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INTEGRAL X-RAY CONSTRAINTS ON SUB-GEV DARK MATTER

Elena Pinetti

Cortona Young, 9th June 2021

INTEGRAL X-ray constraints on sub-GeV Dark Matter

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Bradley J. Kavanagh ^c, Elena Pinetti ^{a,b}

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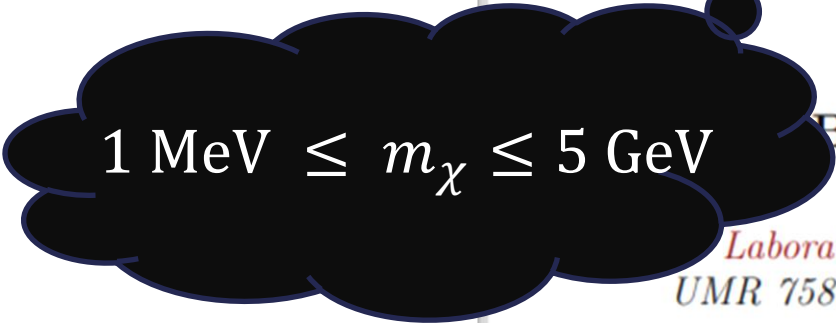
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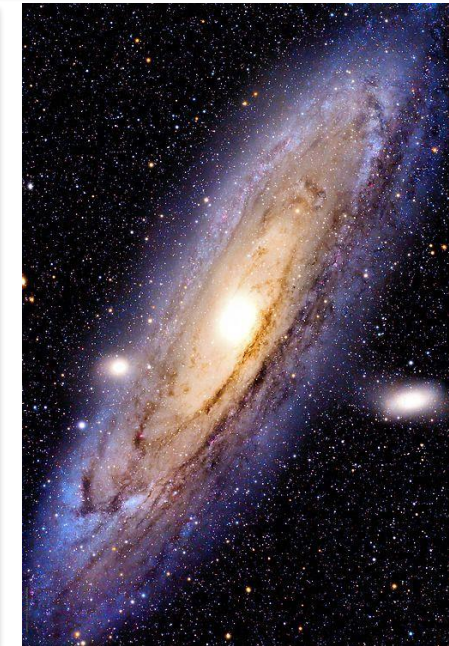
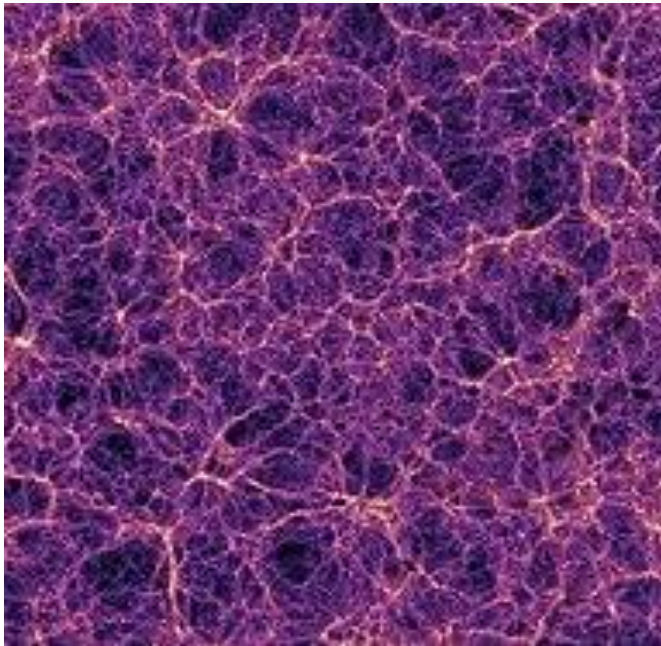
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$$1 \text{ MeV} \leq m_\chi \leq 5 \text{ GeV}$$

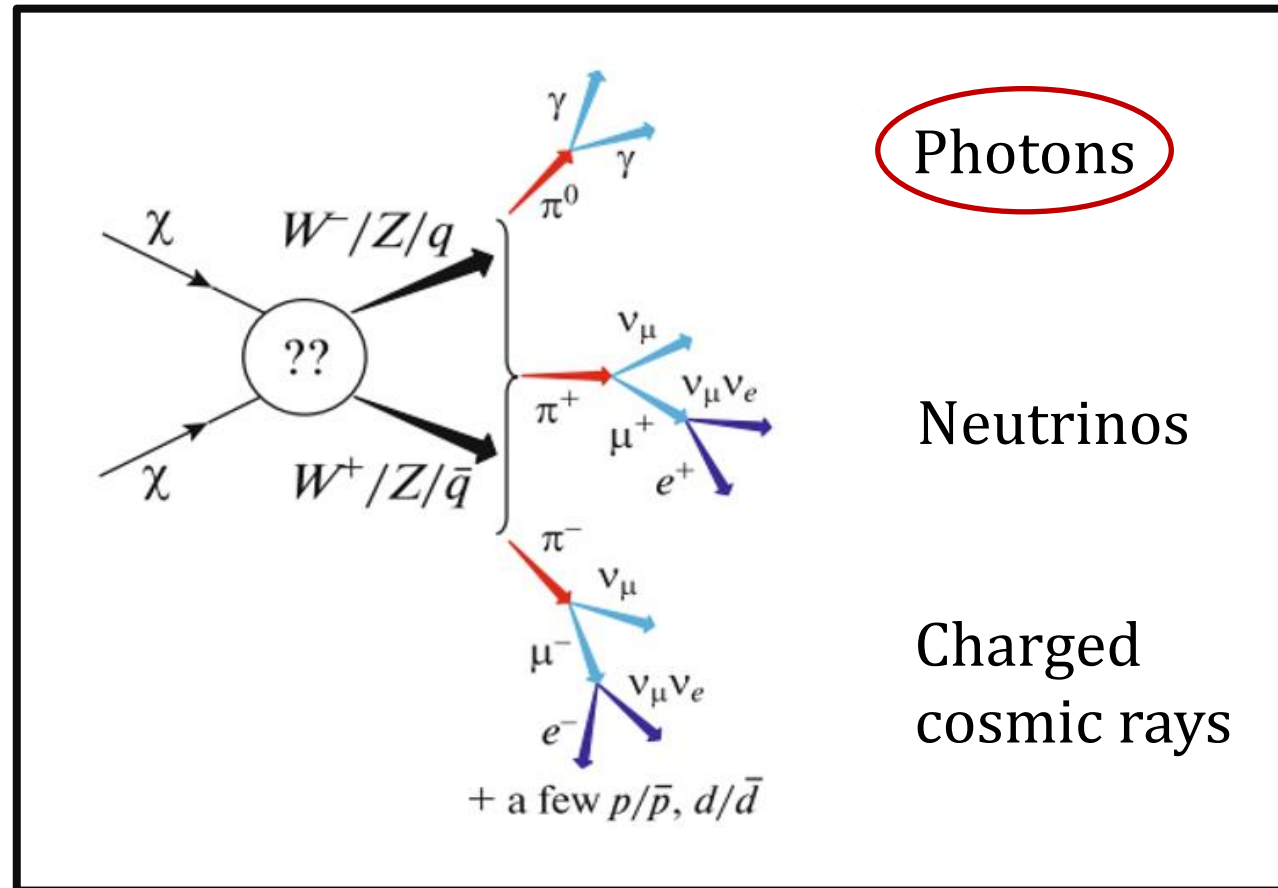
Dark Matter in the Universe

- Milky Way
- Satellite galaxies
- Clusters of galaxies
- Cosmic web



Multimessenger search

Messengers produced by annihilation or decay of DM particles:



MeV gap

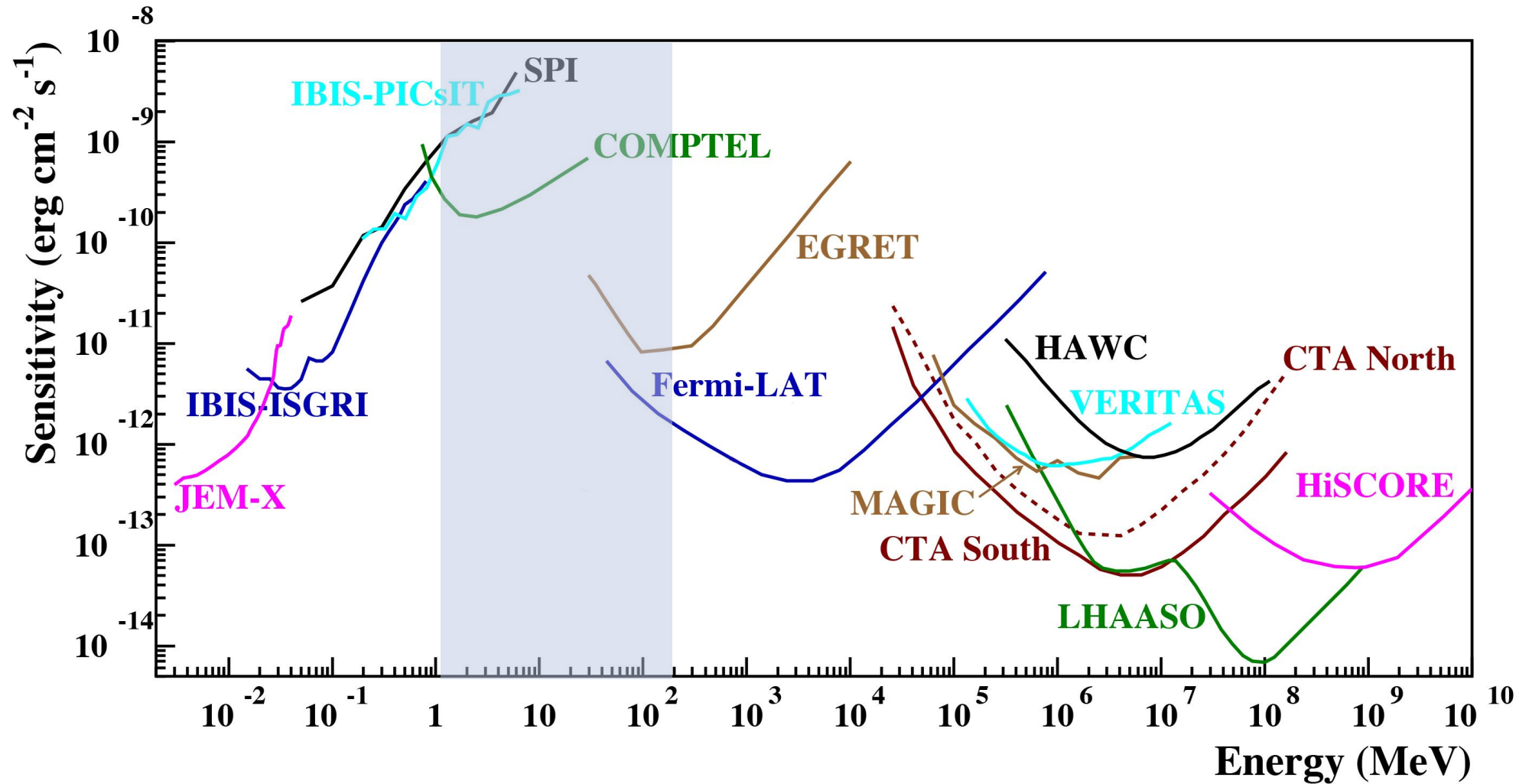


Figure adapted
from Tatischeff+
arxiv:1805.06435

Photon searches

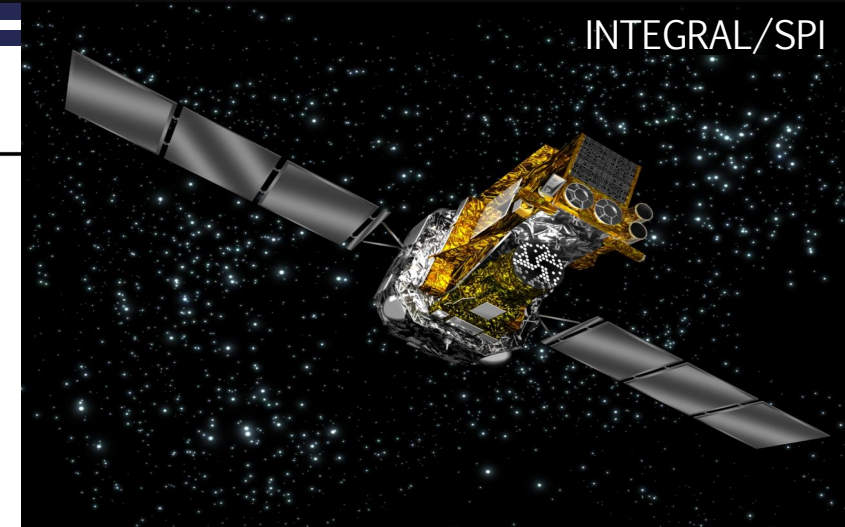
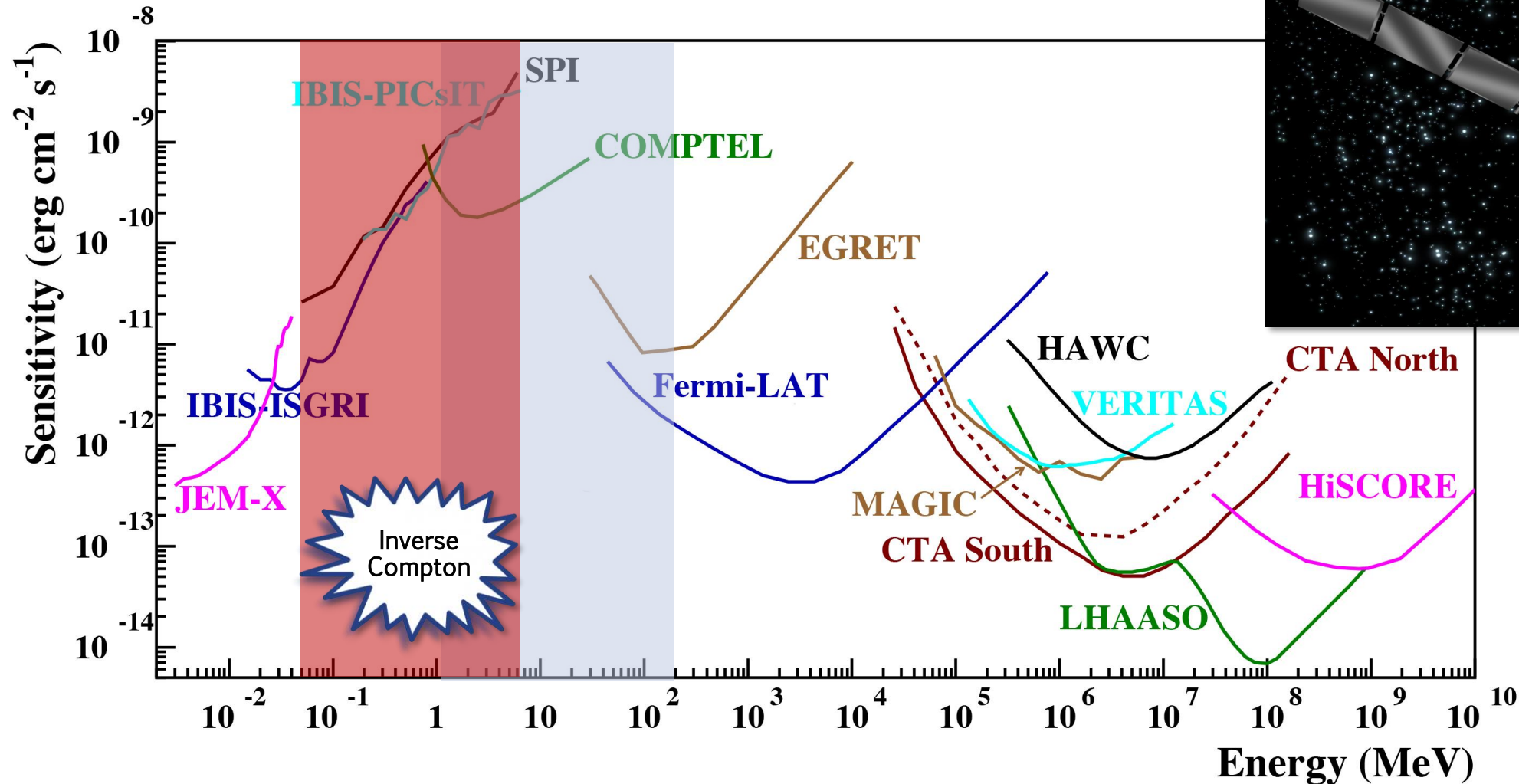


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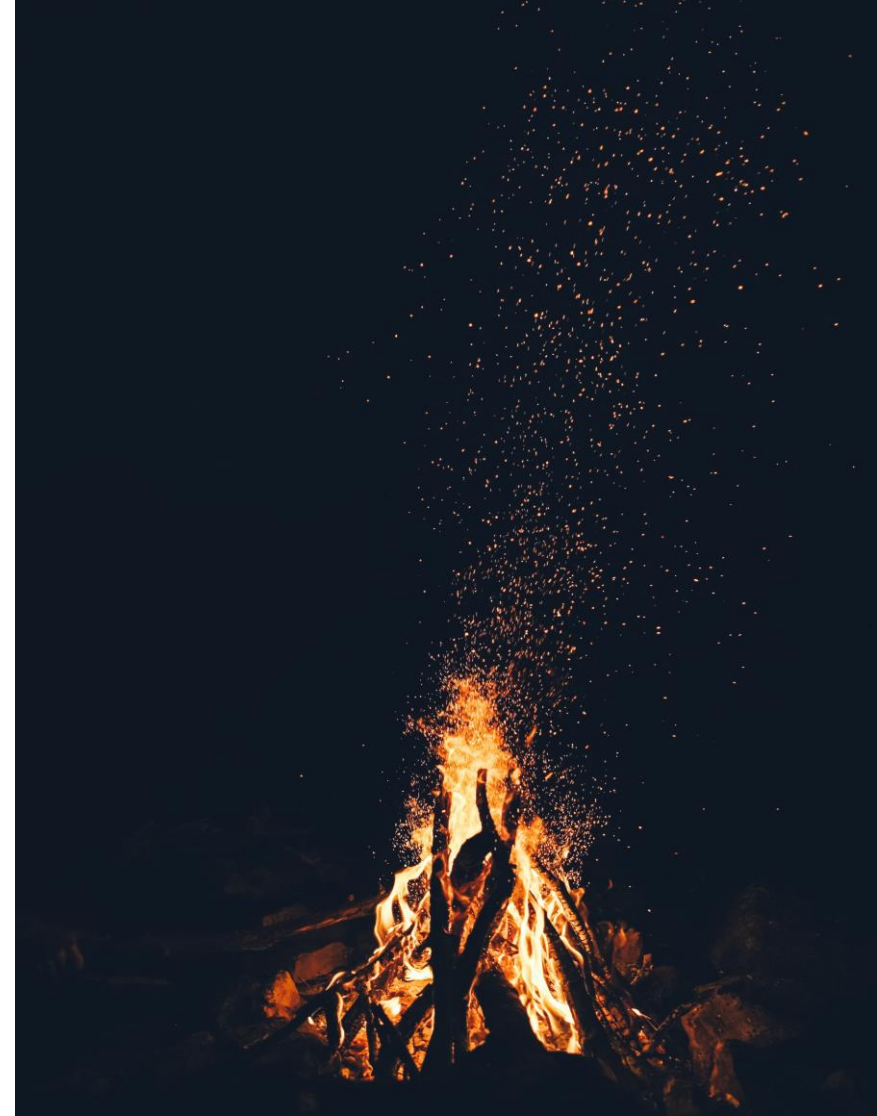
Annihilation channels

3 annihilation channels: $\chi\chi \rightarrow e^+e^-$

$$\chi\chi \rightarrow \mu^+\mu^-$$

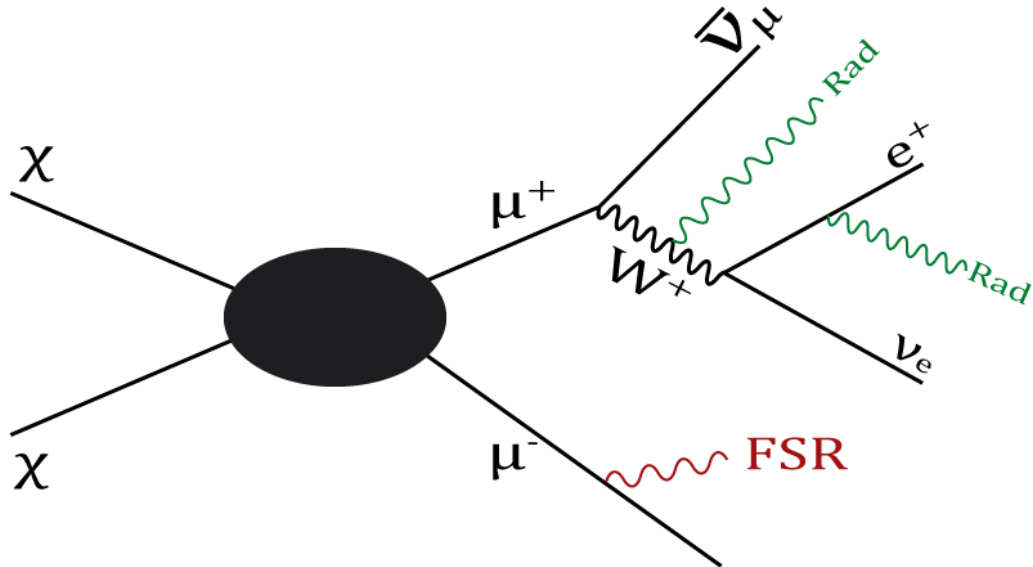
$$\chi\chi \rightarrow \pi^+\pi^-$$

Kinematically open: $m_\chi > m_i \quad i = e, \mu, \pi$



Total Flux

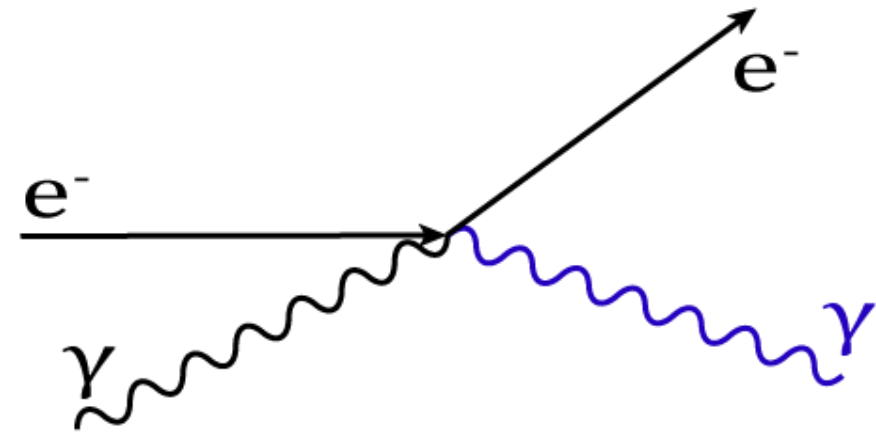
$$\phi_{TOT} = \phi_{FSR} + \phi_{Rad} + \phi_{ICS}$$



$$\chi\chi \rightarrow \mu^+\mu^-\gamma \quad \text{FSR}$$

$$\chi\chi \rightarrow \mu^+\mu^- \quad \text{Rad}$$

$$\rightarrow e^+\nu_e\bar{\nu}_\mu\gamma$$



Inverse Compton Scattering

$$\chi\chi \rightarrow (\dots) \rightarrow e^+ e^-$$

$$e^- + \gamma \rightarrow e^- + \gamma$$

Final State Radiation and Radiative Decay

$$\frac{d\phi_{FSR}}{dE_\gamma d\Omega}(E_\gamma, \theta) = \frac{1}{4\pi} \frac{\langle \sigma_{ann} v \rangle}{2m_{DM}^2} \frac{dN_{FSR}}{dE_\gamma} J(\theta)$$

Particle properties

Energy spectrum

J-factor

Radiative Decay:

$$\left. \begin{array}{l} \mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu \gamma \\ \pi^- \rightarrow l \bar{\nu}_l \gamma \quad l = e, \mu \end{array} \right\} \frac{dN_{Rad}}{dE_\gamma}$$

$$J(\theta) = \int_{l.o.s} \rho^2(r(s, \theta)) ds$$

Line of sight

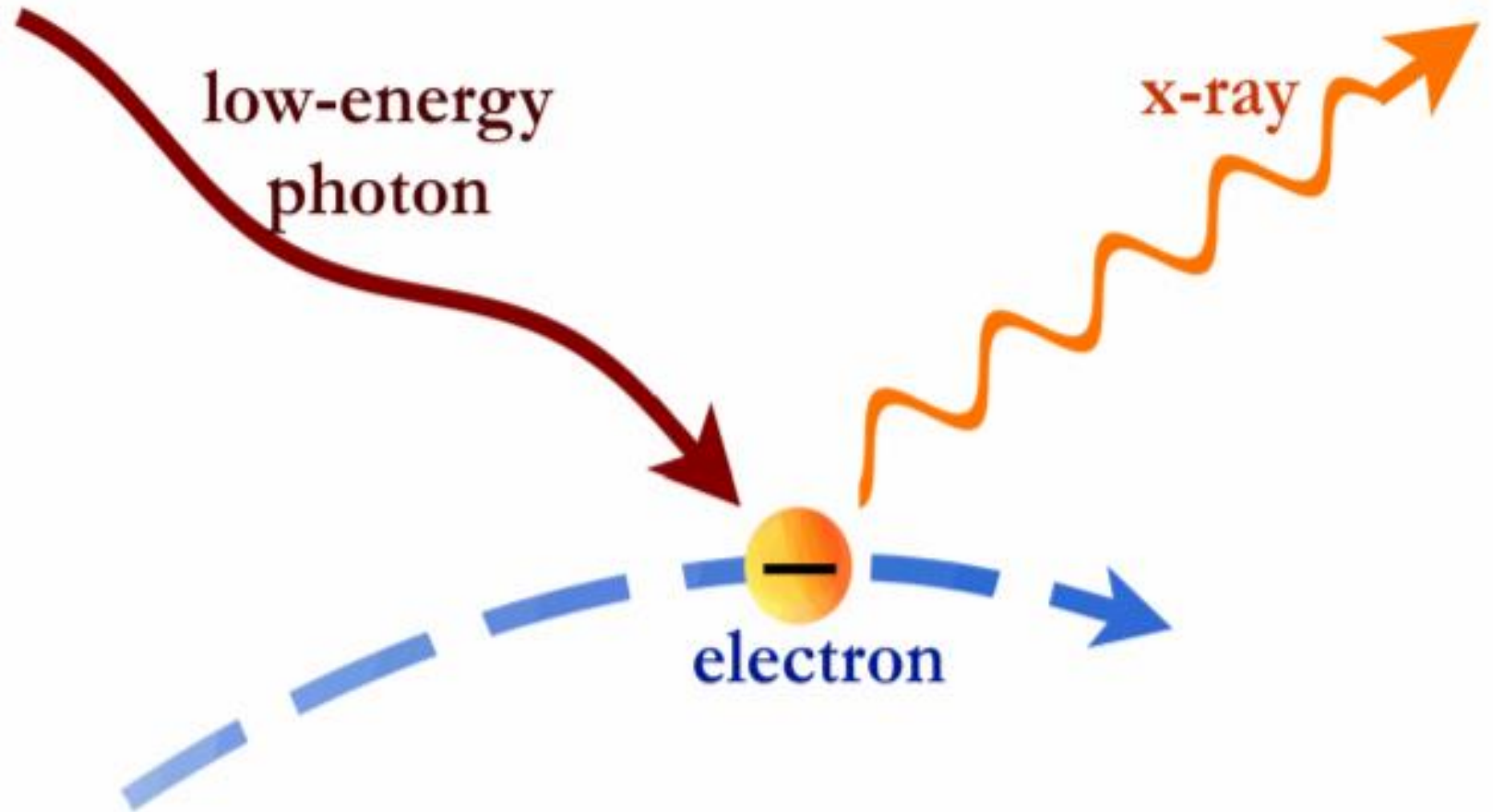
DM density

Inverse Compton Scattering

$$\chi\chi \rightarrow (\dots) \rightarrow e^+ e^-$$

3 kinds of photons:

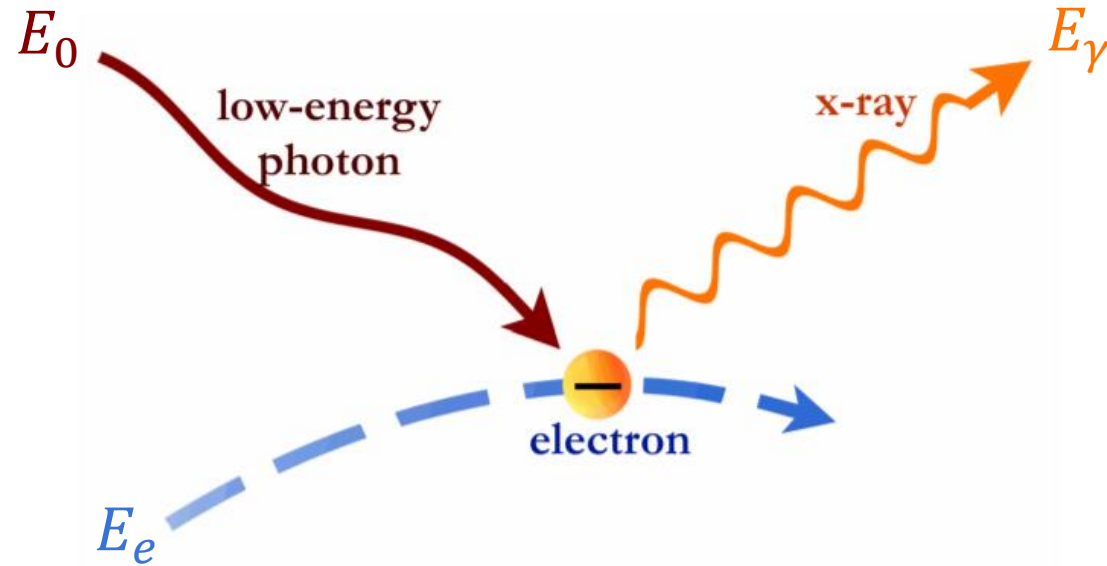
- CMB
- Infrared (dust)
- Optical (starlight)



X rays

$$\gamma = \frac{E_e}{m_e}$$

$$E_\gamma \approx 4\gamma^2 E_0$$



Type	E_0 [eV]	E_e [GeV]	E_γ [keV]
CMB	10^{-4}	5	40
IR	10^{-2}	0.5	40
Opt	10	0.05	400

X rays

Inverse Compton Scattering

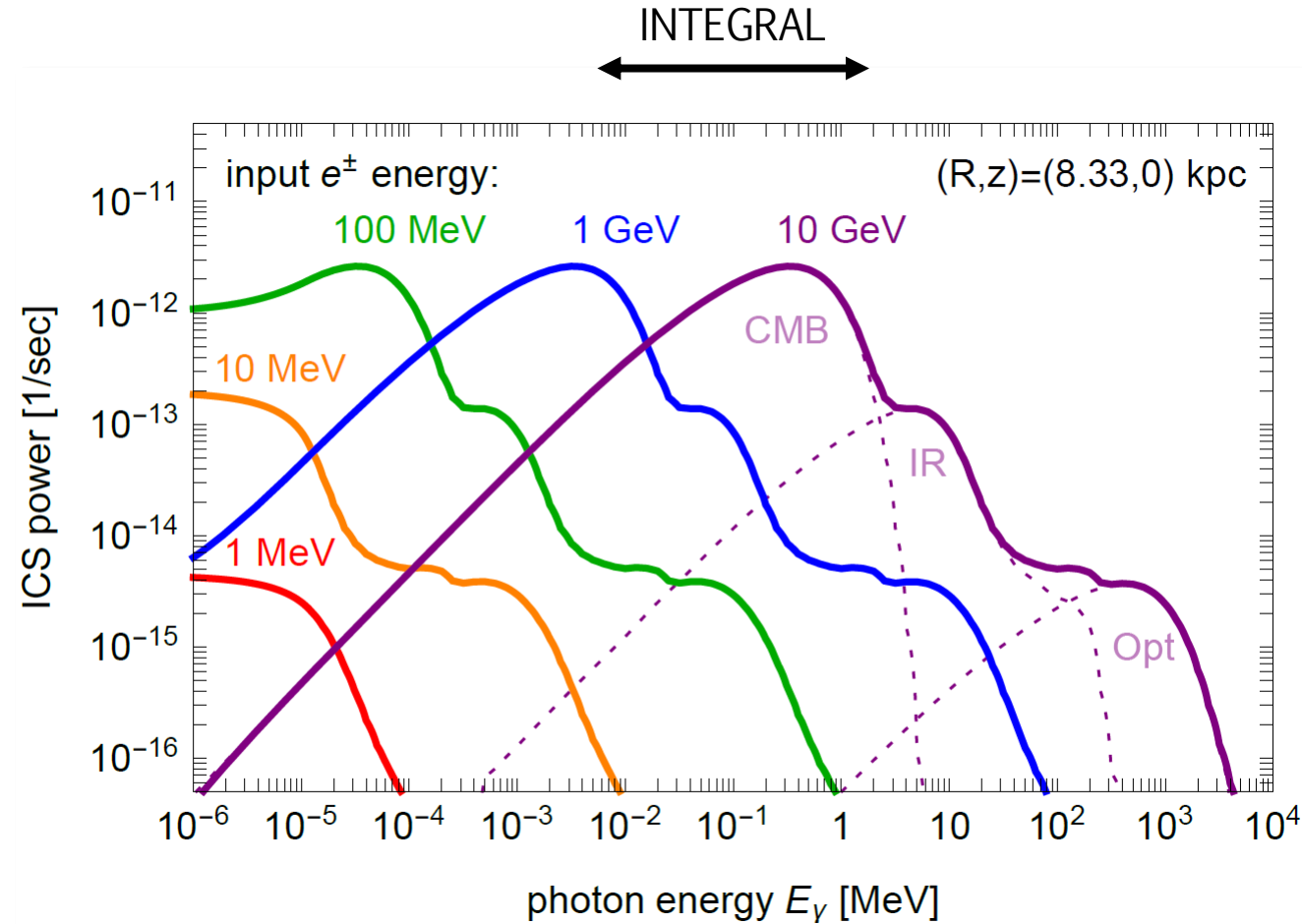
$$\frac{d\phi_{ICS}}{dE_\gamma d\Omega} = \frac{1}{4\pi E_\gamma} \int_{l.o.s.} ds \, j(E_\gamma, \vec{x})$$

$$j(E_\gamma, \vec{x}) = 2 \int_{m_e}^{m_\chi} dE_e \, P_{IC}(E_\gamma, E_e, \vec{x}) \frac{dn_e}{dE_e}(E_e, \vec{x})$$

$e^\pm$

Differential
Power

Number
density



Number density

$$\frac{dn_{e^\pm}}{dE_e}(E_e, \vec{x}) = \frac{1}{b_{tot}(E_e, \vec{x})} \int_{E_e}^{m_\chi} d\tilde{E}_e Q_e(\tilde{E}_e, \vec{x})$$

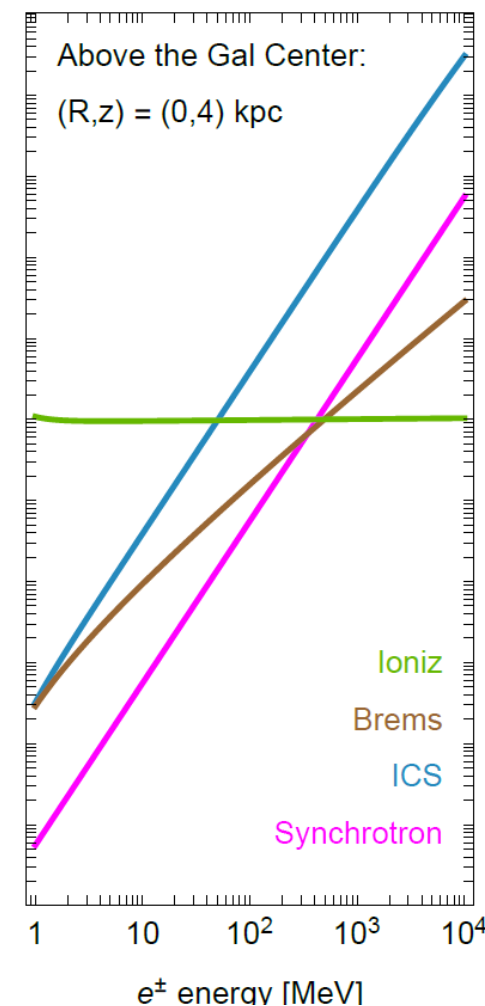
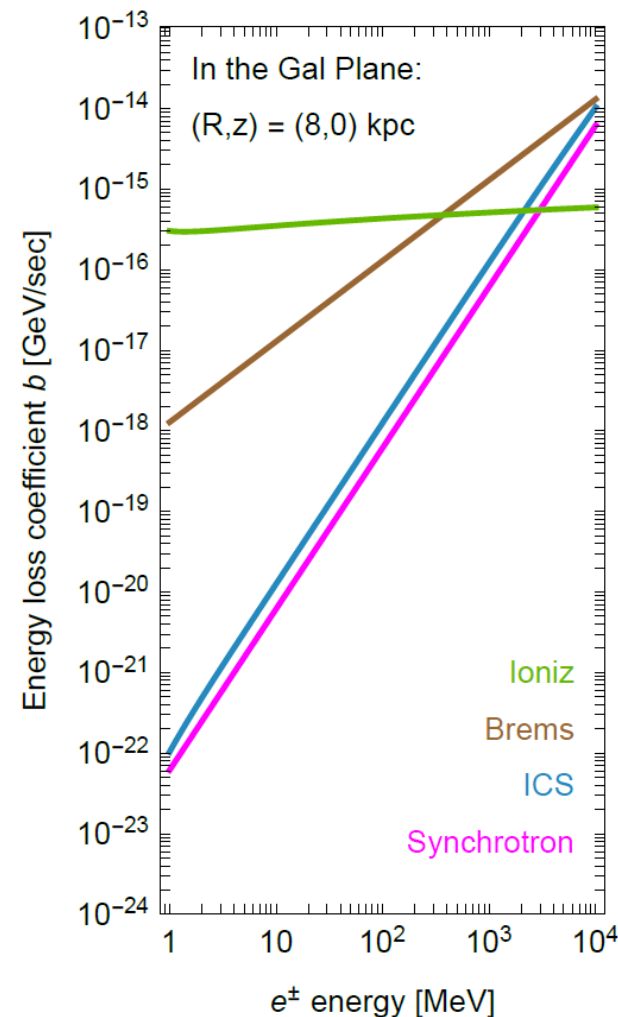
$$Q_e(\tilde{E}_e, \vec{x}) = \frac{\langle \sigma_{ann} v \rangle}{2 m_{DM}^2} \frac{dN_{e^\pm}}{d\tilde{E}_e} \rho_{DM}^2$$

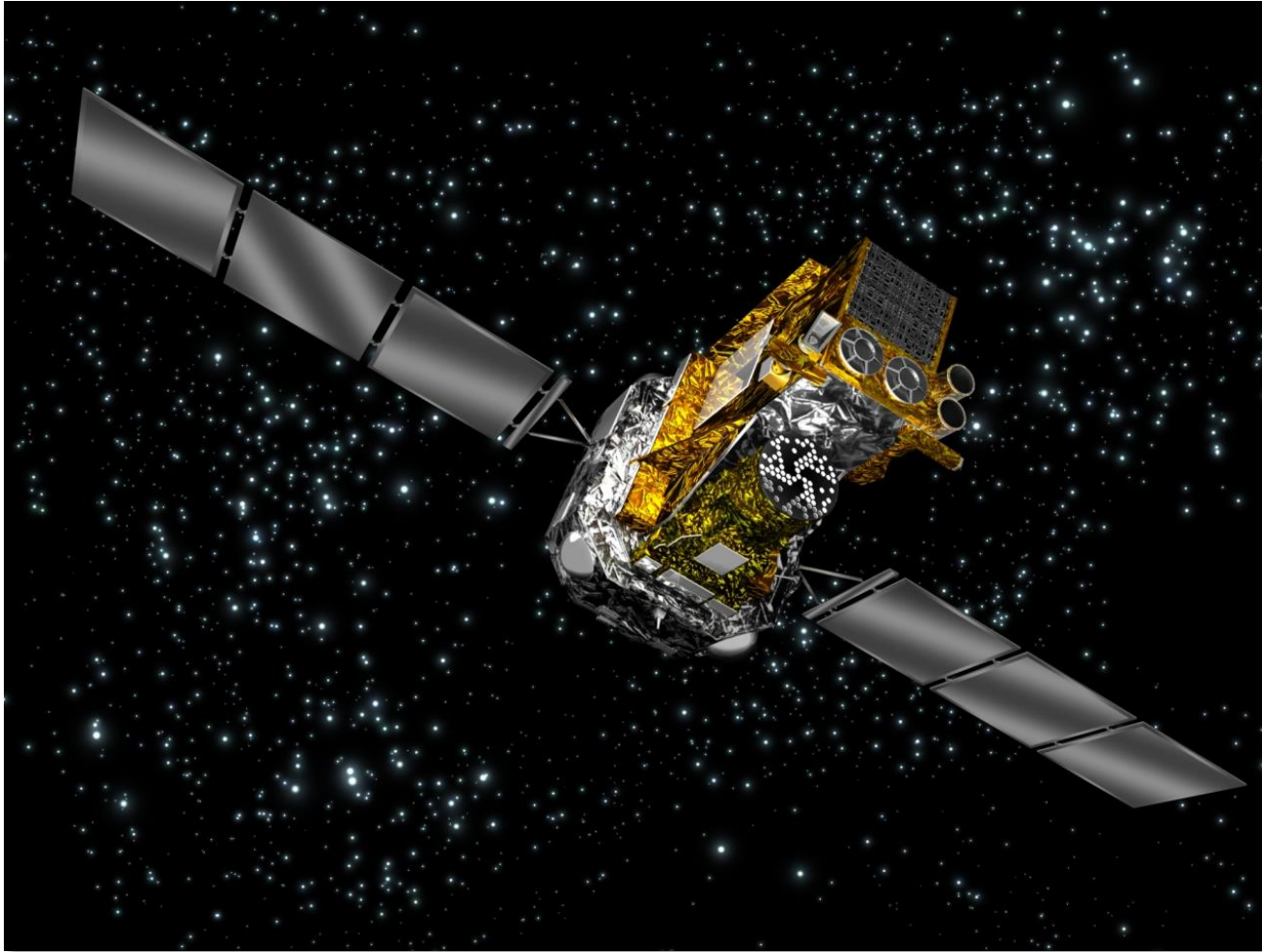
Particle
Properties

Energy
spectrum

Density
distribution

Energy losses $b_{tot}(E_e, \vec{x})$





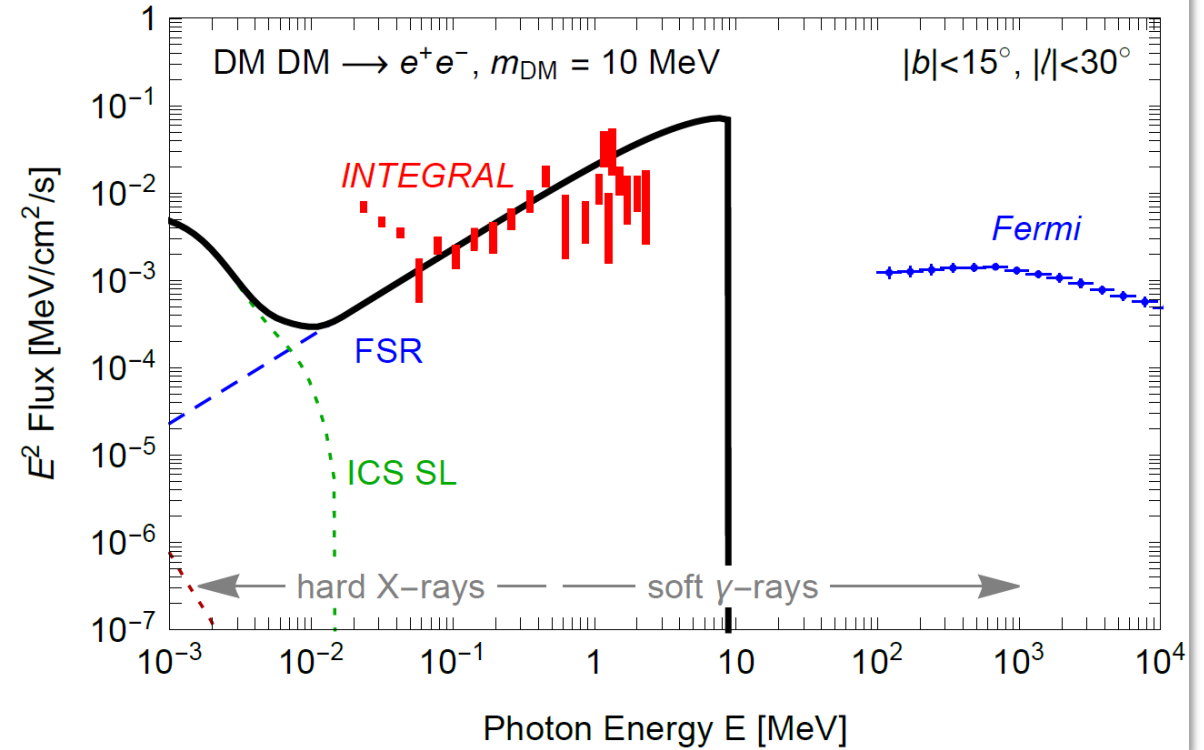
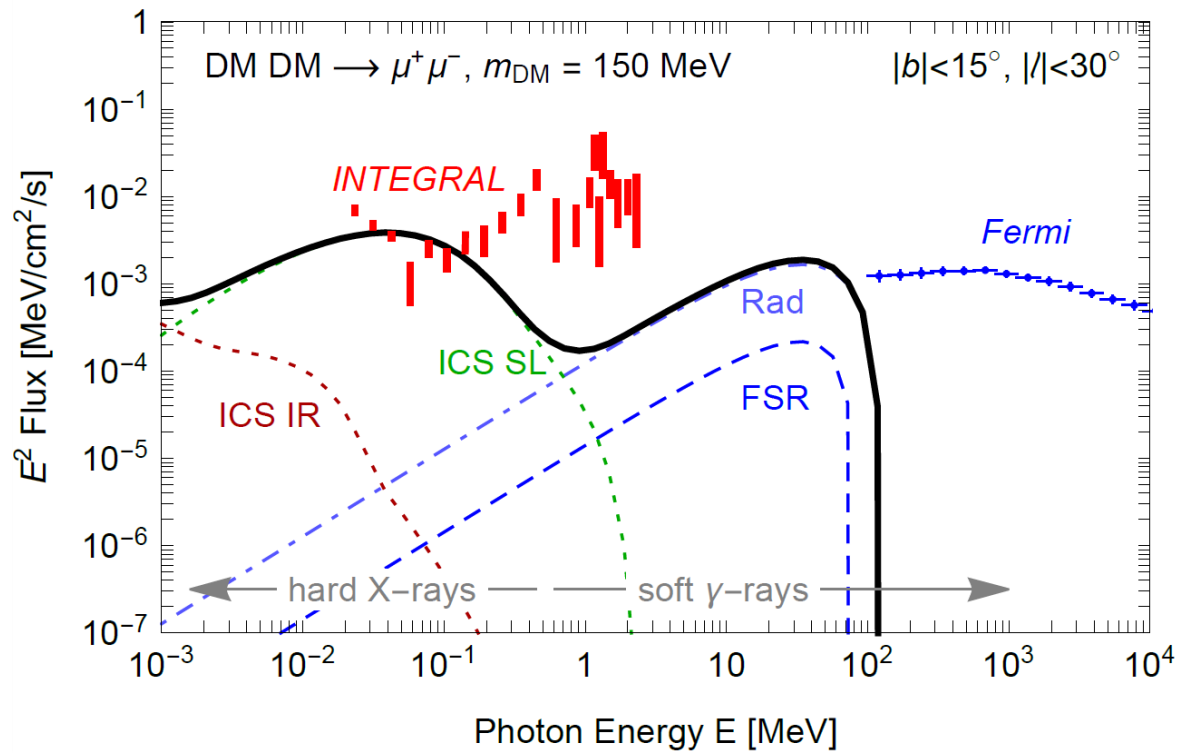
Operational time: 2003-2009

Energy range: 20 keV ~ 8 MeV

- Hard X rays
- Soft gamma rays

INTEGRAL:
INTErnational Gamma-Ray Astrophysics Laboratory

Photon Spectra



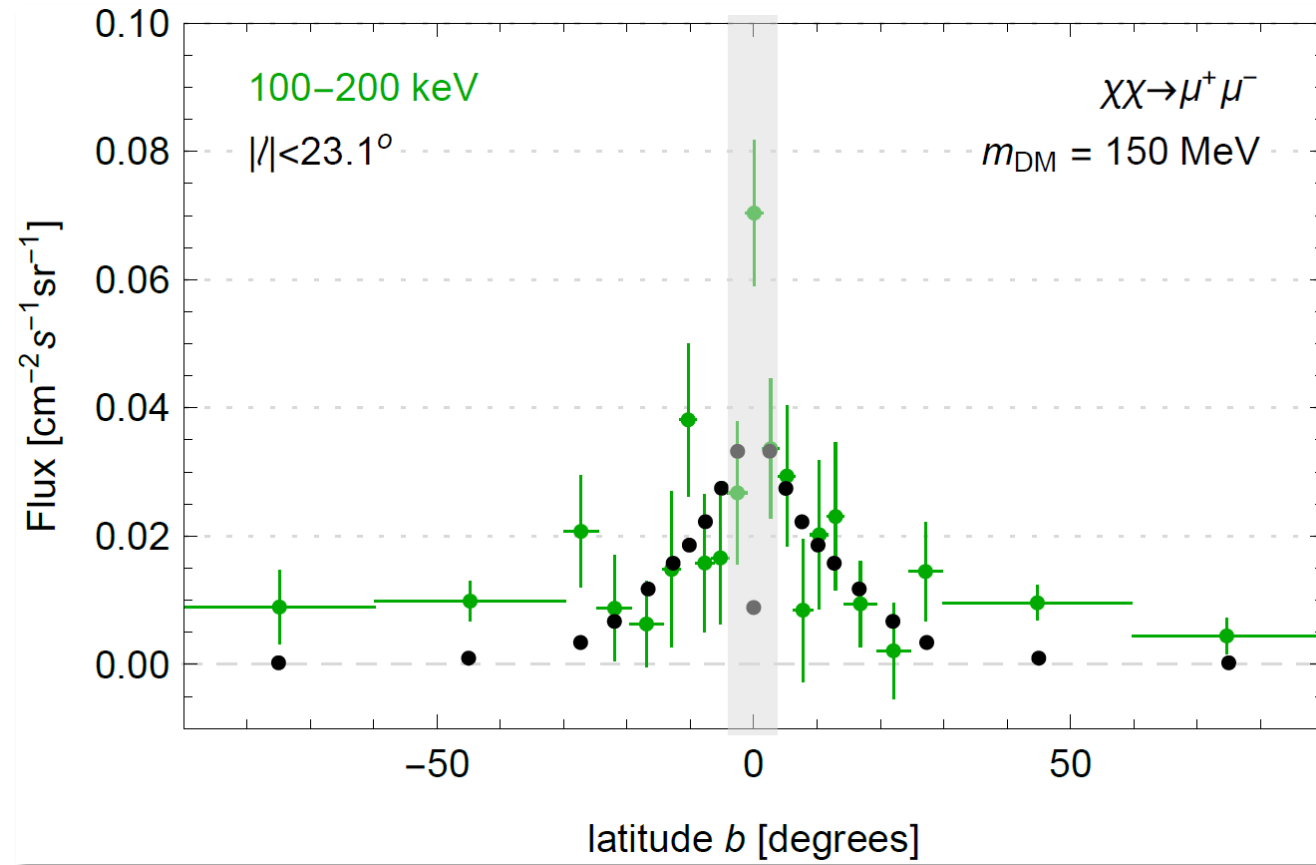
Angular profile

5 energy bands:

- 27-49 keV
- 49-490 keV
- 100-200 keV
- 200-600 keV
- 600-1800 keV

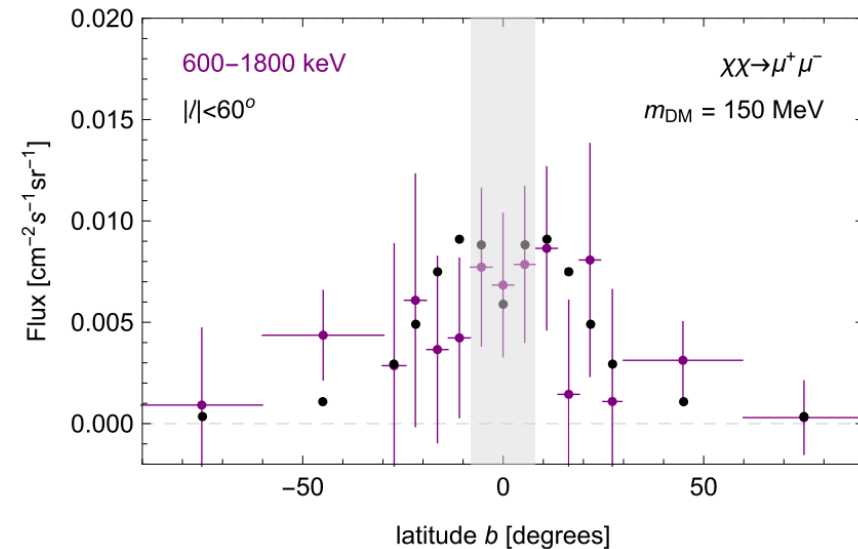
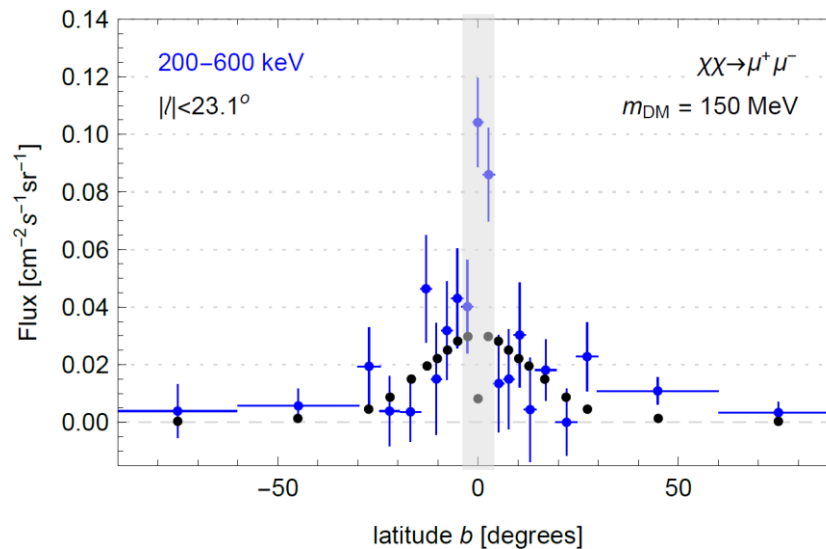
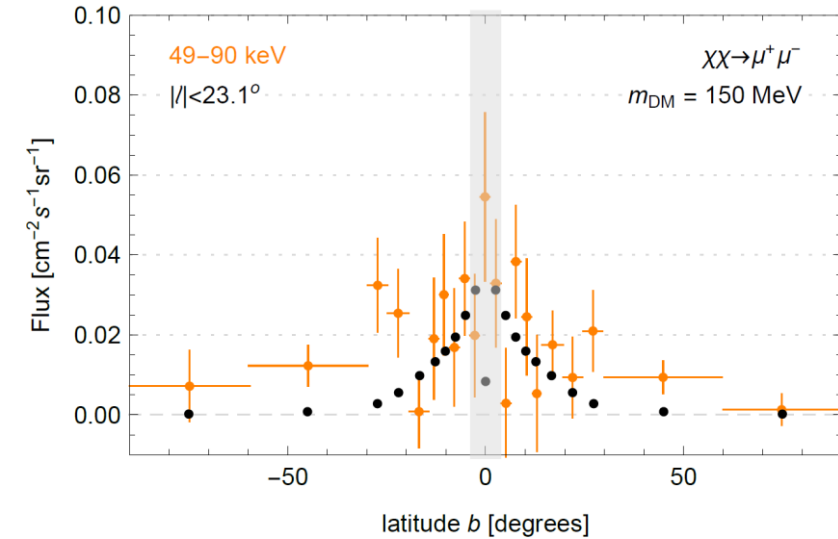
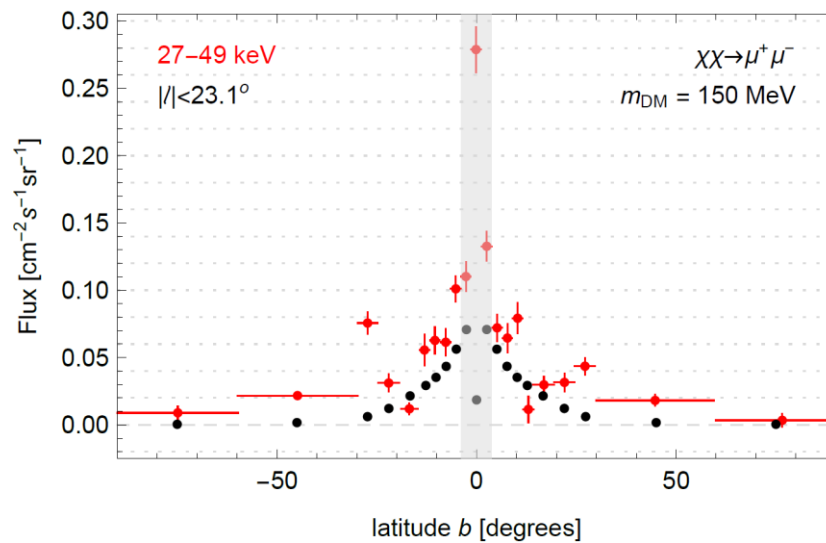
21 bins in latitude (15 for the fifth band)

$-23.1^\circ < l < 23.1^\circ$ ($|l| < 60^\circ$ for the fifth band)

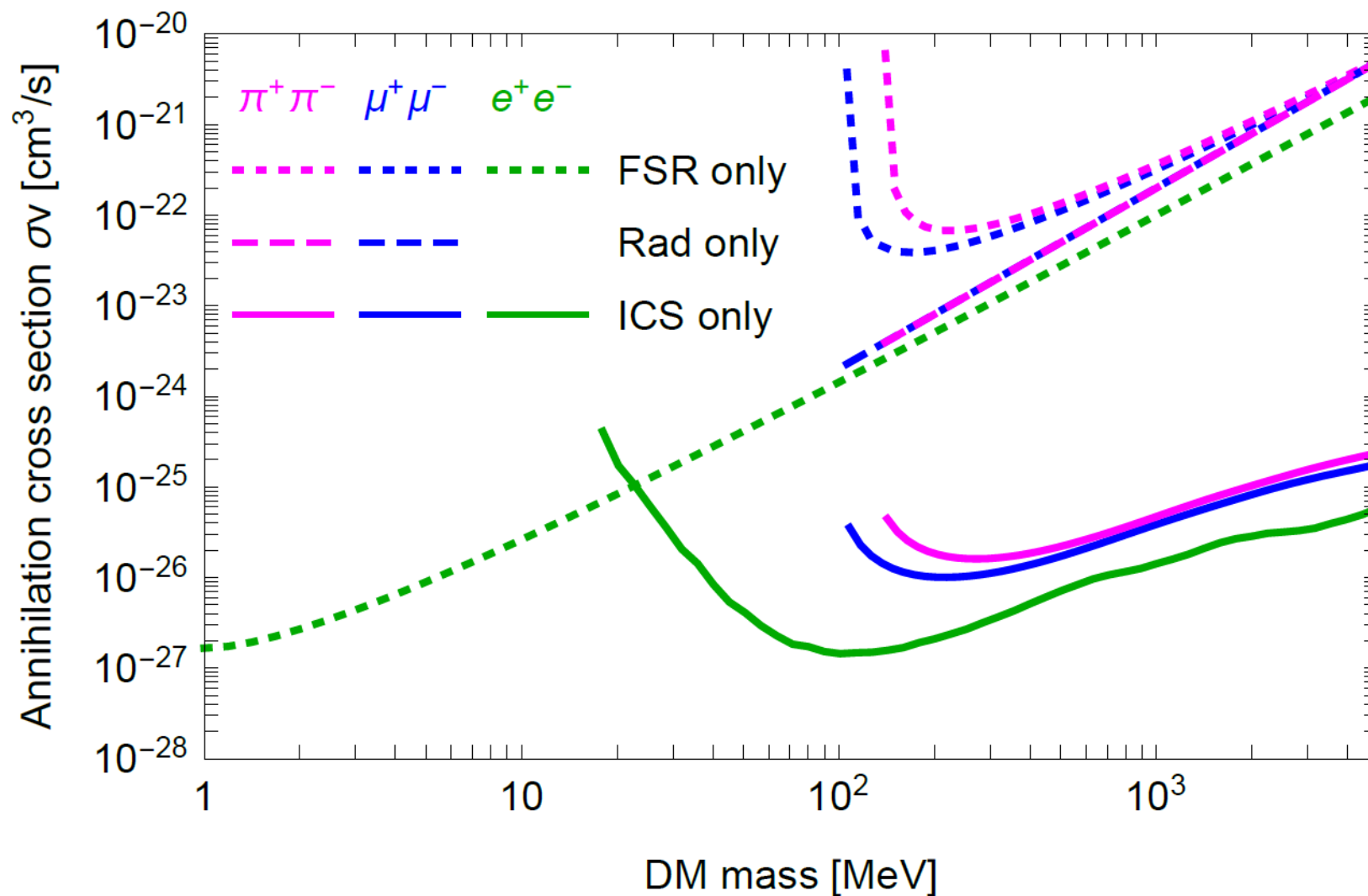


INTEGRAL data (green points)
Bouchet et al. (2011)

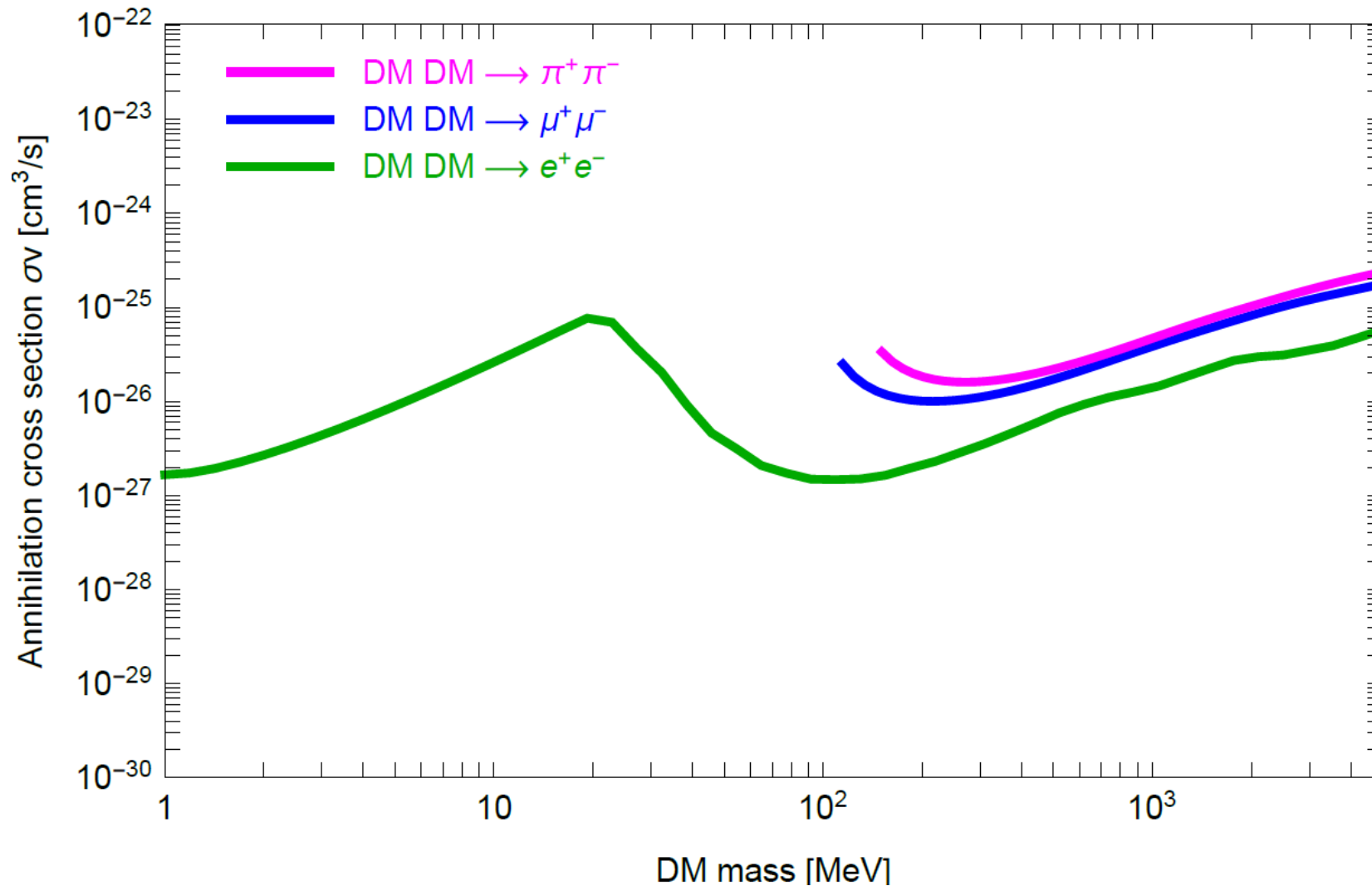
Angular profile



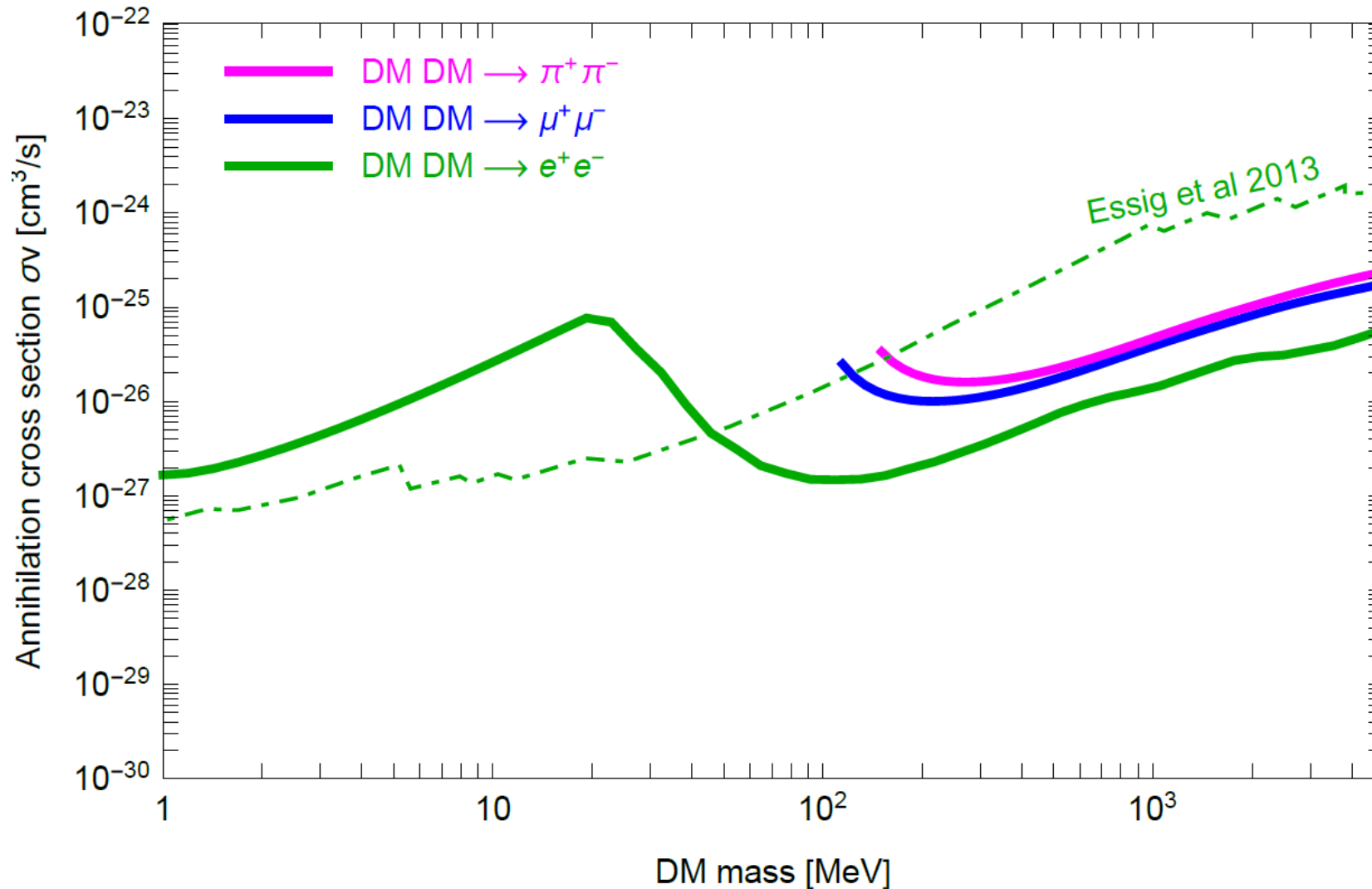
Constraints from FSR, Rad, ICS



Constraints on sub-GeV Dark Matter

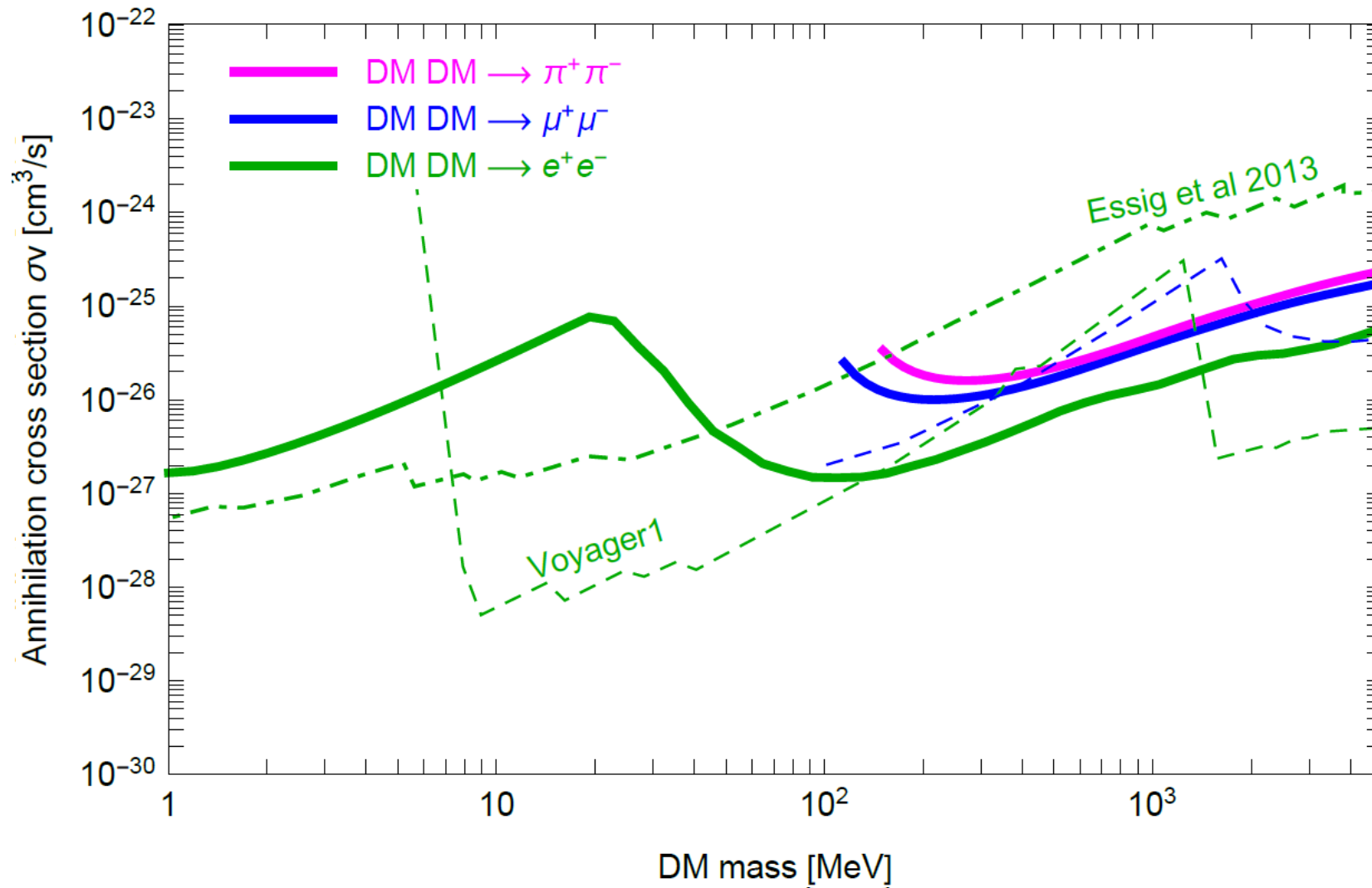


Constraints on sub-GeV Dark Matter



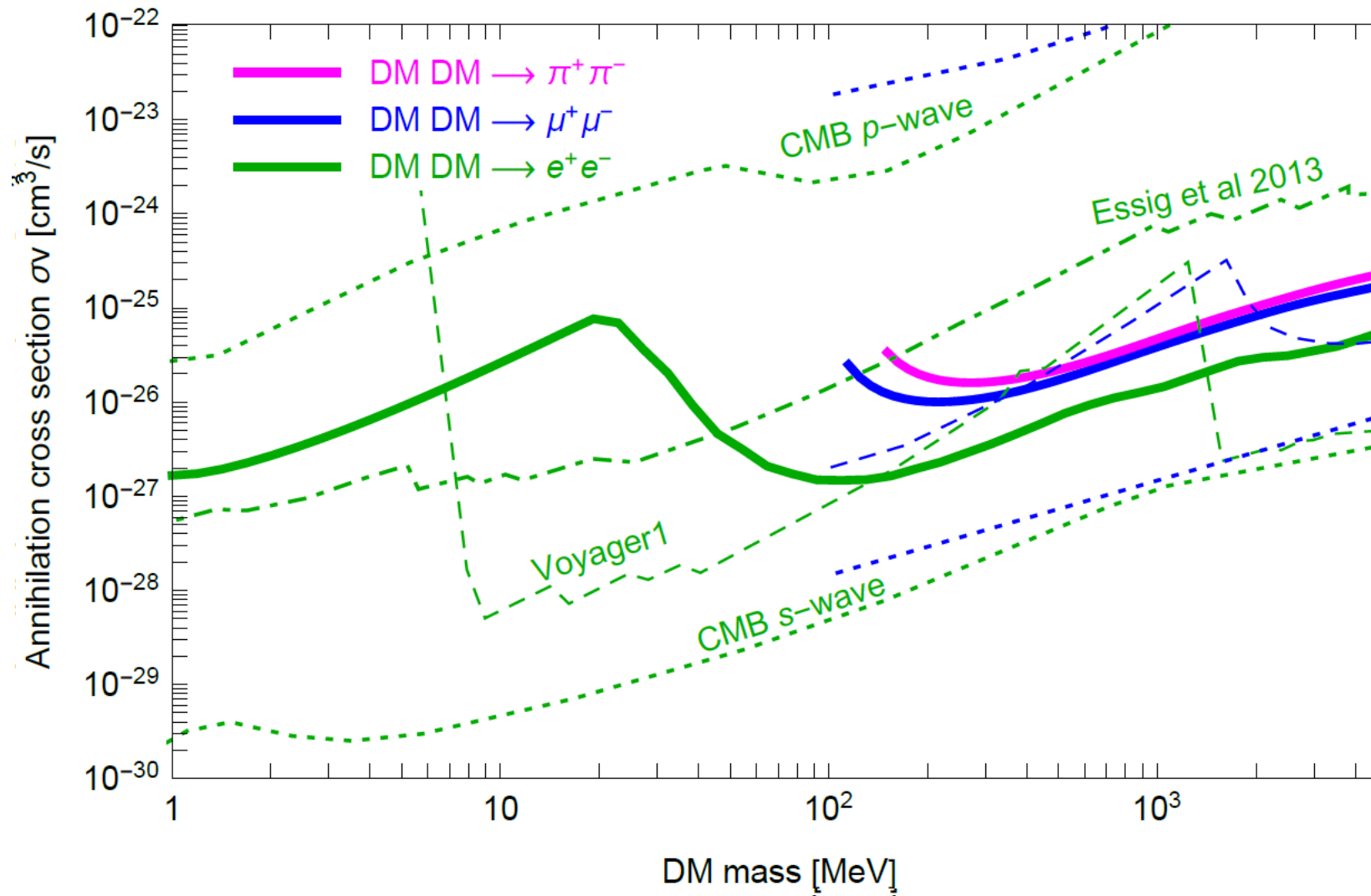
Essig et al., JHEP 11
(2013) 193

Constraints on sub-GeV Dark Matter



Boudaud et al., Phys. Rev. Lett. 119 (2017) 021103

Constraints on sub-GeV Dark Matter



Slatyer, Phys. Rev. D 93
(2016) 023527

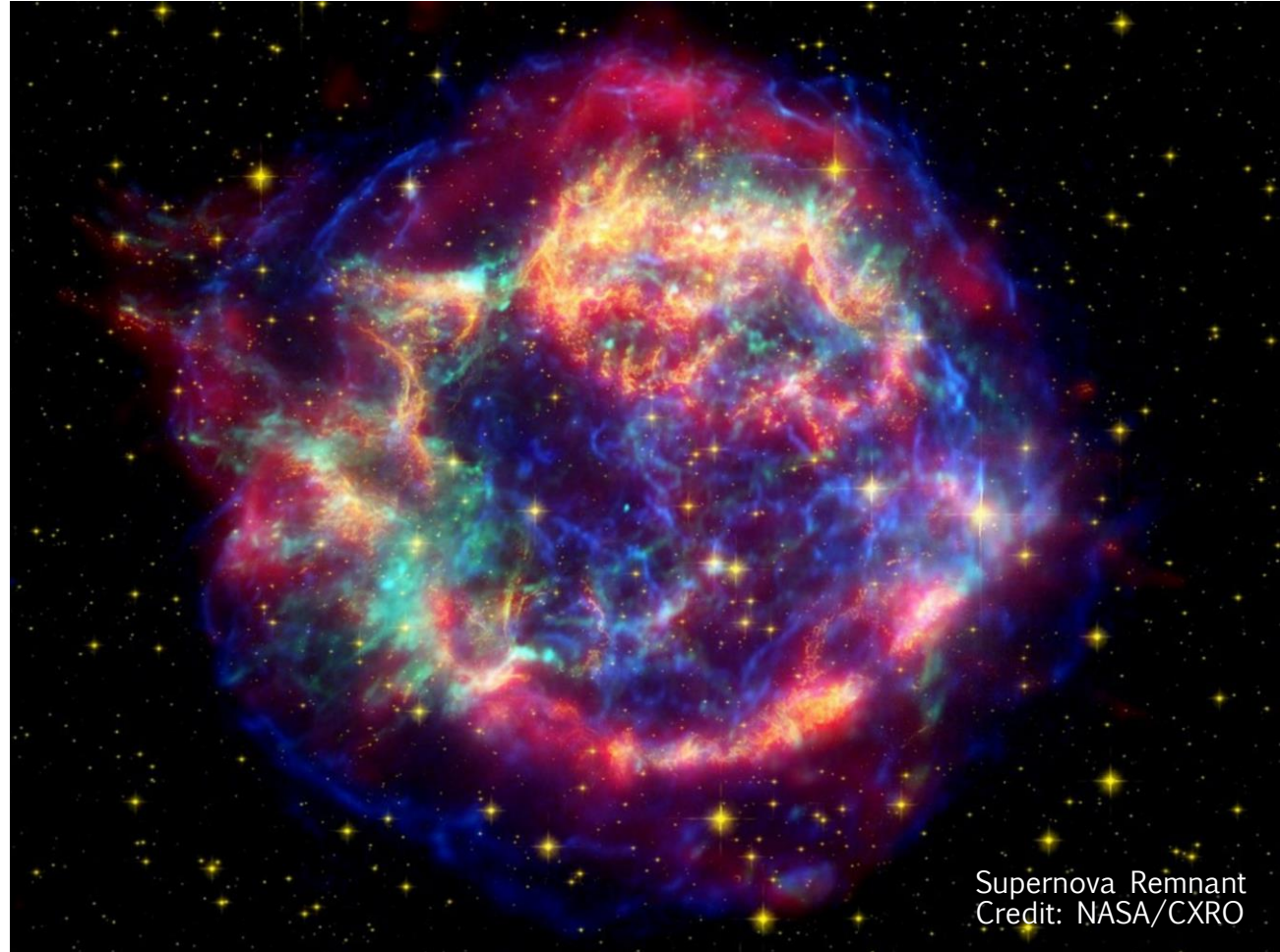
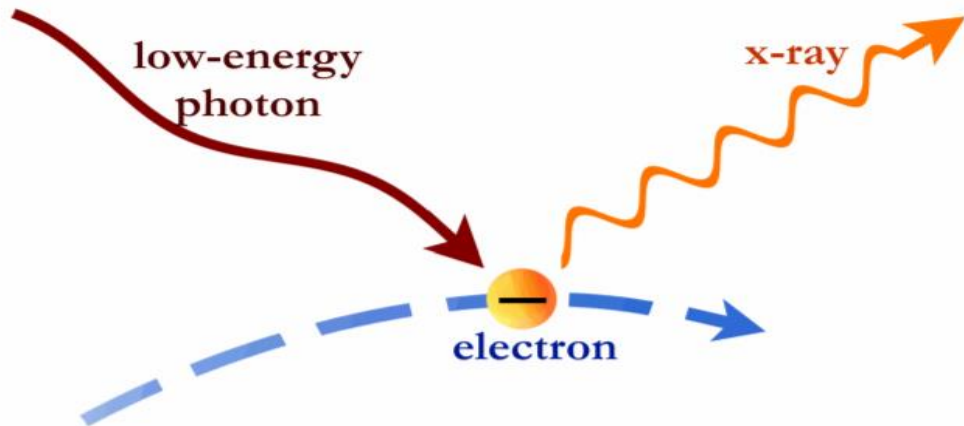
Lopez-Honorez et al., JCAP
07 (2013) 046

Diamanti et al., JCAP 02
(2014) 017
Liu et al., arXiv:2008.01084

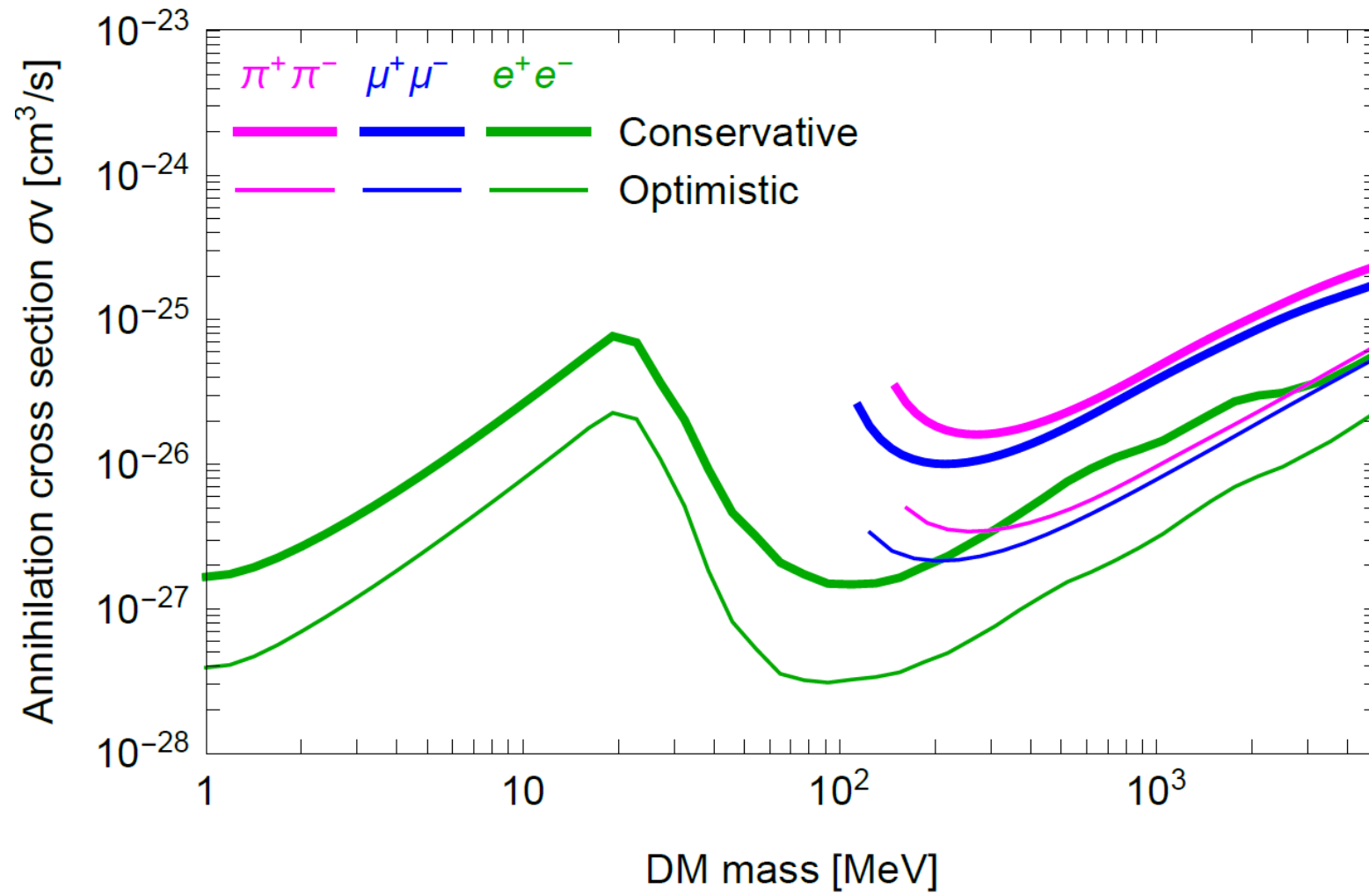
Astrophysical background

Diffusive inverse Compton scattering:

- Supernova remnants
- Interstellar medium
- Active Galactic Nuclei
- (...)



Optimistic constraints

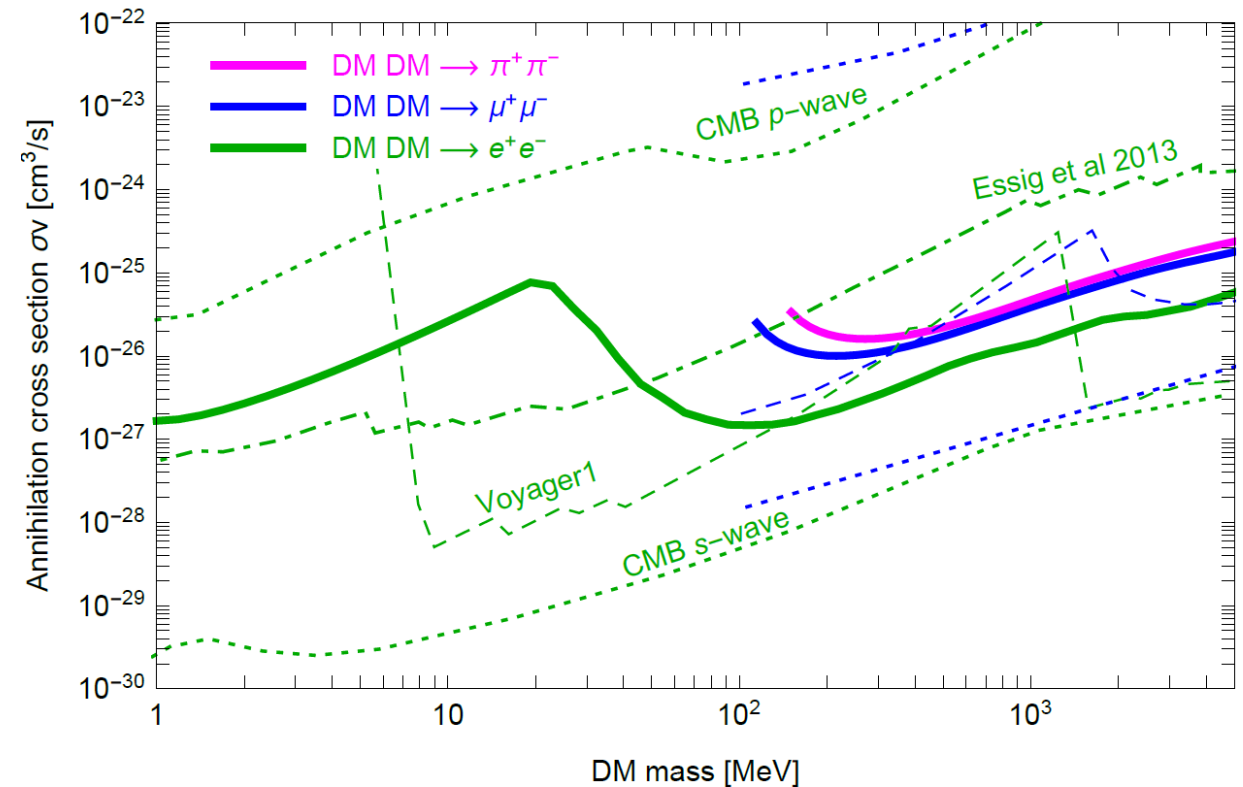


Conclusions

- $1 \text{ MeV} \leq m_\chi \leq 5 \text{ GeV}$
- Include inverse Compton scattering
- X-ray data from INTEGRAL telescope

Strongest bound (if p-wave):

$$150 \text{ MeV} \leq m_\chi \leq 1.5 \text{ GeV}$$

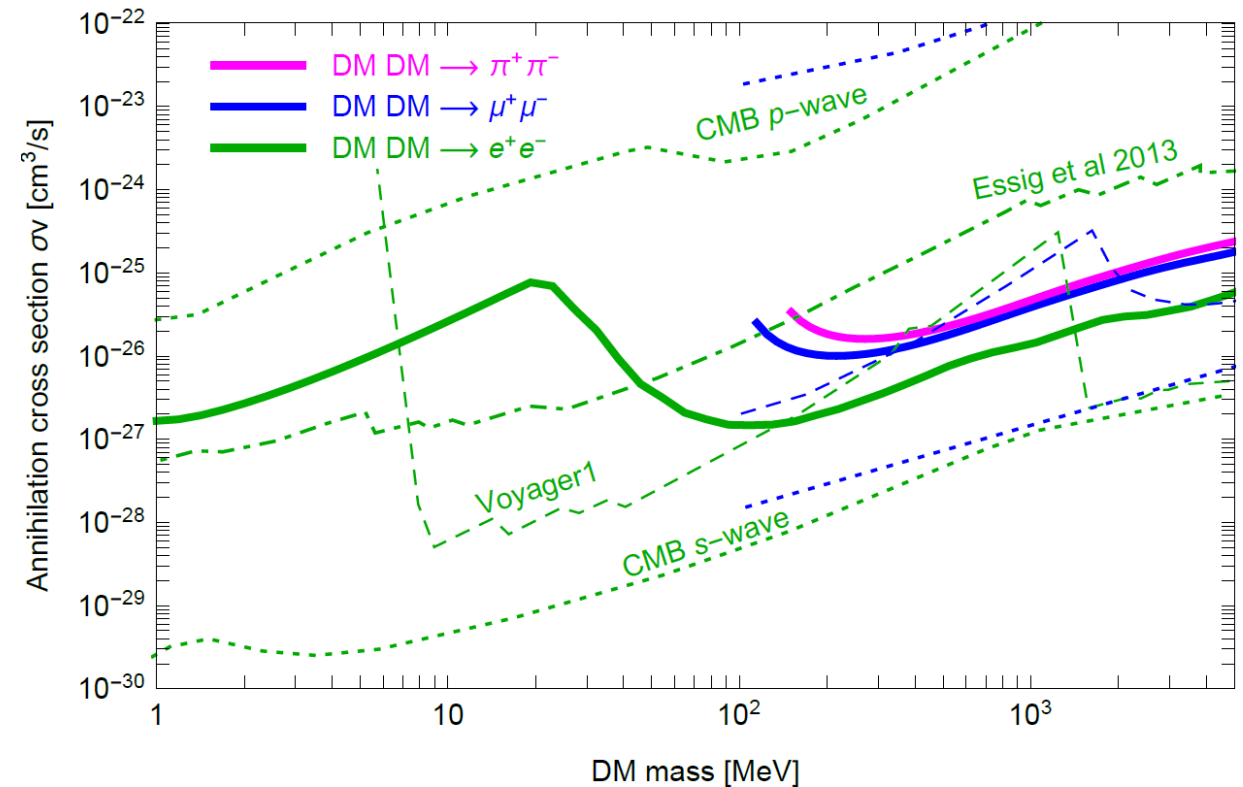


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Thank you for your attention!