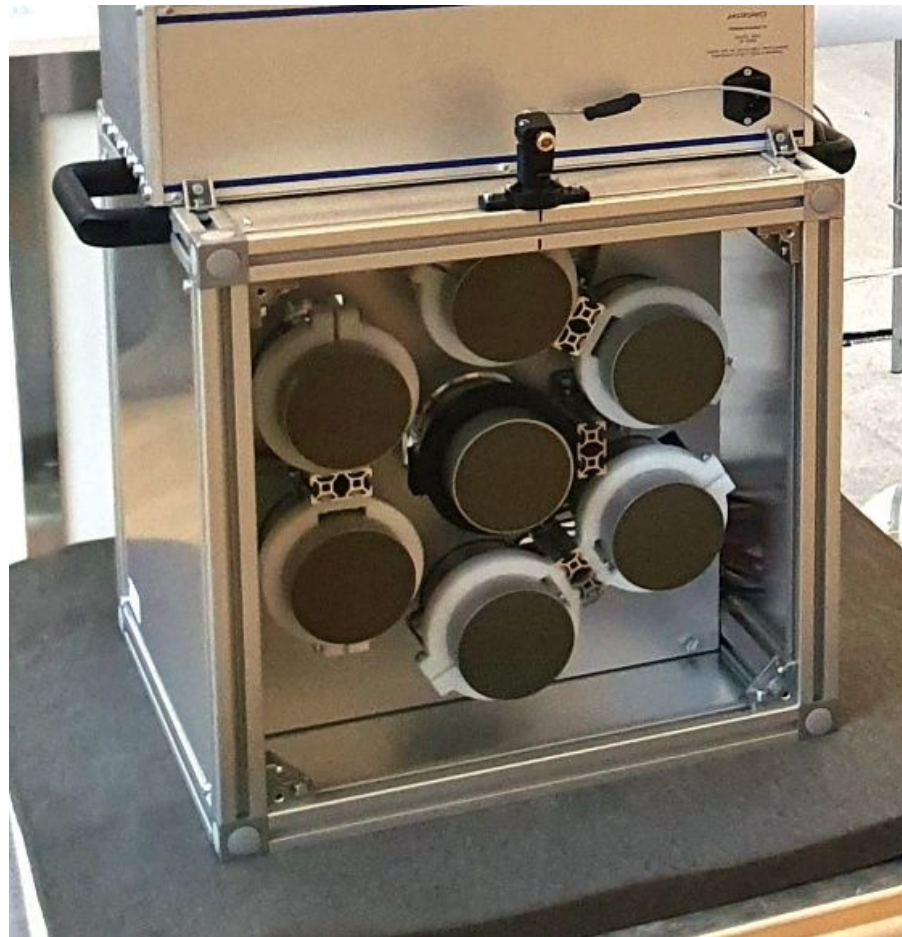


- Analysis of the sky per region
- 22 years of SPI data used



- Creation of TS maps to search for new sources
- Test with known source to evaluate method

Scintillation detector-based Localization and Characterization of Radioactive Material (scintLaCHARM)

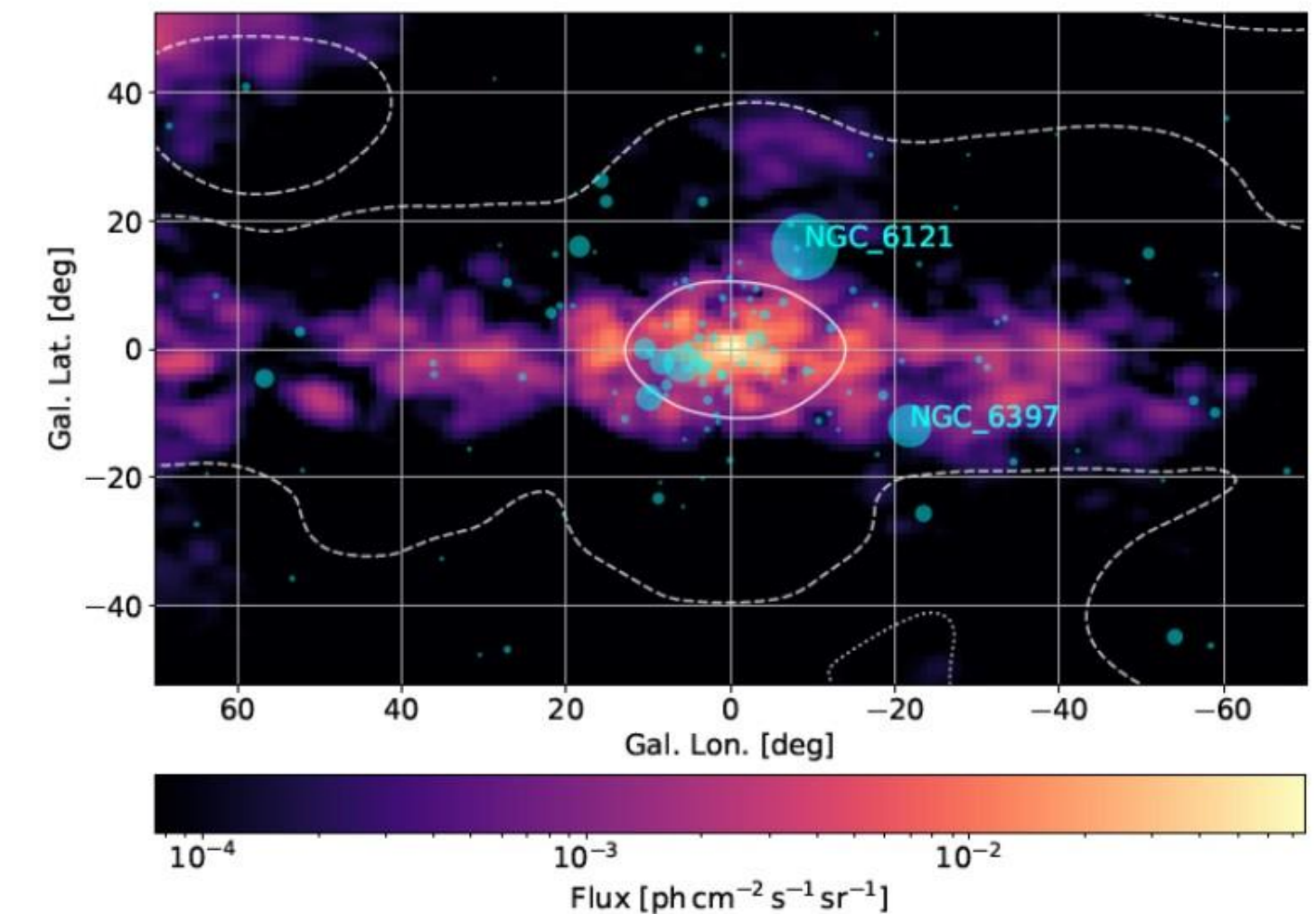
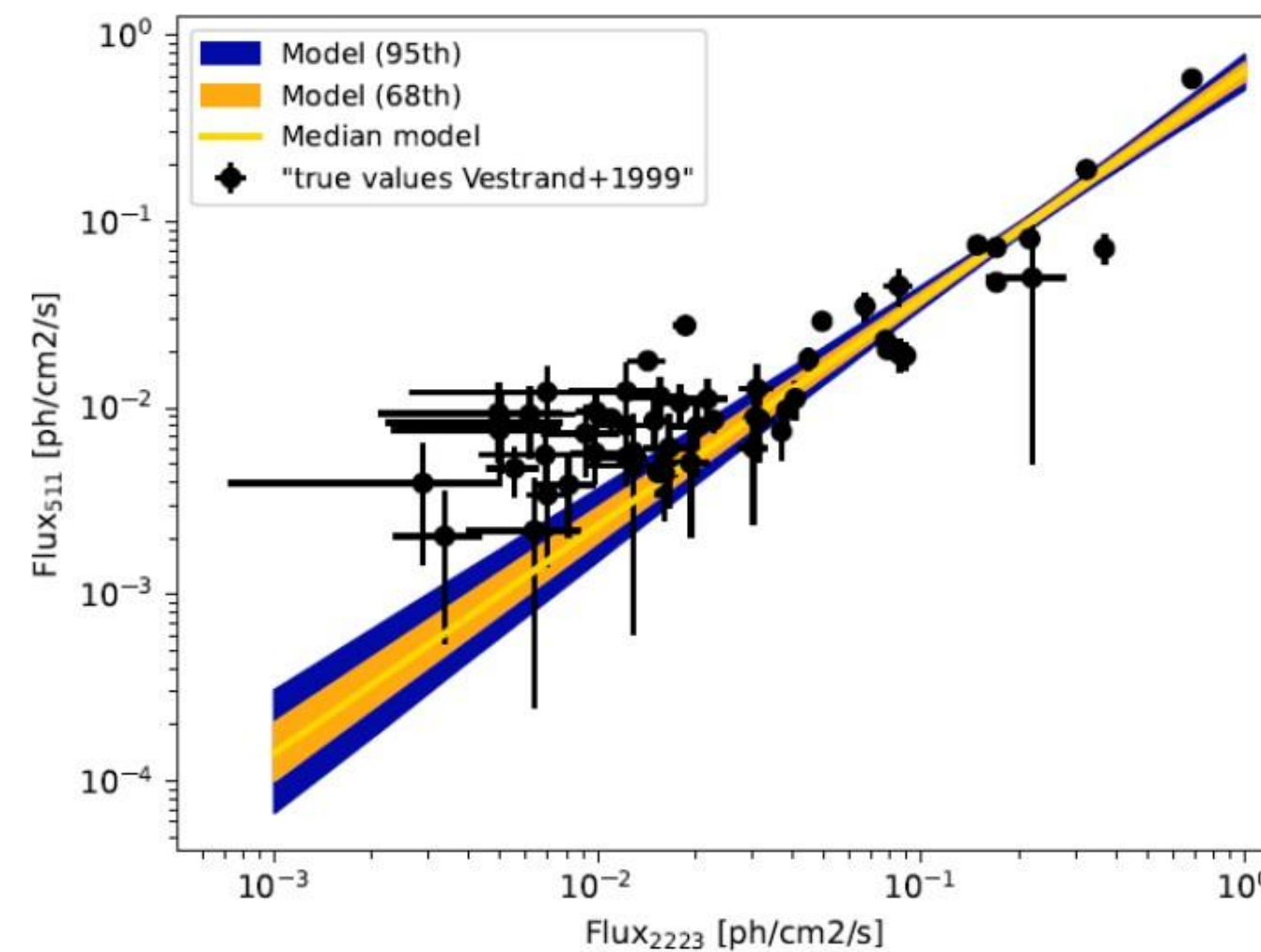


- Using a Compton camera for clearance measurements at former nuclear power plants
- utilizing GEANT4 simulations → Compton and photo event responses
- generate simulated data by applying the response to a certain model (spectral + spatial)
- Using COSIpy analysis tools (template fit, image reconstruction, ...)



Investigating the 511 keV and 2.223 MeV Lines

- Reduce the ambiguity in the interpretation of galactic electron-positron annihilation radiation
 - Distribution of positron sources in the galaxy remains unresolved
- 511 keV and 2.223 MeV emission
 - Search for the astrophysical 2.223 MeV line
 - Use correlation to constrain positron source distribution
- Constraining possible positron sources
 - Analyzing 22 years of INTEGRAL/SPI data
- Future:
 - Distinguish GC spectra from total galactic emission in soft γ -ray range
 - Create 2.223 MeV All-Sky Map
 - Determine luminosity ratios of 511 keV and 2.223 MeV lines in GC's and the entire galaxy

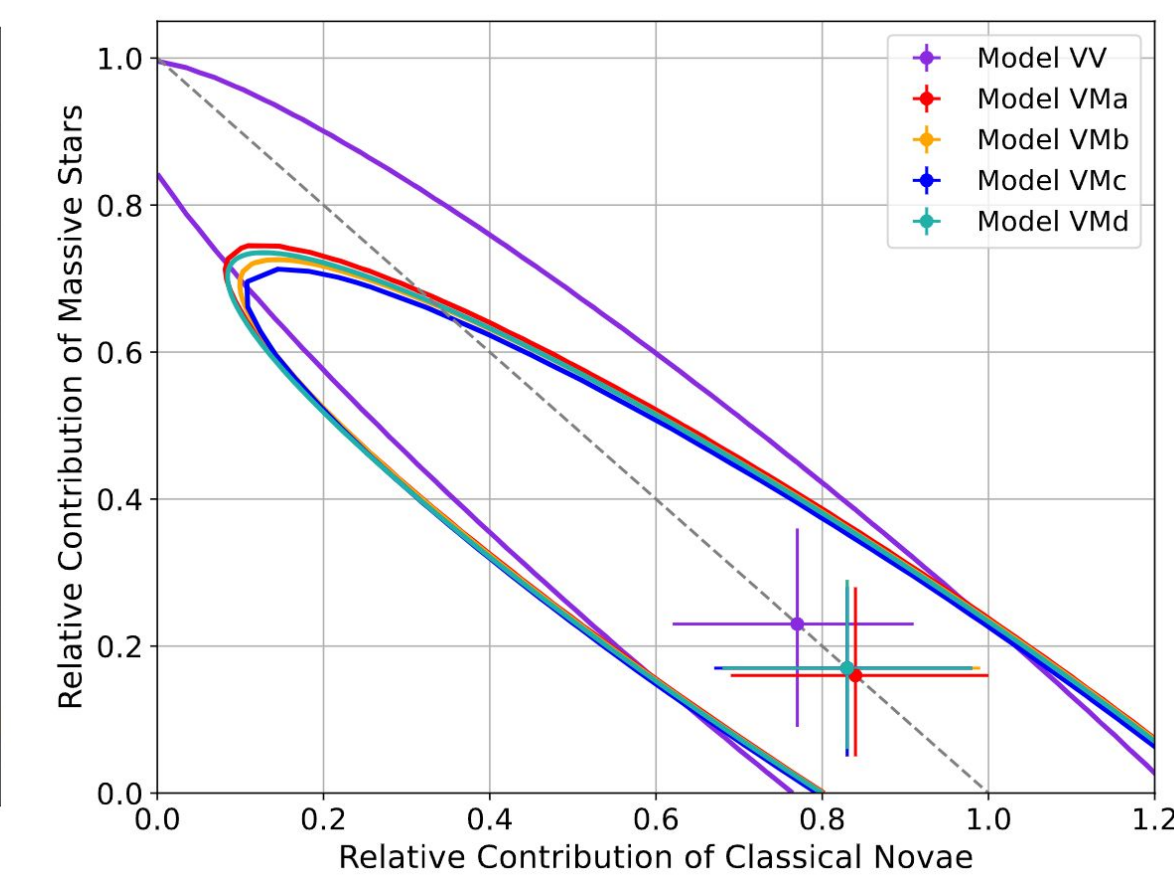
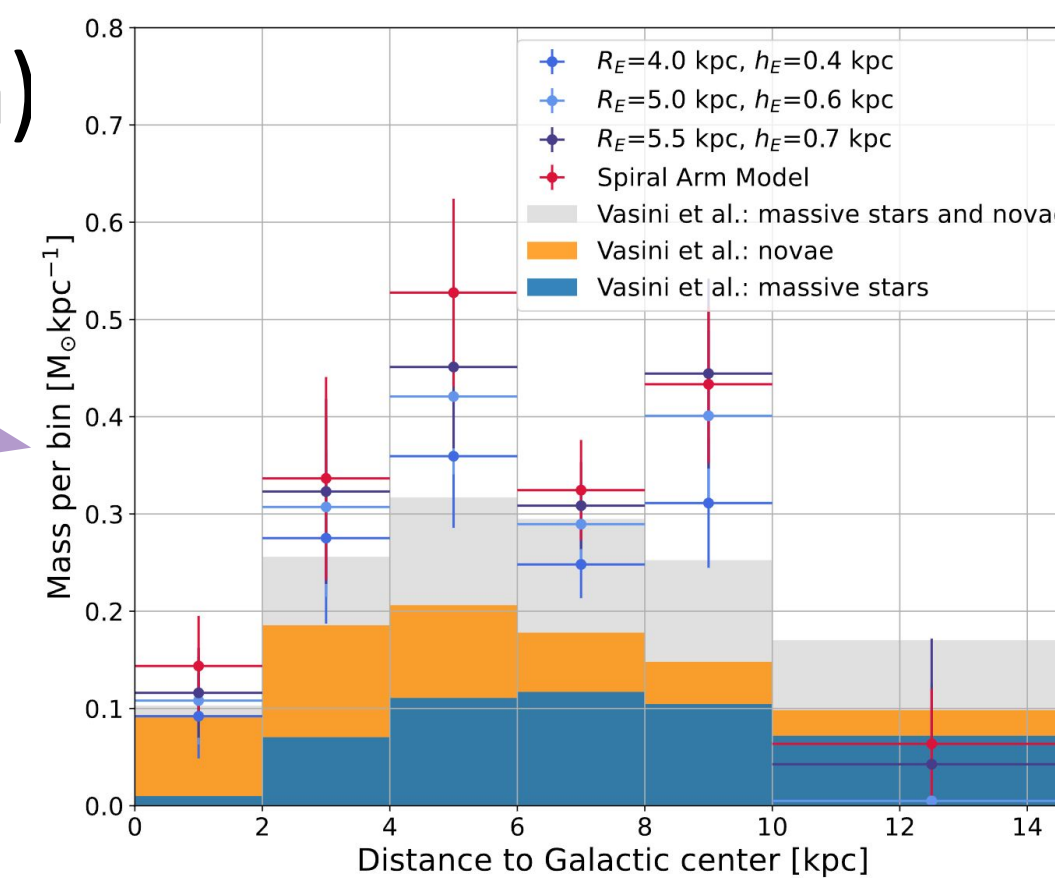


Left: Correlation of prompt 511 keV and 2.223 MeV line (Mittal et al. 2026)

Right: γ -ray sky map of the 511 keV line with GC distribution (cyan color). Close sources indicated by larger circles (Yoneda et al. 2025)

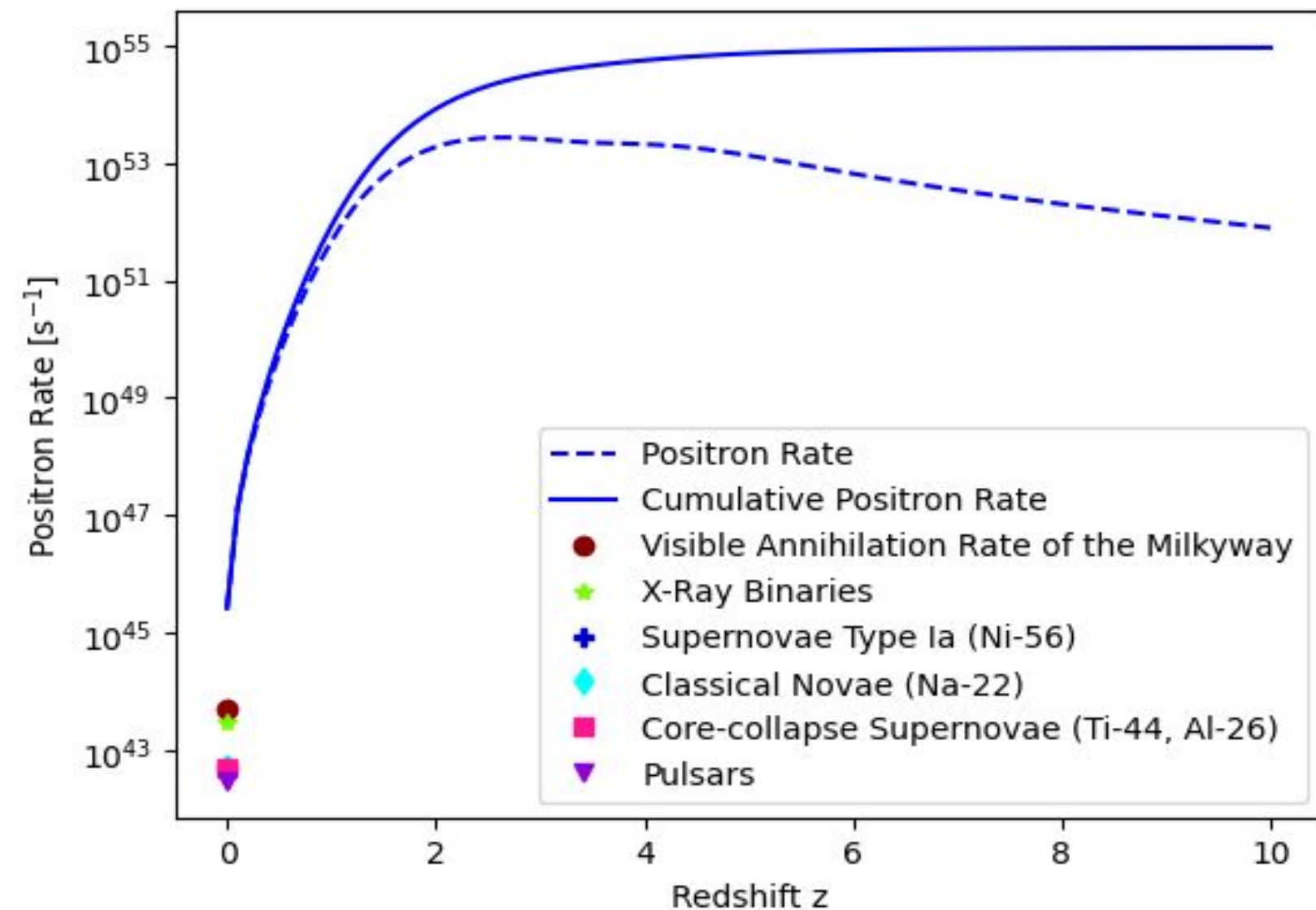
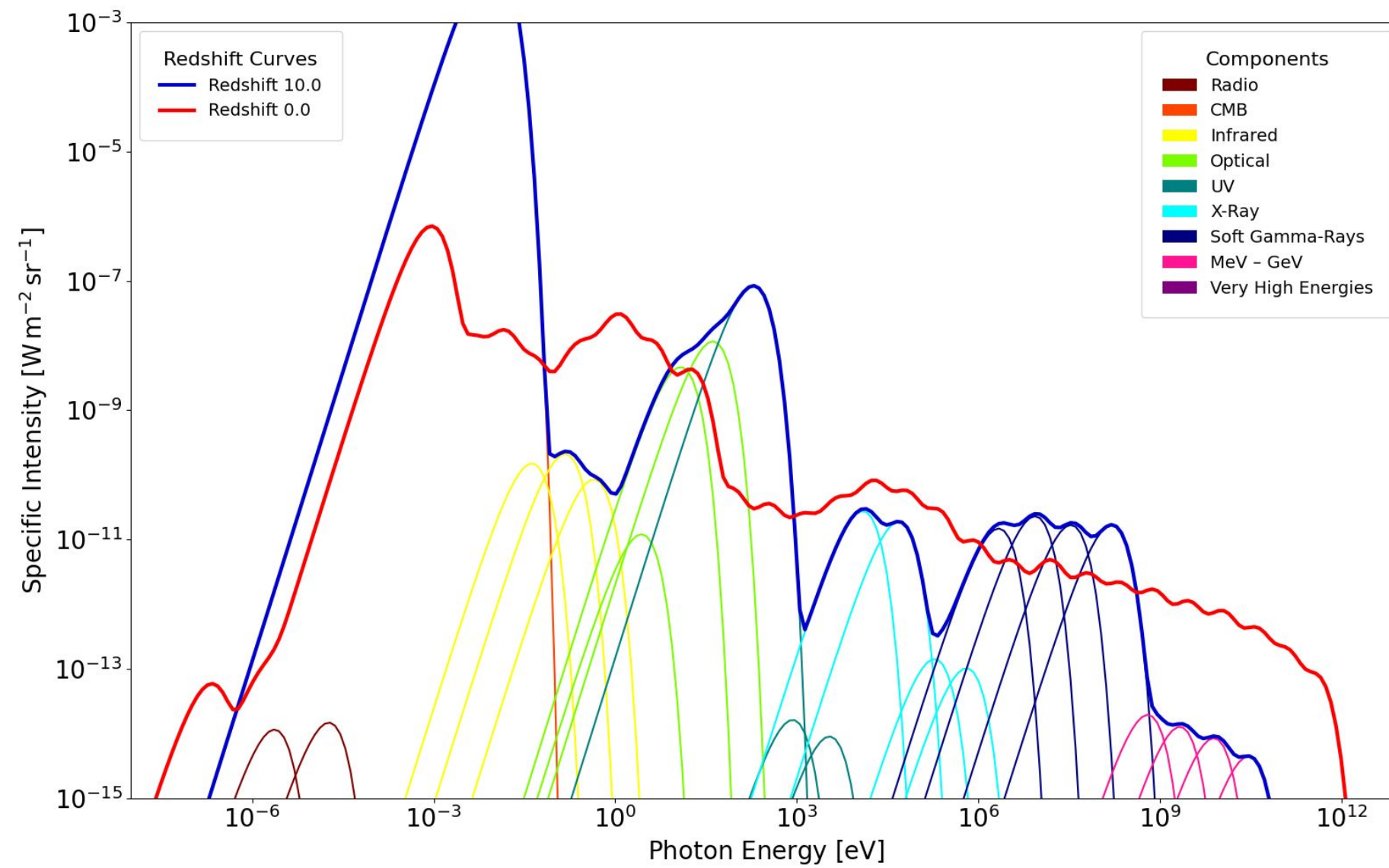
Classical Novae

- Surface explosion on white dwarfs
- Responsible (supposedly) for ^7Li in the Galaxy and partly ^{26}Al
- Explosive burning has many **uncertainties**:
(cross sections, astro setup, WD composition, mixing, rates, ...)
- Interesting γ -ray signals:
 - $^7\text{Be} \Rightarrow ^7\text{Li}$: 478 keV, $\tau = 76$ days
 - $^{22}\text{Na} \Rightarrow ^{22}\text{Ne}$: 1275 keV, $\tau = 3.5$ yr
 - ^{13}N , ^{15}O , ^{18}F β^+ -decay: 511 keV + continuum, $\tau = \text{O}(\text{min})$
 - $^{26}\text{Al} \Rightarrow ^{26}\text{Mg}$: 1809 keV, $\tau = 1.04$ Myr
- Observed γ -ray emission: **None**



Paper *Contributions of massive stars and classical novae to Galactic ^{26}Al*
(submitted to A&A)

Pair Production from Cosmic Photon Background (CPB)



- Modeling redshift evolution of the CPB as a combination of blackbody spectra
→ production of electron-positron pairs
- Positron production rate increases sharply up to $z \approx 2.7$
- Positrons lead to secondary emission, dominated by inverse Compton scattering
- may significantly reduce gap between observations and theoretical models in the MeV range
→ Paper *Cosmological γ - γ pair-production background* (recently accepted by A&A)

