

# Half-sky Dark Matter Line Search using eROSITA DR1

Chingam Fong<sup>1</sup>, Qishan Liu<sup>2</sup>, Kenny. C. Y. Ng<sup>1</sup>

<sup>1</sup>The Chinese University of Hong Kong

<sup>2</sup>Institute of High Energy Physics, Chinese Academy of Sciences

# Decaying DM Search in X-ray

- Unexplained signature -> decay?
- Rate determined by particle physics & DM profile

$$\Phi = \frac{\Gamma}{4\pi m_\chi} \Delta\Omega \frac{dN}{dE} \int \rho[r(l, \phi)] dl$$

D-factor

- Sterile neutrino: (1 photon)

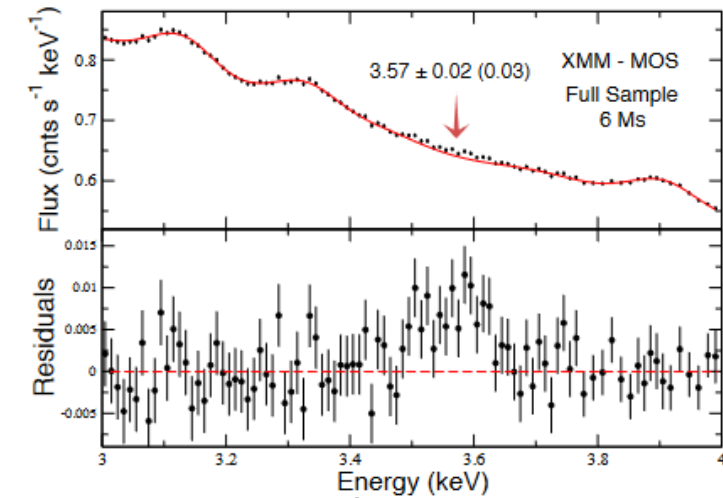
$$\Gamma_{\nu_s} = 1.38 \cdot 10^{-29} s^{-1} \left[ \frac{\sin^2(2\theta)}{10^{-7}} \right] \left( \frac{m_{\nu_s}}{1keV} \right)^5$$

- Axion-like particles: (2 photons)

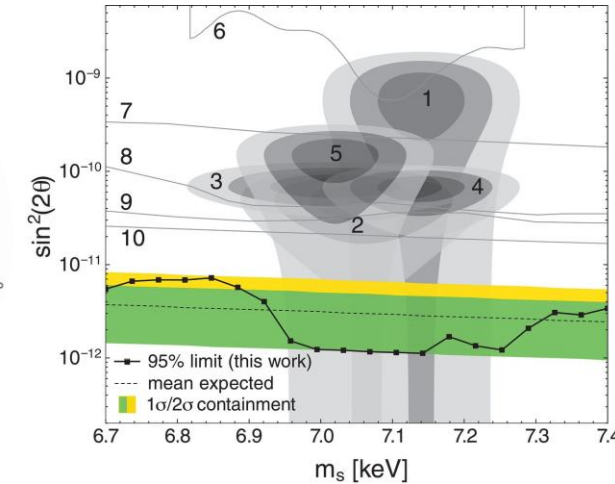
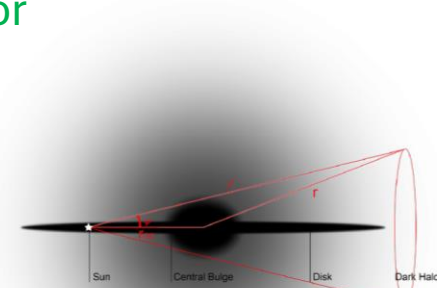
$$\Gamma_{a\gamma\gamma} = 5 \cdot 10^{-29} s^{-1} \left( \frac{m_a}{7keV} \right)^3 \left( \frac{g_{a\gamma\gamma}}{1.74 \cdot 10^{-18} GeV^{-1}} \right)^2$$

- DM -> 1 or 2 equal energy photon(s)

$$\frac{dN}{dE} = \delta(E - m_\chi/2)$$



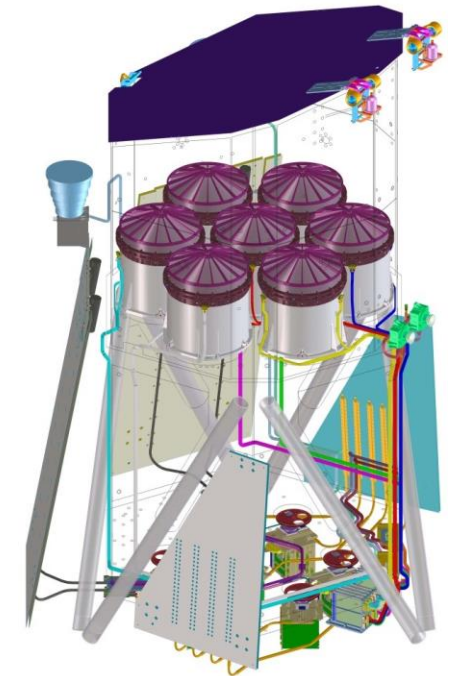
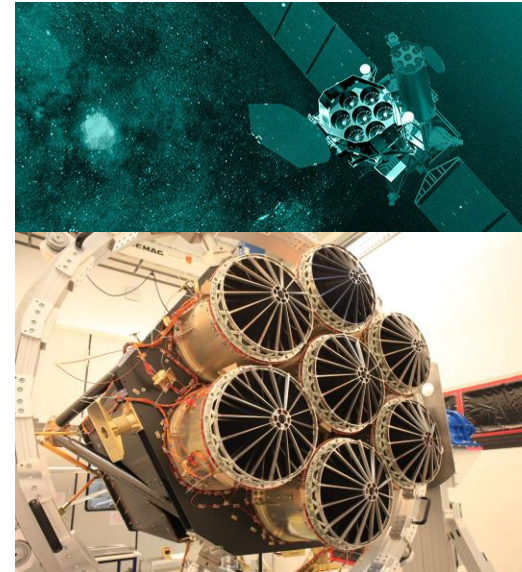
Galaxy cluster data Bulbul et al., 2014



V. V. Barinov et al., 2020  
XMM Newton blank sky  
C. Dessert, 2020

# eROSITA Instrument & Mission

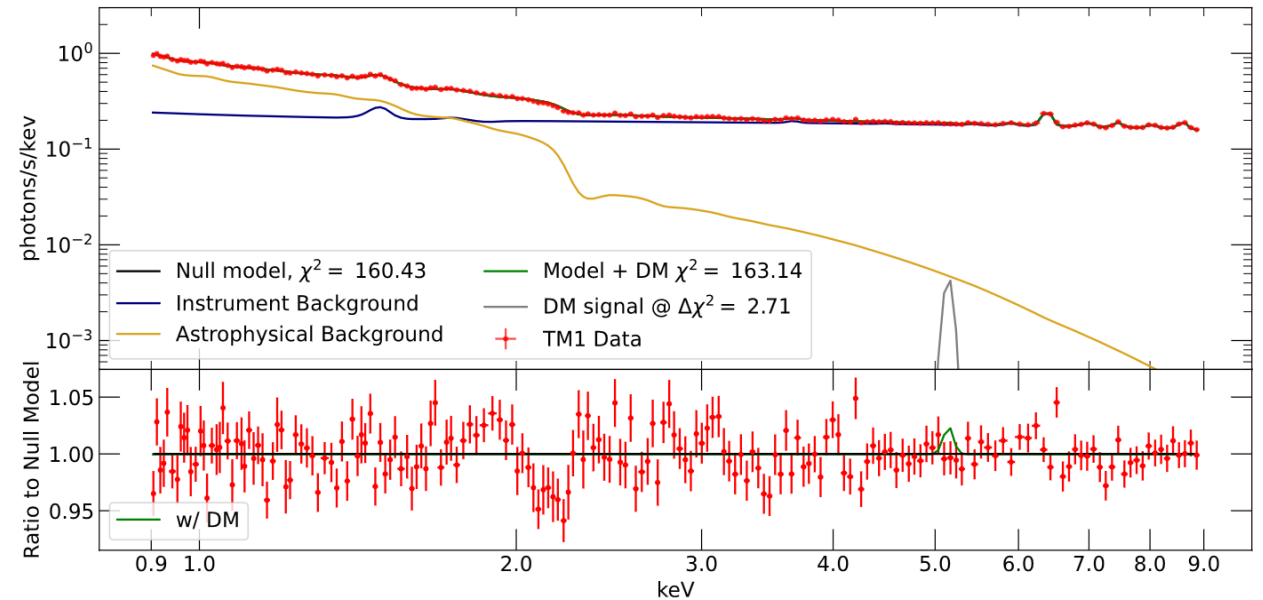
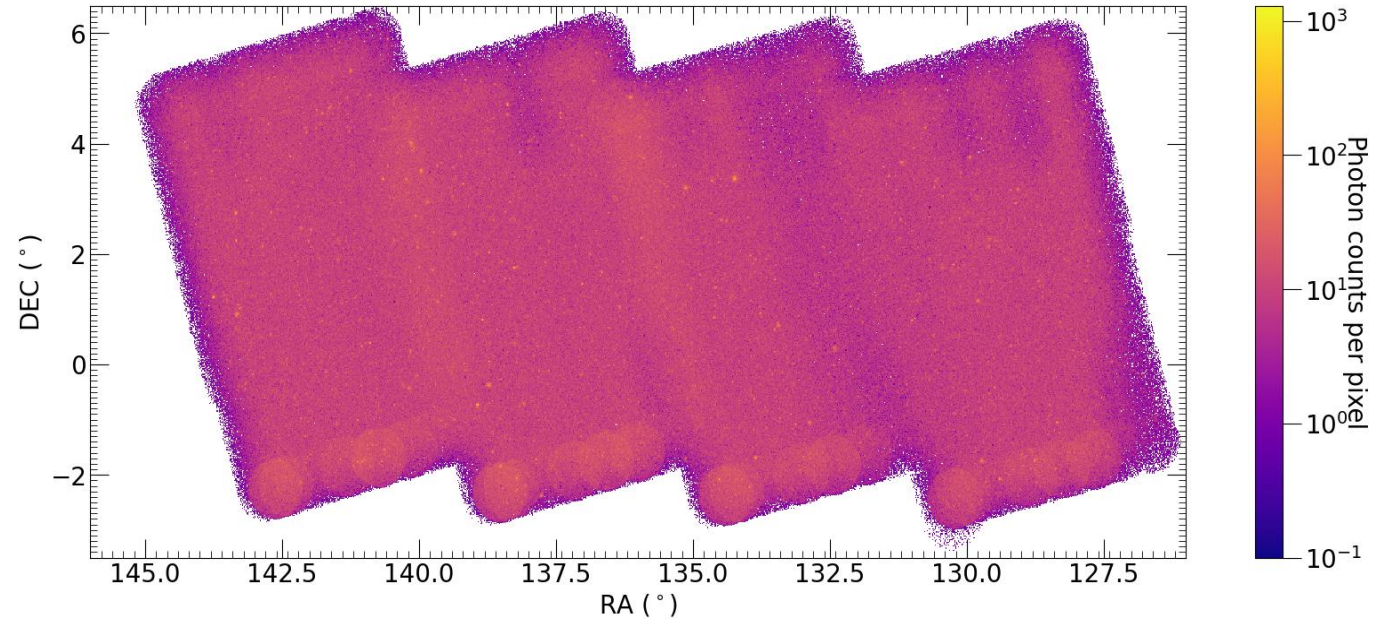
- On board Spectr-Roentegn-Gamma (SRG) mission
- Joint German-Russian operation launched in 2019
  - On hold since 2022
- Excellent angular and energy resolution
- Deepest all-sky X-ray survey after 4-year mission



P. Predehl et al., 2021

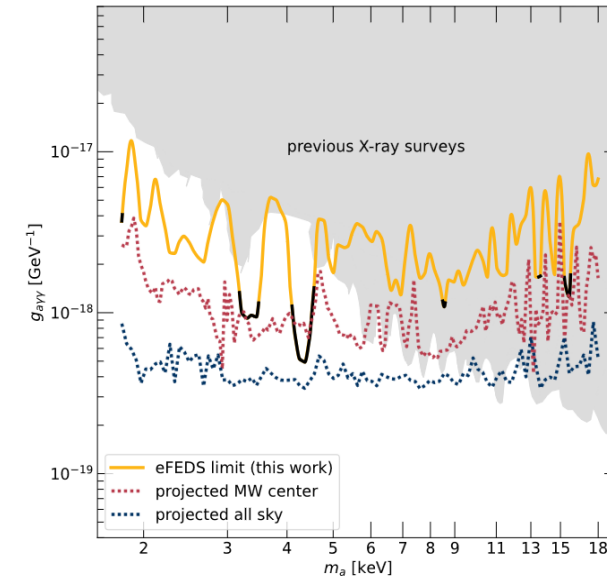
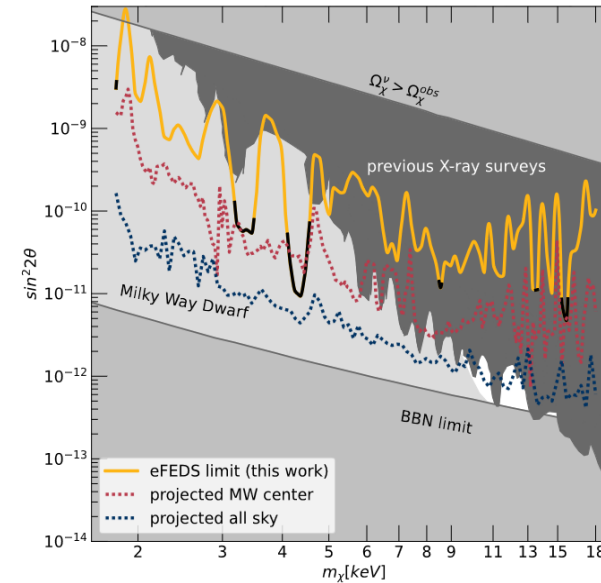
# eFEDS Data

- Part of eROSITA Early Data Release in 2021
- 360 ks, 140 deg<sup>2</sup> observation
  - Same exposure depth as eFEDS
- Background fit with xspec:
  - Instrument
    - Power law + gaussian lines
  - Astrophysical
    - Absorbed apec + power law



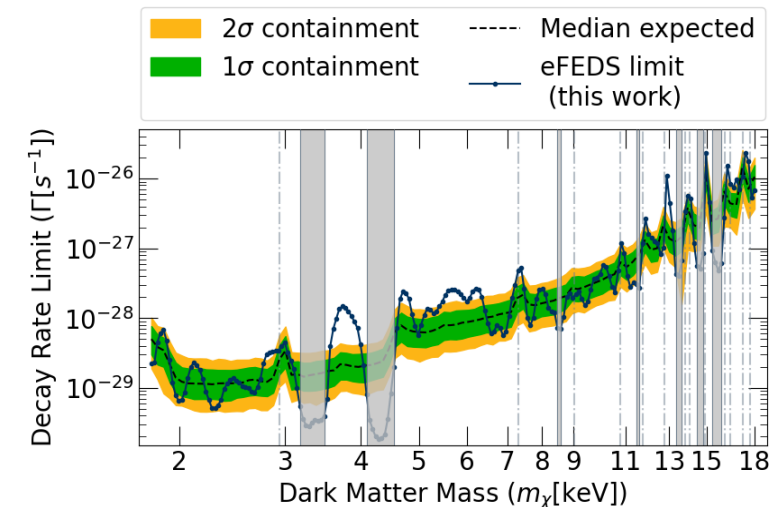
# eFEDS DM Particle Constraints

- Major improvement to existing limits in lower energy range
- We project eROSITA all-sky can (nearly) close out  $\nu$ MSM



C. Fong, K. C. Y. Ng, Q. Liu, 2025 (Phys. Rev. D)  
arxiv: 2401.16747

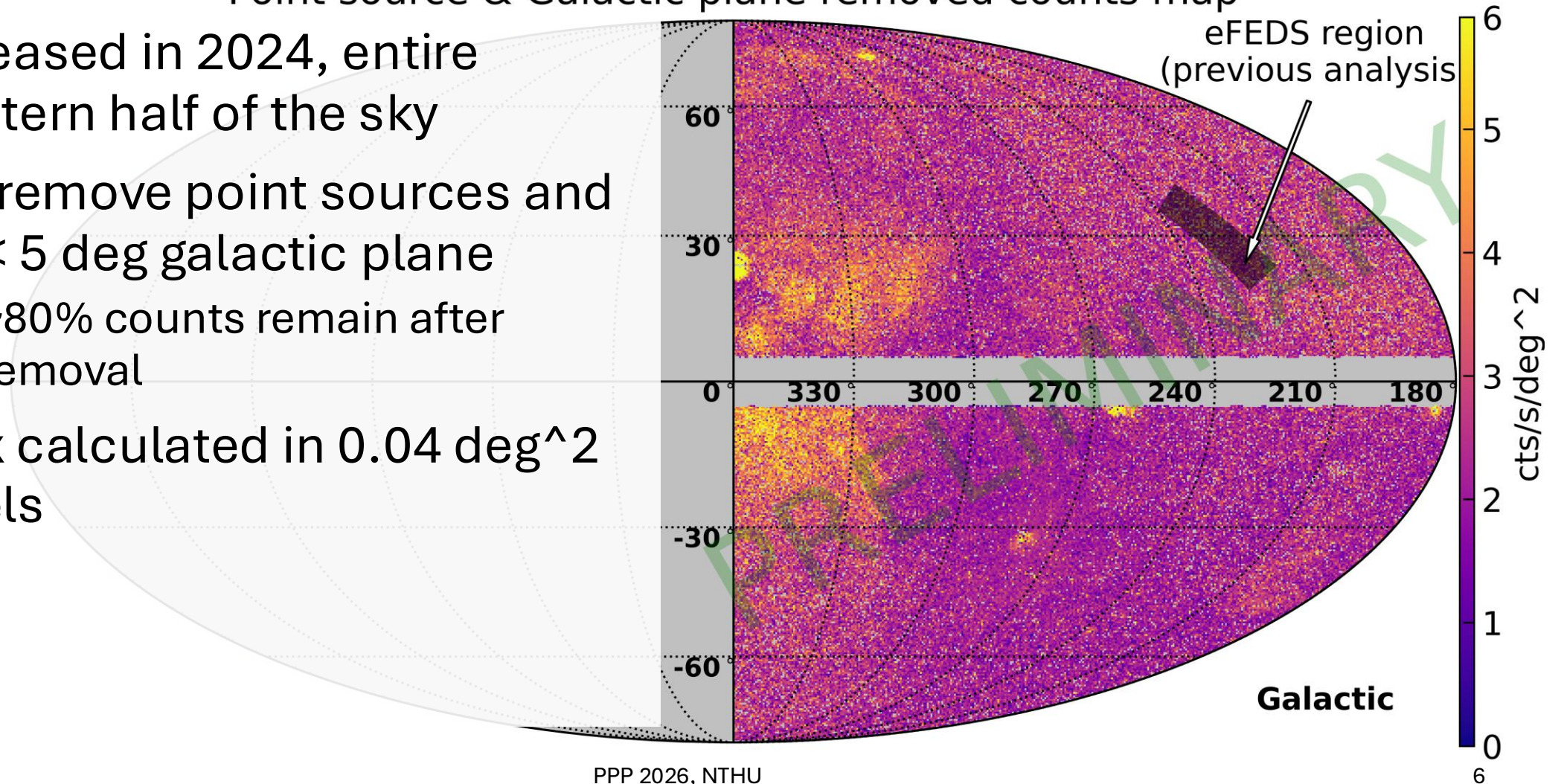
*Takeaway: even only with early data, eROSITA is already probing into uncharted territories!*



# eROSITA Data Release 1 (DR1)

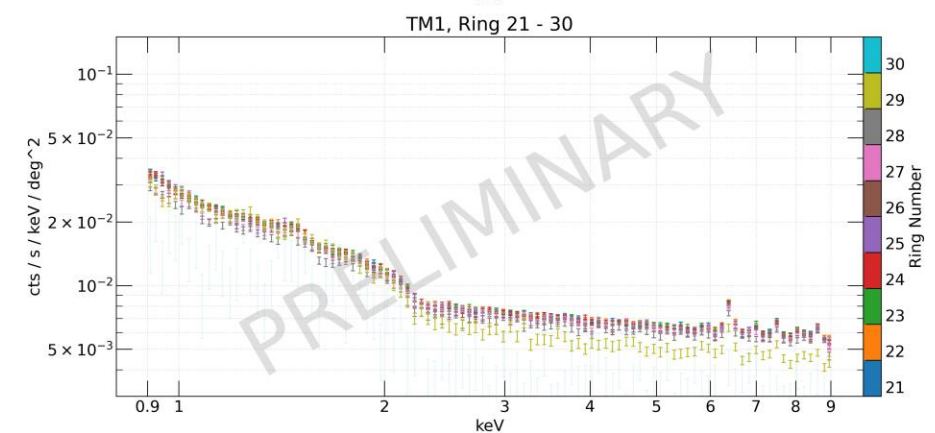
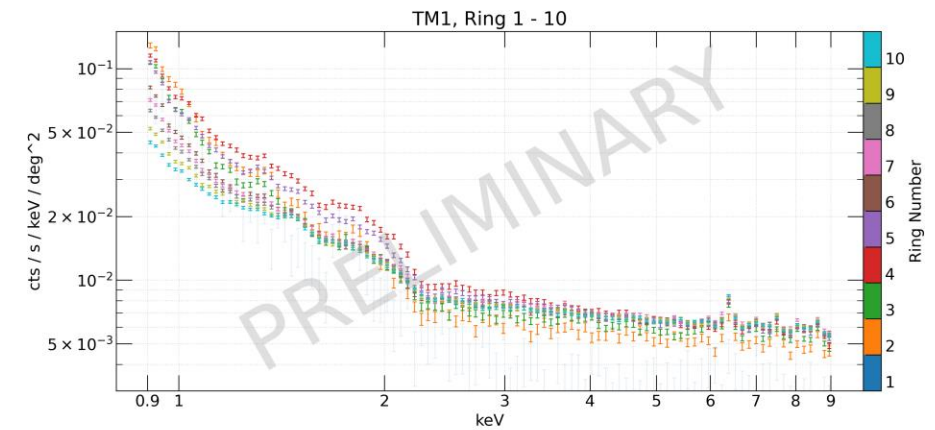
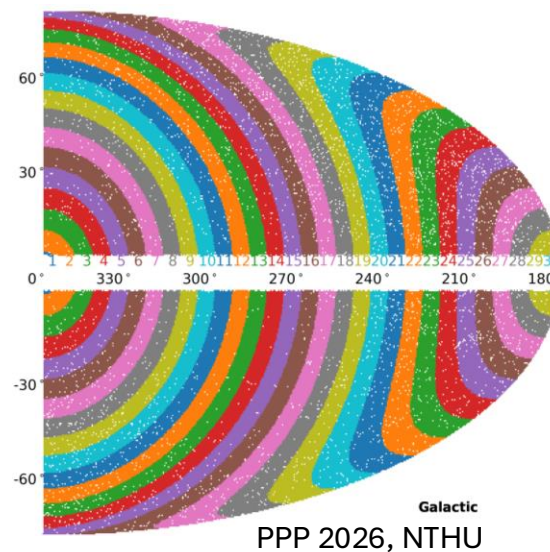
Point source & Galactic plane removed counts map

- Released in 2024, entire western half of the sky
- We remove point sources and  $|b| < 5$  deg galactic plane
  - ~80% counts remain after removal
- Flux calculated in  $0.04 \text{ deg}^2$  pixels



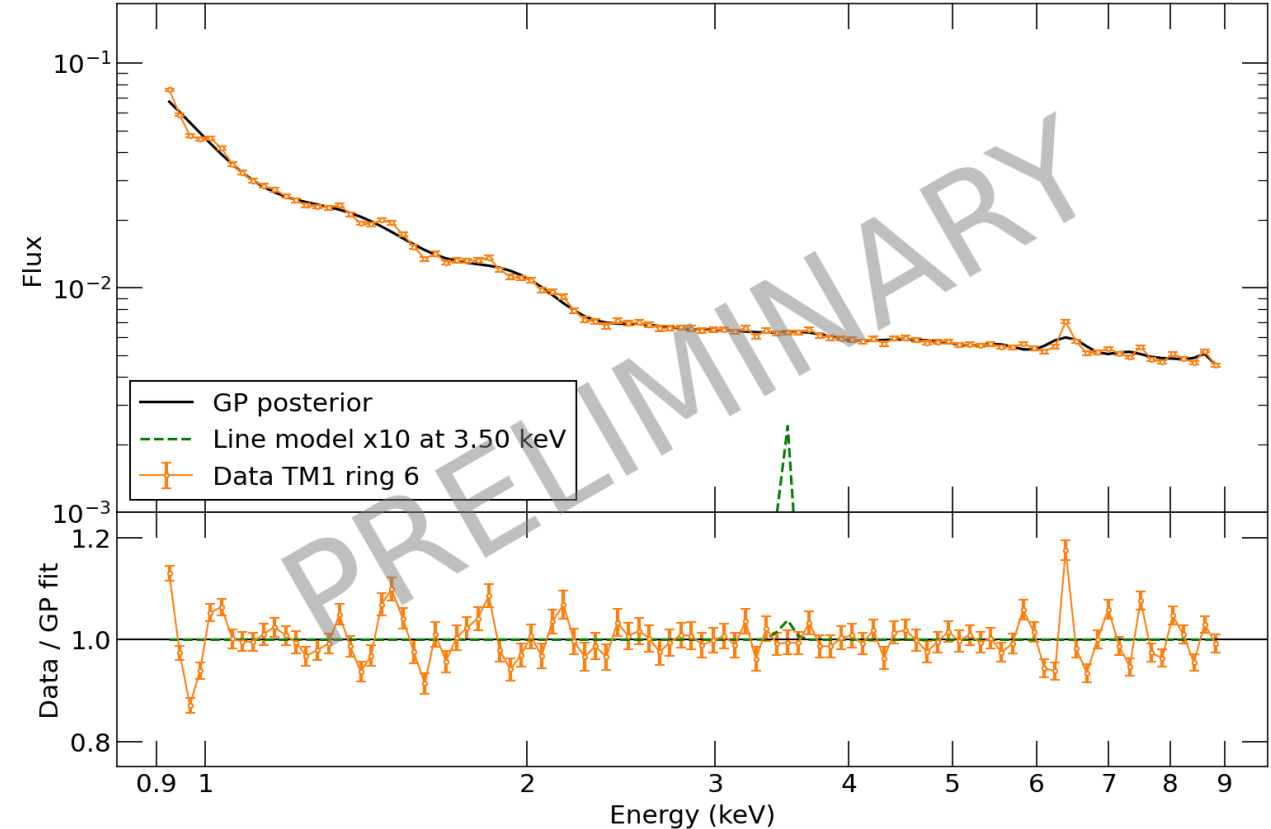
# Spectra of Rings

- We divide the sky into 30 concentric (half)annuli spectra
- Constant DM column density in each ring
- DM origin feature must be line-like and consistent with MW DM halo morphology D-factor



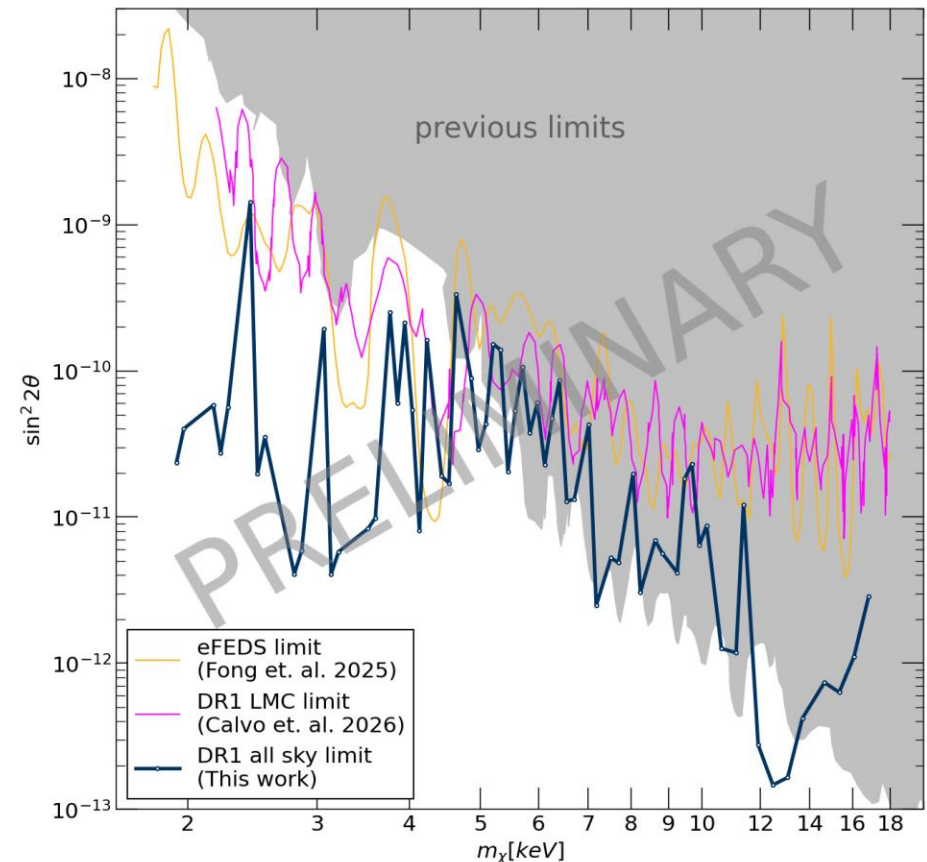
# Gaussian Process Fitting

- Due to the large volume of data, we use Gaussian Processes, non-stationary Gibbs Kernel to model the smooth astrophysical background.
  - Correlation length sets to a few times energy resolution to avoid line mismodel.



# Preliminary Line Search Results

- Our program recovers locations with known line in the data.
- In other places, we set limits on DM
  - Surpasses our previous results using eROSITA, including our early data and DR1 results using LMC (Calvo et. Al, 2603.19109)



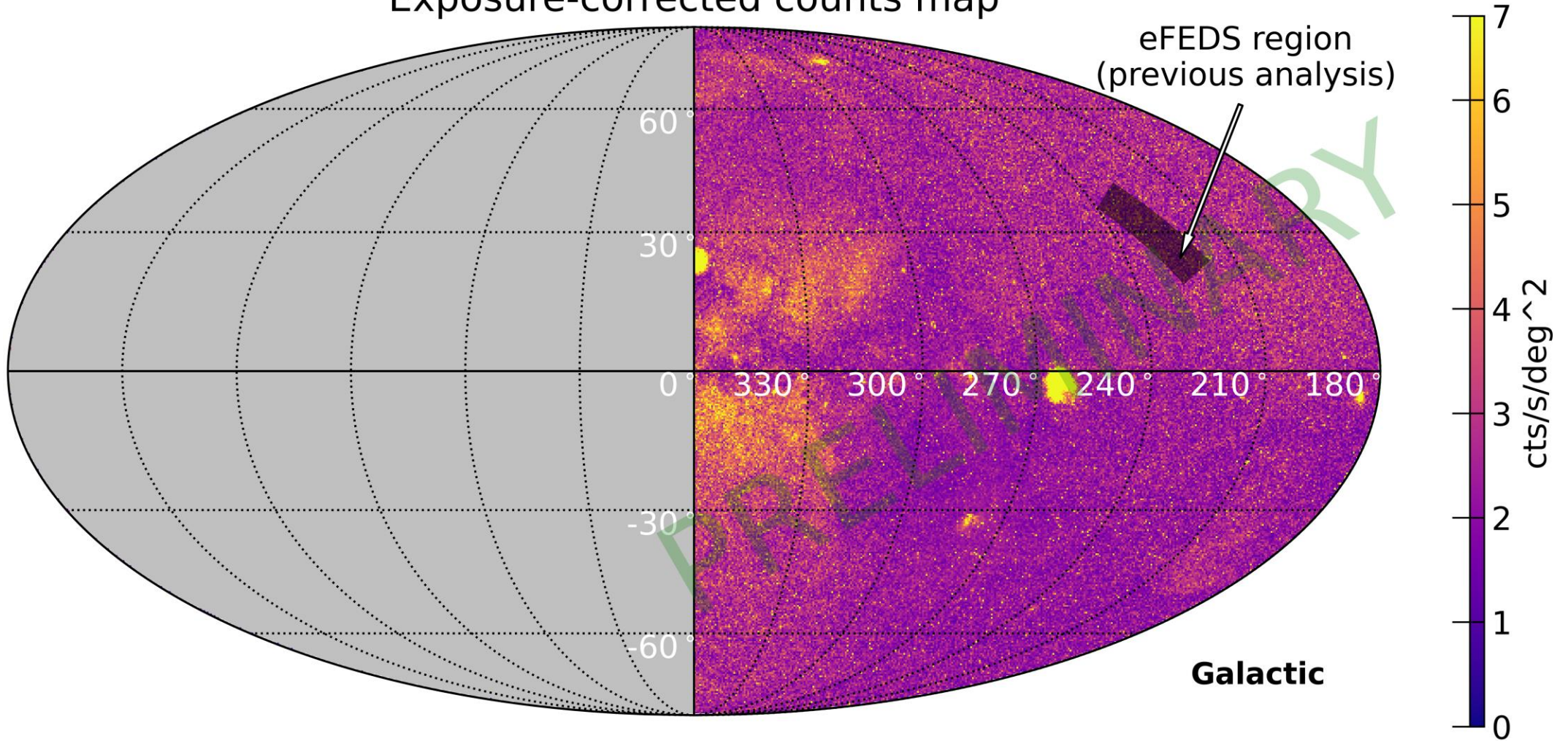
# Conclusion & Prospects

- In this work, we use all available half sky data from eROSITA first data release to **set new limit on DM decay rate**, with Gaussian process providing the model of continuum background flux
- We plan to adopt our limit to other DM models, and improve our confidence with Monte Carlo confinement
- With two more eROSITA data releases planned and more DM rich targets available, there is great potential for future eROSITA DM studies

# Questions?

# Appendix: Sky map before source removal

Exposure-corrected counts map



# Appendix: GP Process Gibbs kernel, line search

- Correlation length scale is proportional to eROSITA energy resolution

$$K(E_i, E_j) = A \cdot \sqrt{\frac{2l(E_i)l(E_j)}{l(E_i)^2 + l(E_j)^2}} \cdot \exp\left(-\frac{(E_i - E_j)^2}{l(E_i)^2 + l(E_j)^2}\right)$$

- Minimize negative log likelihood

$$\log L = -\frac{1}{2}y^T C^{-1}y - \frac{1}{2} \log \det C - \frac{n}{2} \log(2\pi)$$

- With TS of line discovery and constraint

$$TS_{\text{line}} = 2(-\log L_{\text{line}} - \min(-\log L_{\text{null}}))$$