# INTEGRAL X-RAY CONSTRAINTS ON SUB-GEV DARK MATTER

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## INTEGRAL X-ray constraints on sub-GeV Dark Matter


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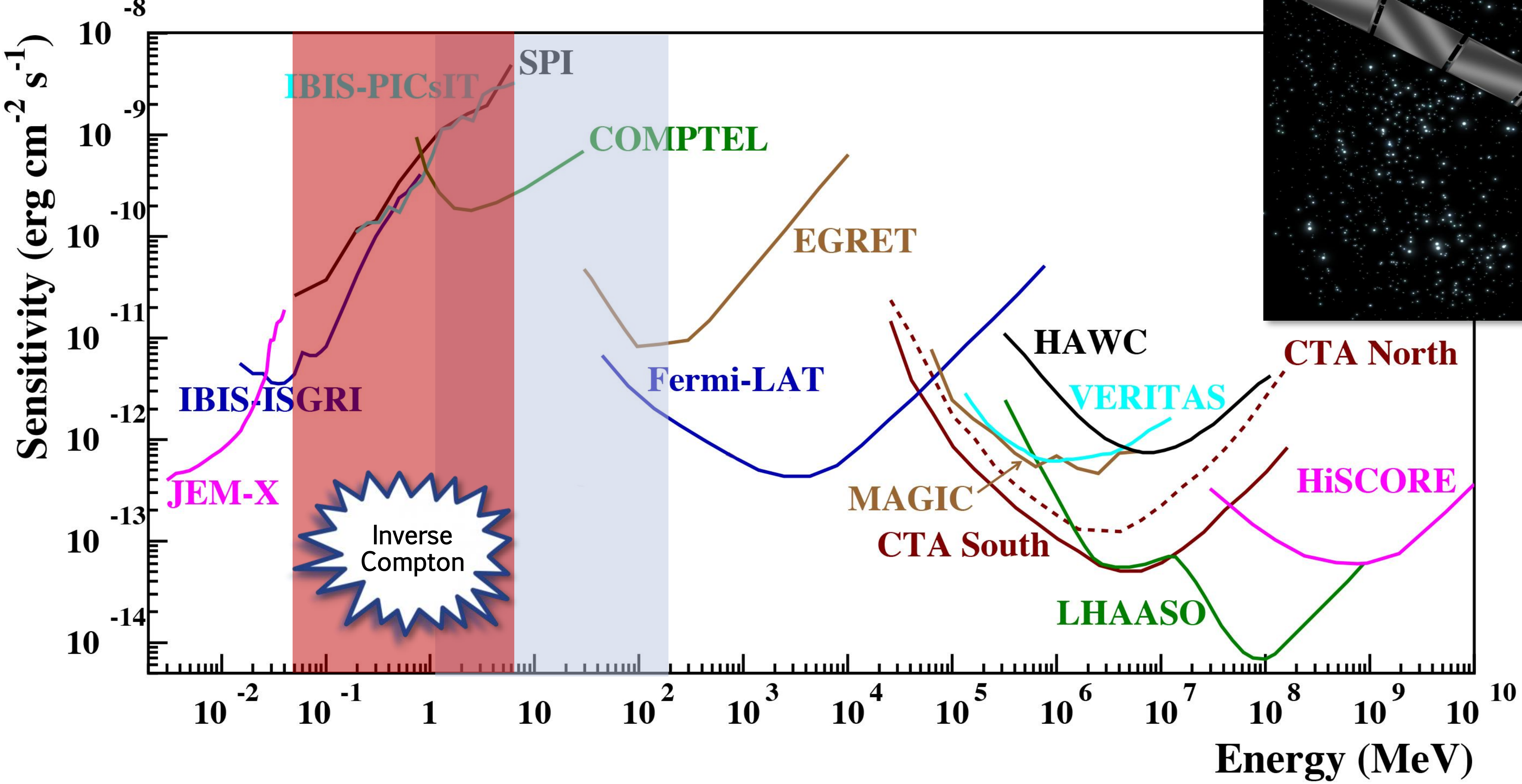
$1\ \mathrm{MeV} \leq m_\chi \leq 5\ \mathrm{GeV}$

# Photon searches



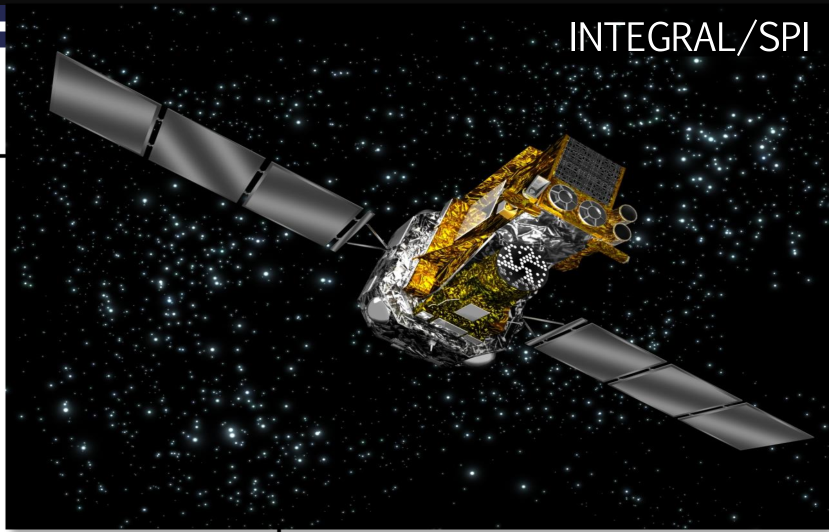




Figure adapted from Tatischeff+ arxiv:1805.06435

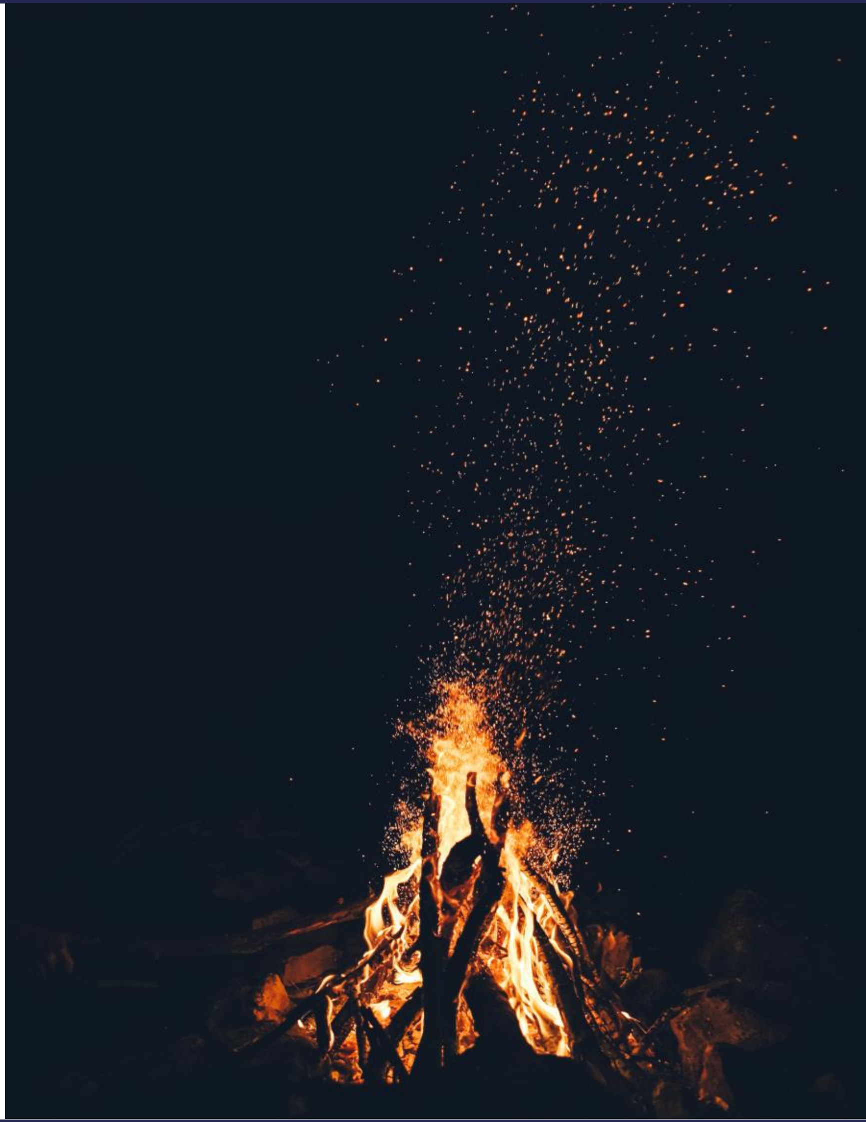
# Annihilation channels

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

$\chi\chi \longrightarrow \mu^+\mu^-$

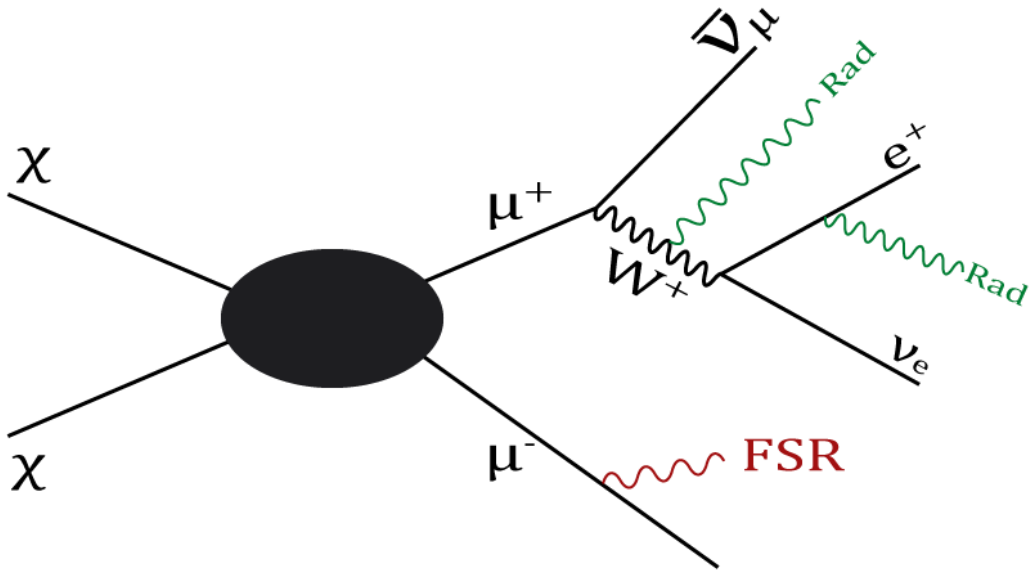
$\chi\chi \longrightarrow \pi^+\pi^-$

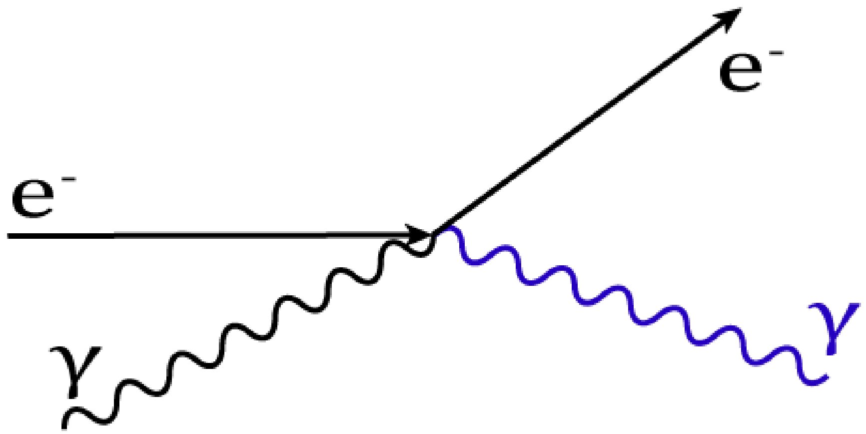
Kinematically open: $m_\chi > m_i \qquad i = e, \mu, \pi$



# Total Flux

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




Inverse Compton Scattering

$\chi\chi \longrightarrow \mu^+\mu^-\gamma$ FSR

$\chi\chi \longrightarrow \mu^+\mu^-$ Rad

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

$\chi\chi \longrightarrow (\ldots) \rightarrow e^+\, e^-$

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

# Final State Radiation and Radiative Decay

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

Particle properties

Energy spectrum

J-factor

**Radiative Decay:**

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

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

Line of sight

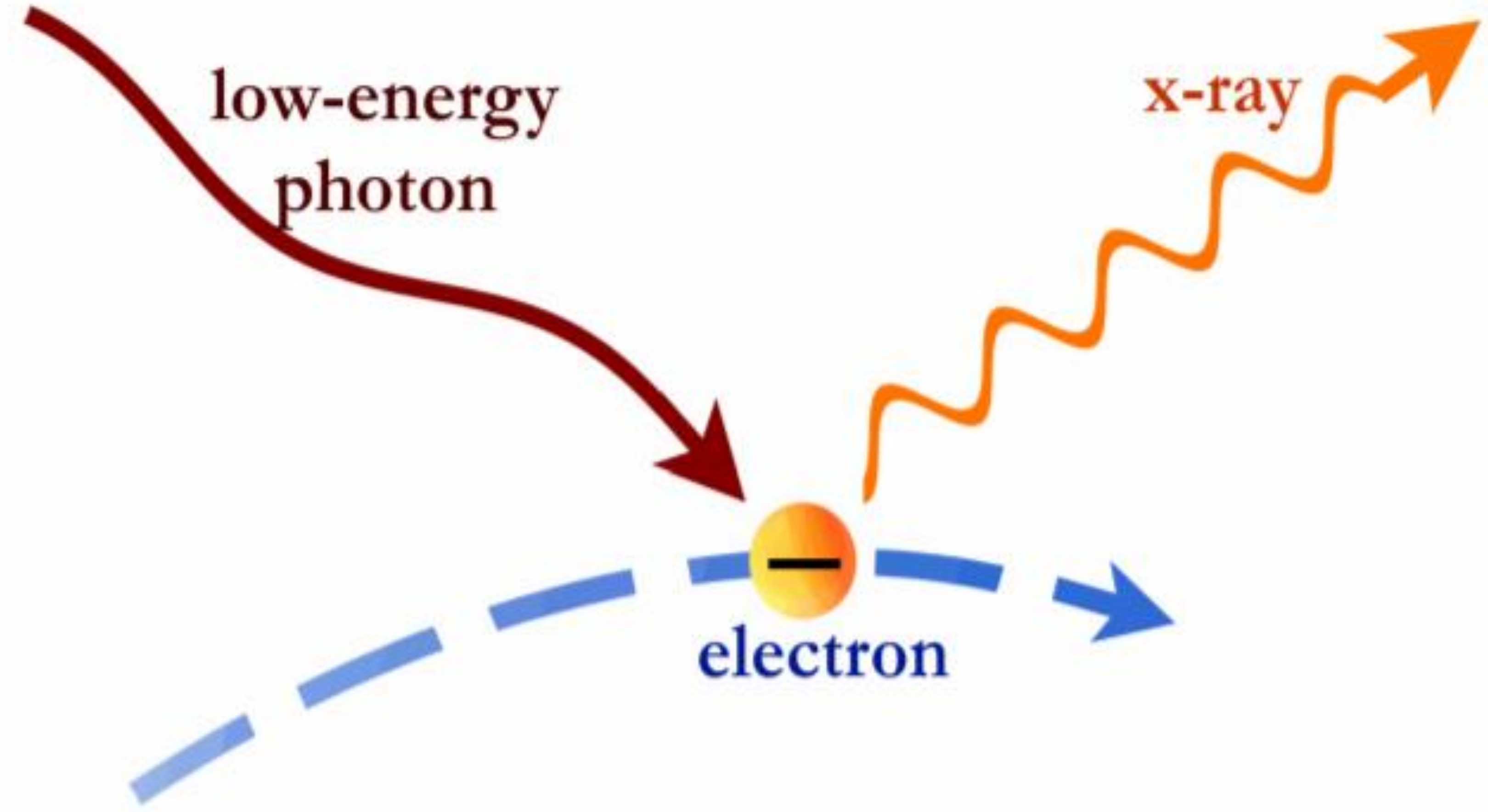
DM density

# Inverse Compton Scattering

$$\boxed{\chi\chi \longrightarrow (\dots) \rightarrow e^{+}\, e^{-}}$$

3 kinds of photons:

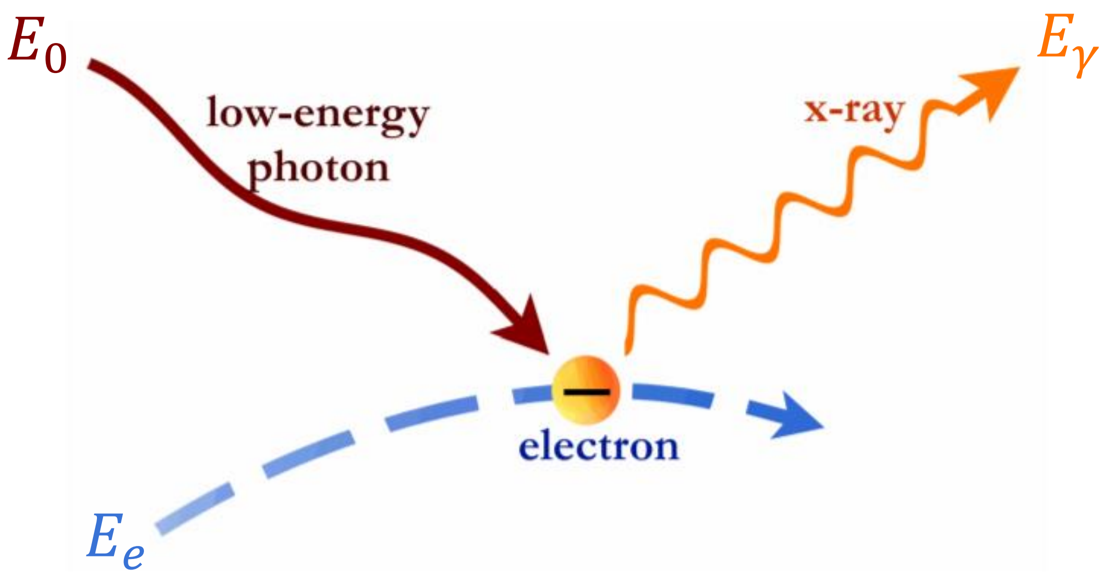
- CMB
- Infrared (dust)
- Optical (starlight)



# X rays

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

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




| Type | $E_0$ [eV] | $E_e$ [GeV] | $E_\gamma$ [keV] |
|---|---|---|---|
| CMB | $10^{-4}$ | 5 | 40 |
| IR | $10^{-2}$ | 0.5 | 40 |
| Opt | 10 | 0.05 | 400 |

X rays

# Inverse Compton Scattering

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

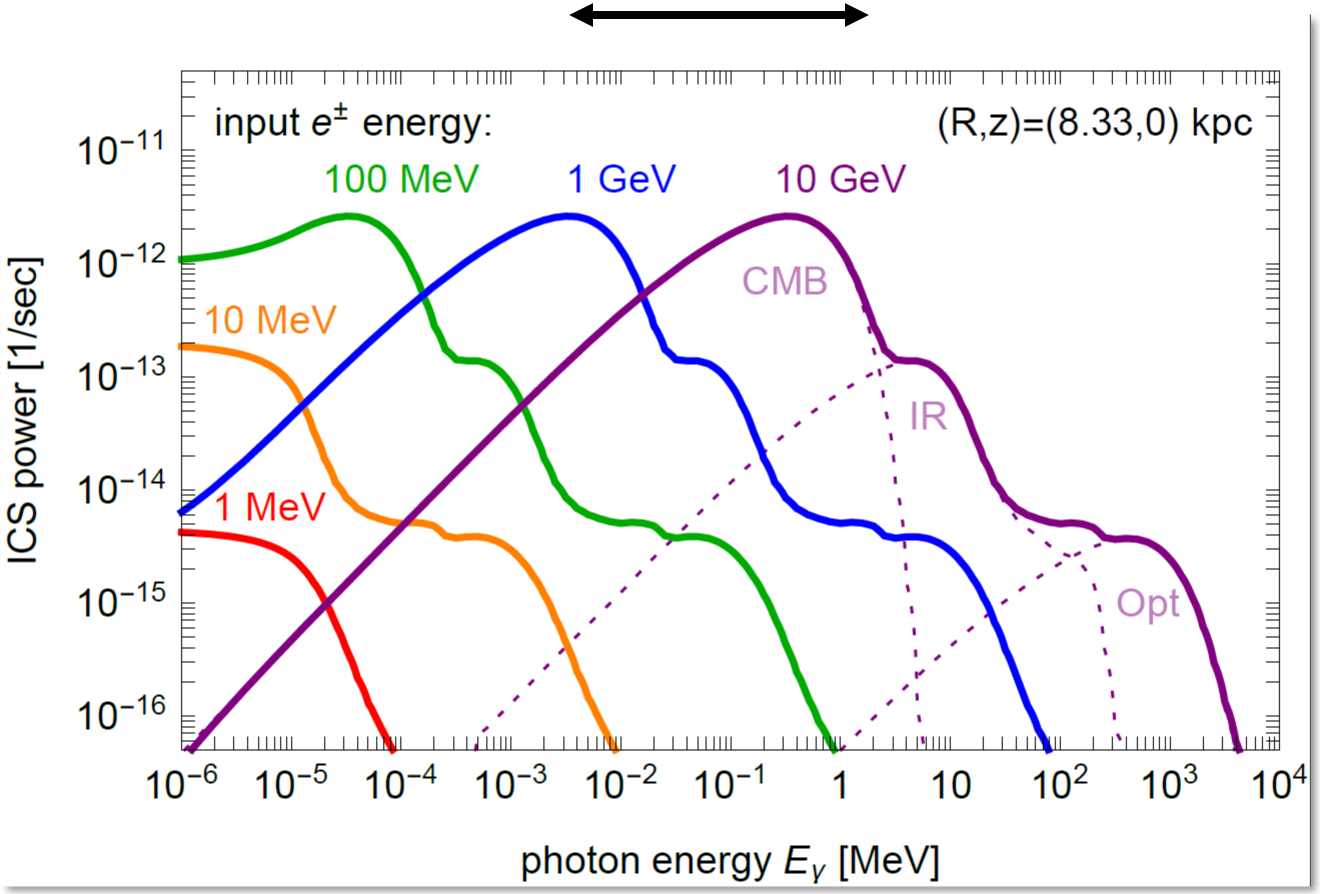
$$\boxed{j(E_\gamma, \vec{x}) = 2 \int_{m_e}^{m_\chi} dE_e\, P_{IC}(E_\gamma, E_e, \vec{x}) \frac{dn_e}{dE_e}(E_e, \vec{x})}$$

$e^\pm$

Differential Power

Number density

INTEGRAL



# Number density

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

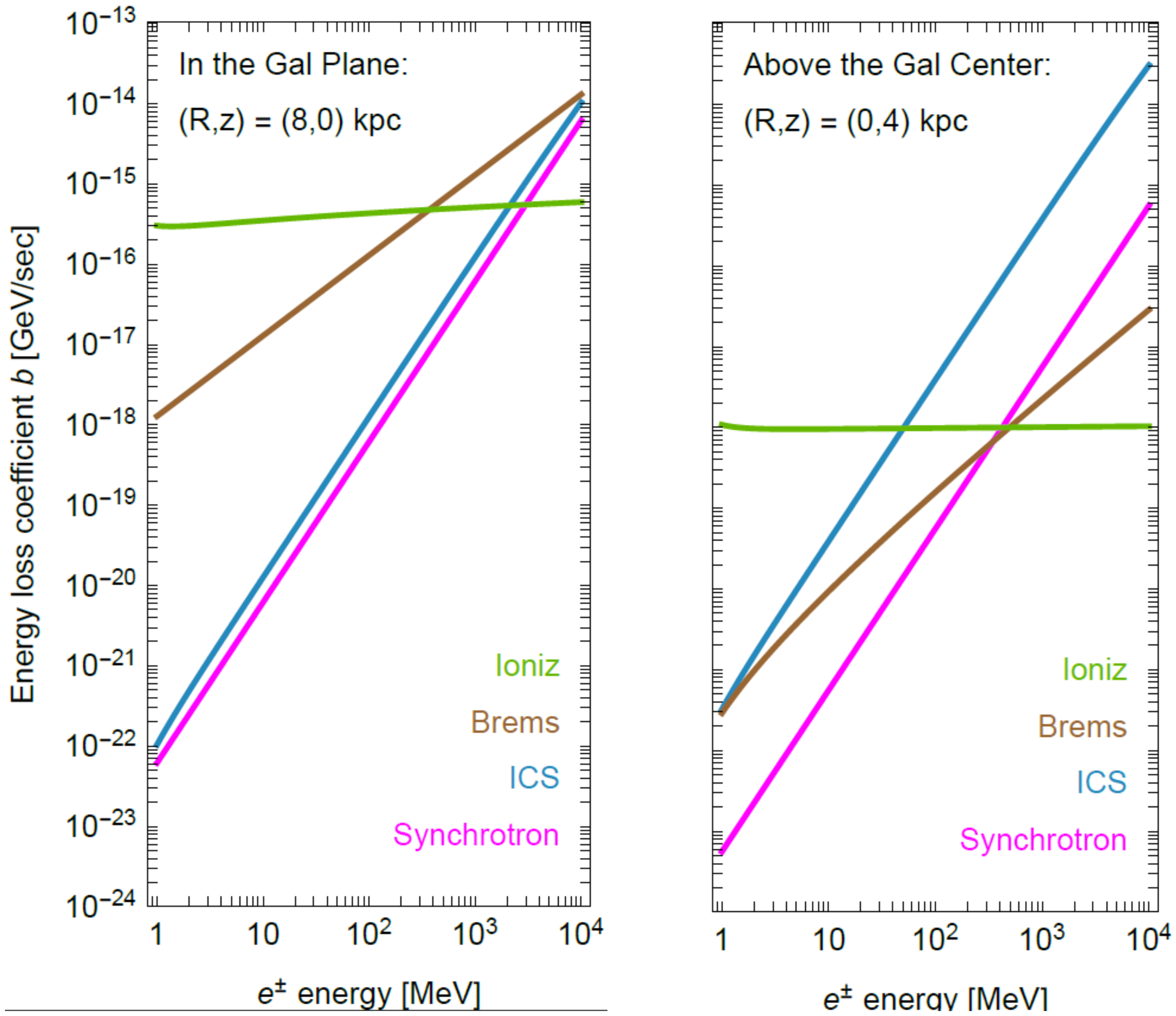
$$Q_e(\tilde{E}_e,\vec{x}) = \frac{\langle\sigma_{ann}v\rangle}{2\,m_{DM}^2}\,\frac{dN_{e^\pm}}{d\tilde{E}_e}\,\rho_{DM}^2$$

Particle Properties

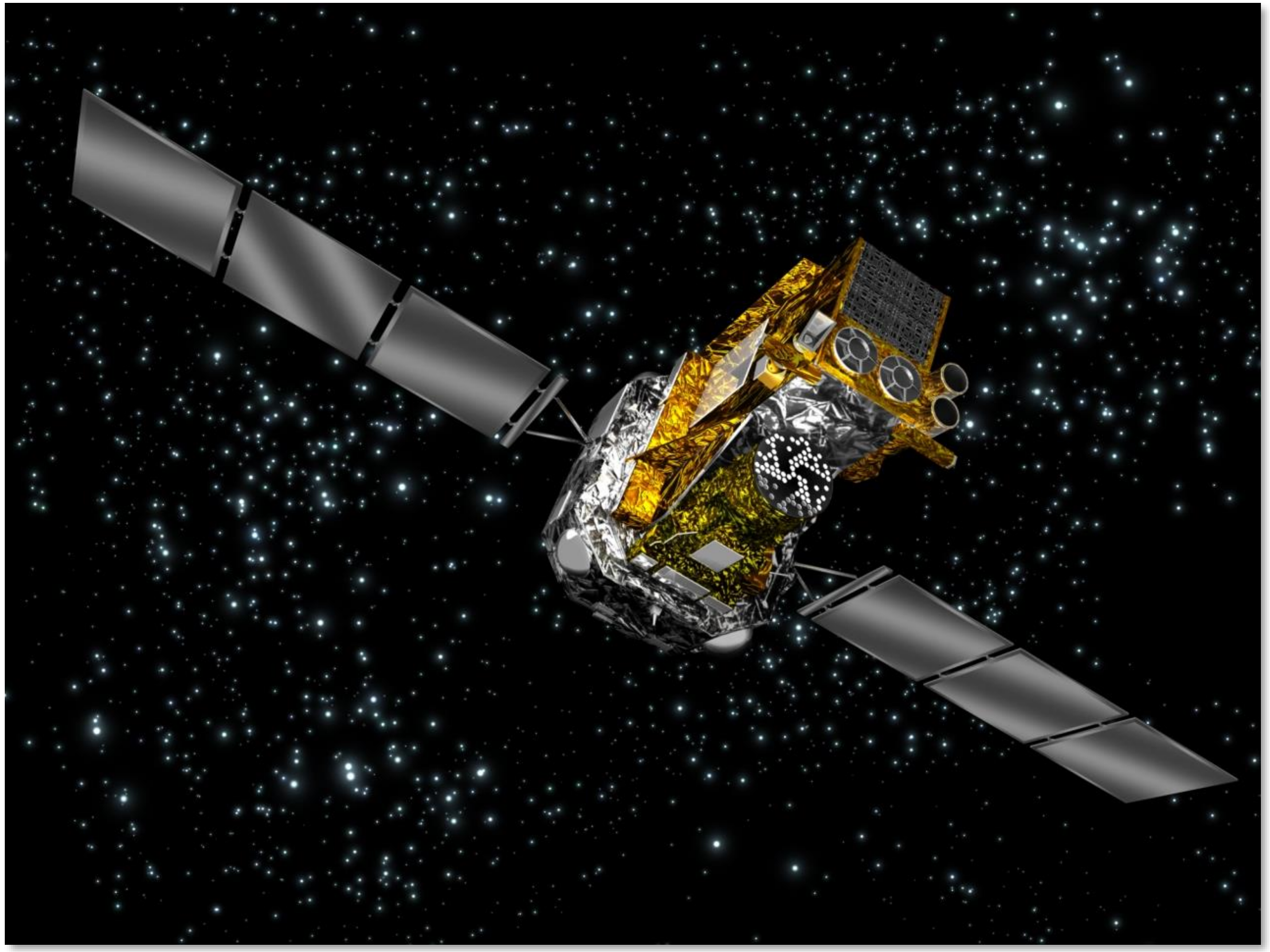
Energy spectrum

Density distribution

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



# INTEGRAL Space Telescope



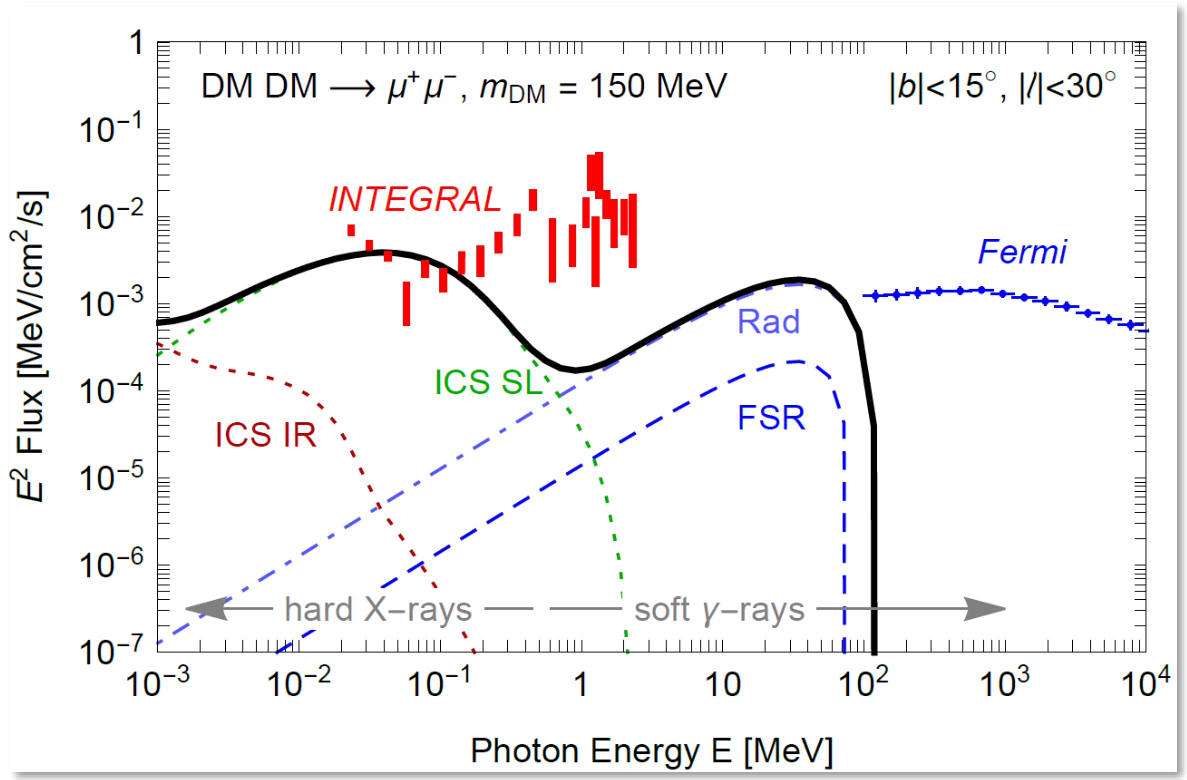
Operational time: 2003-2009

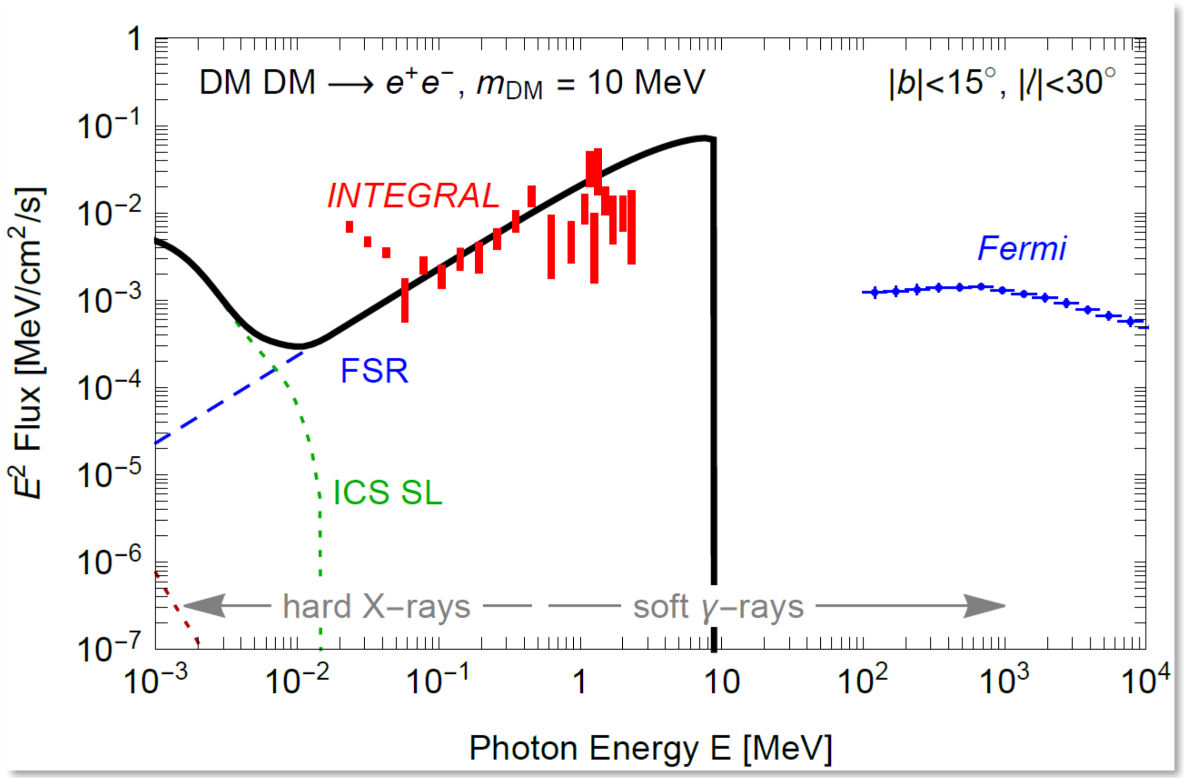
Energy range: 20 keV ~ 8 MeV

- Hard X rays
- Soft gamma rays

INTEGRAL:
INTErnational Gamma-Ray Astrophysics Laboratory

# Photon Spectra



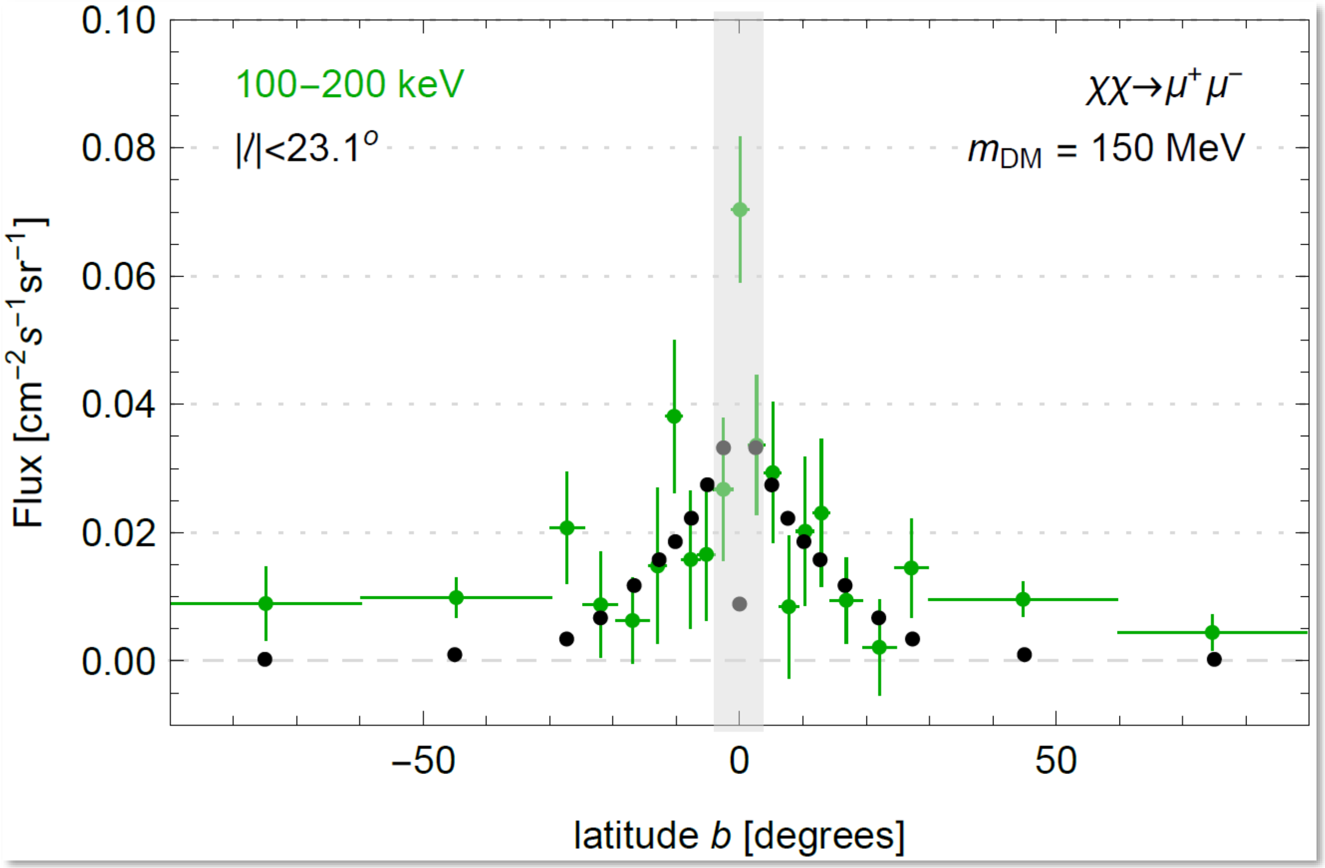
# Angular profile

5 energy bands:

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

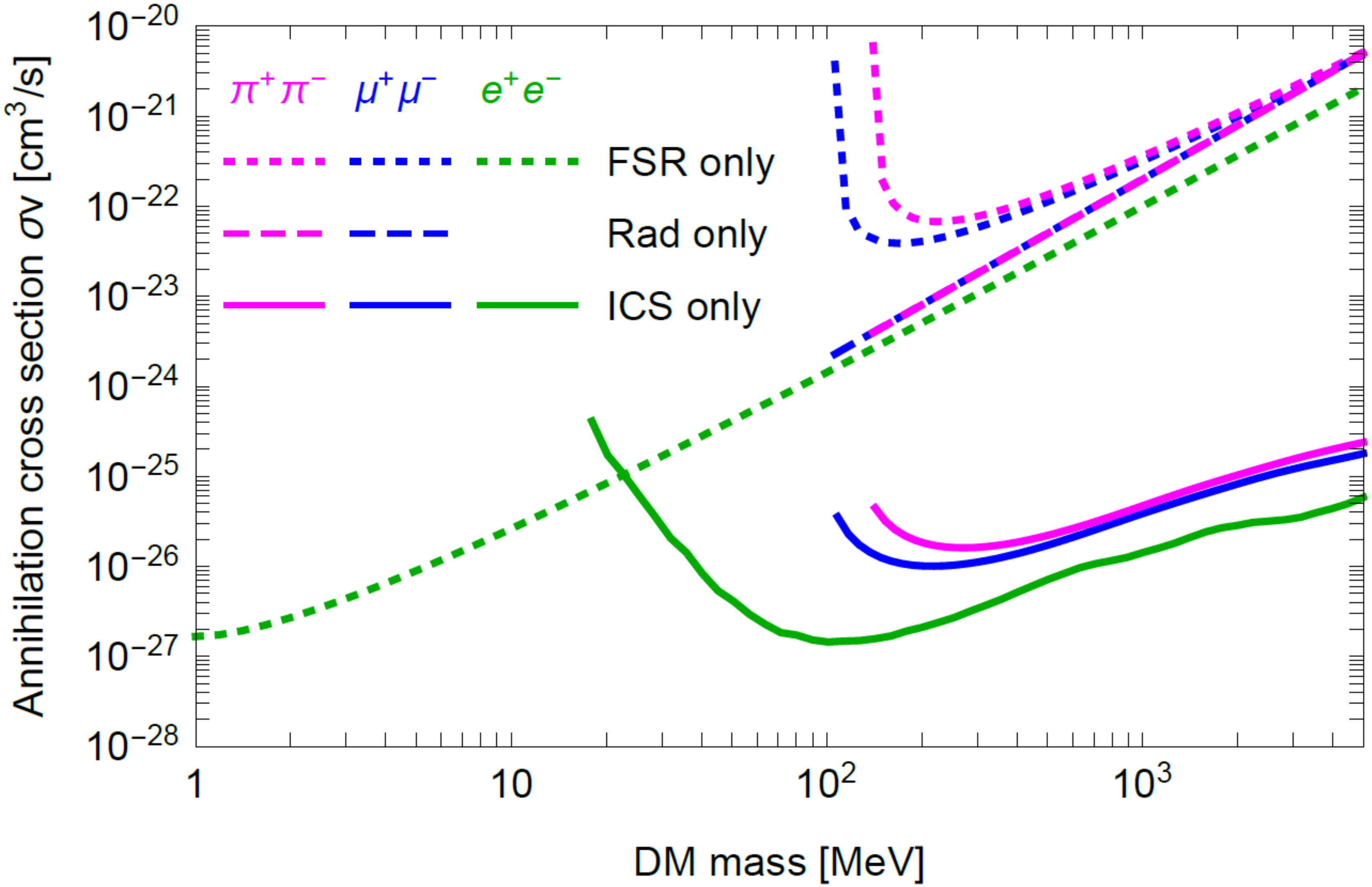
21 bins in latitude (15 for the fifth band)

-23.1° < l < 23.1° (|l|<60° for the fifth band)

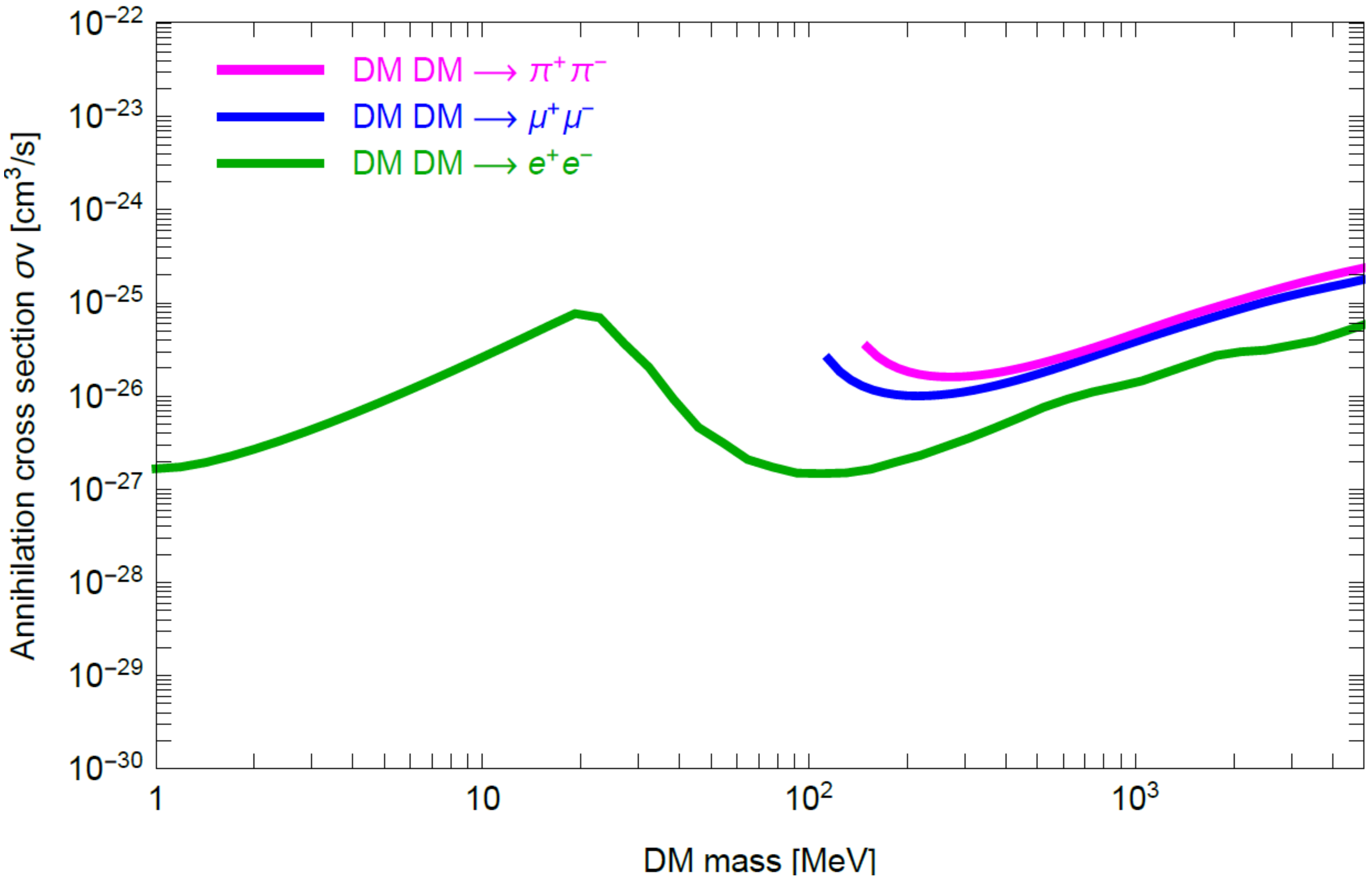



INTEGRAL data (green points)
Bouchet et al. (2011)

# Constraints from FSR, Rad, ICS



# Constraints on sub-GeV Dark Matter



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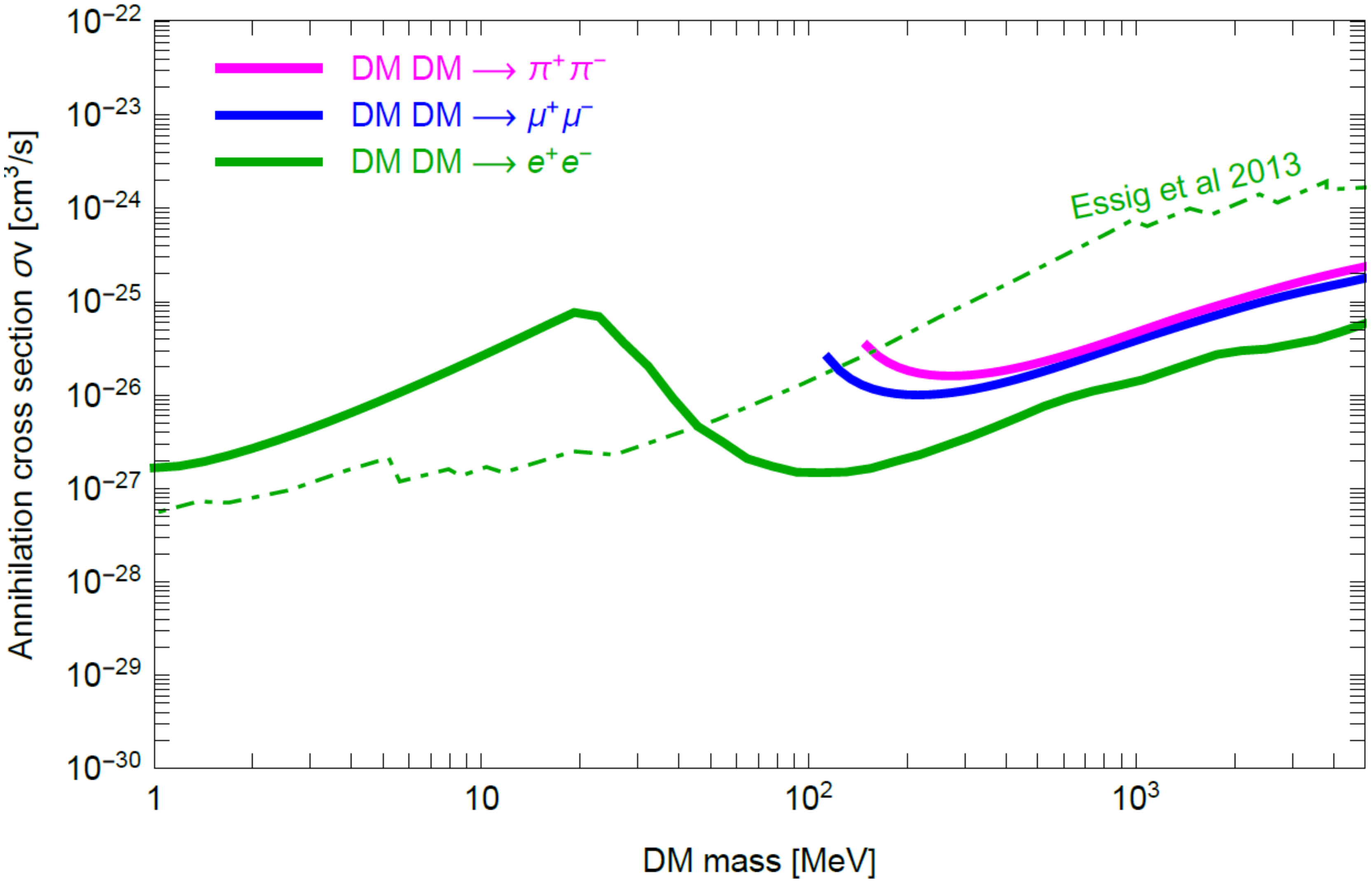


Essig et al., JHEP 11 (2013) 193

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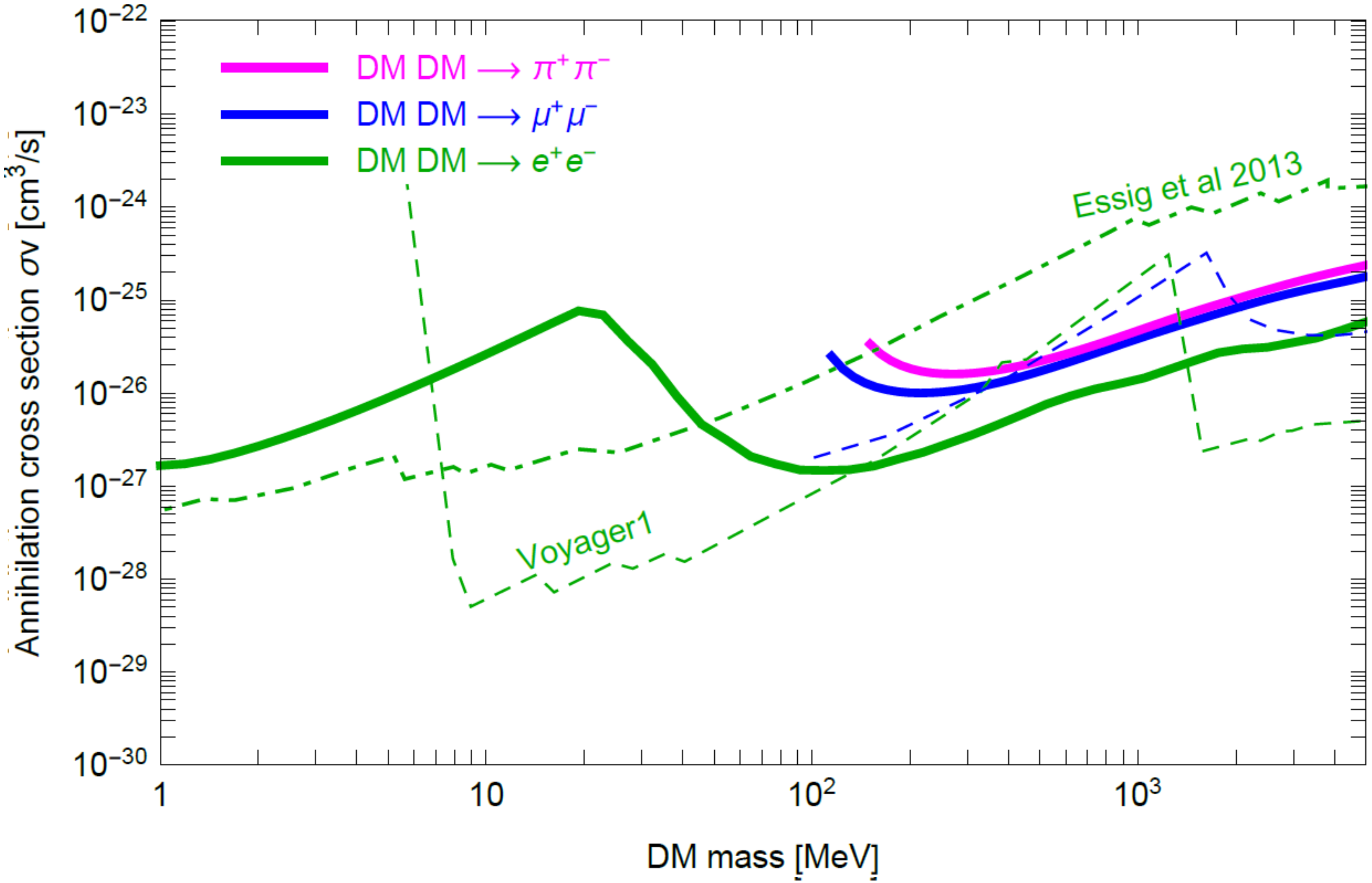
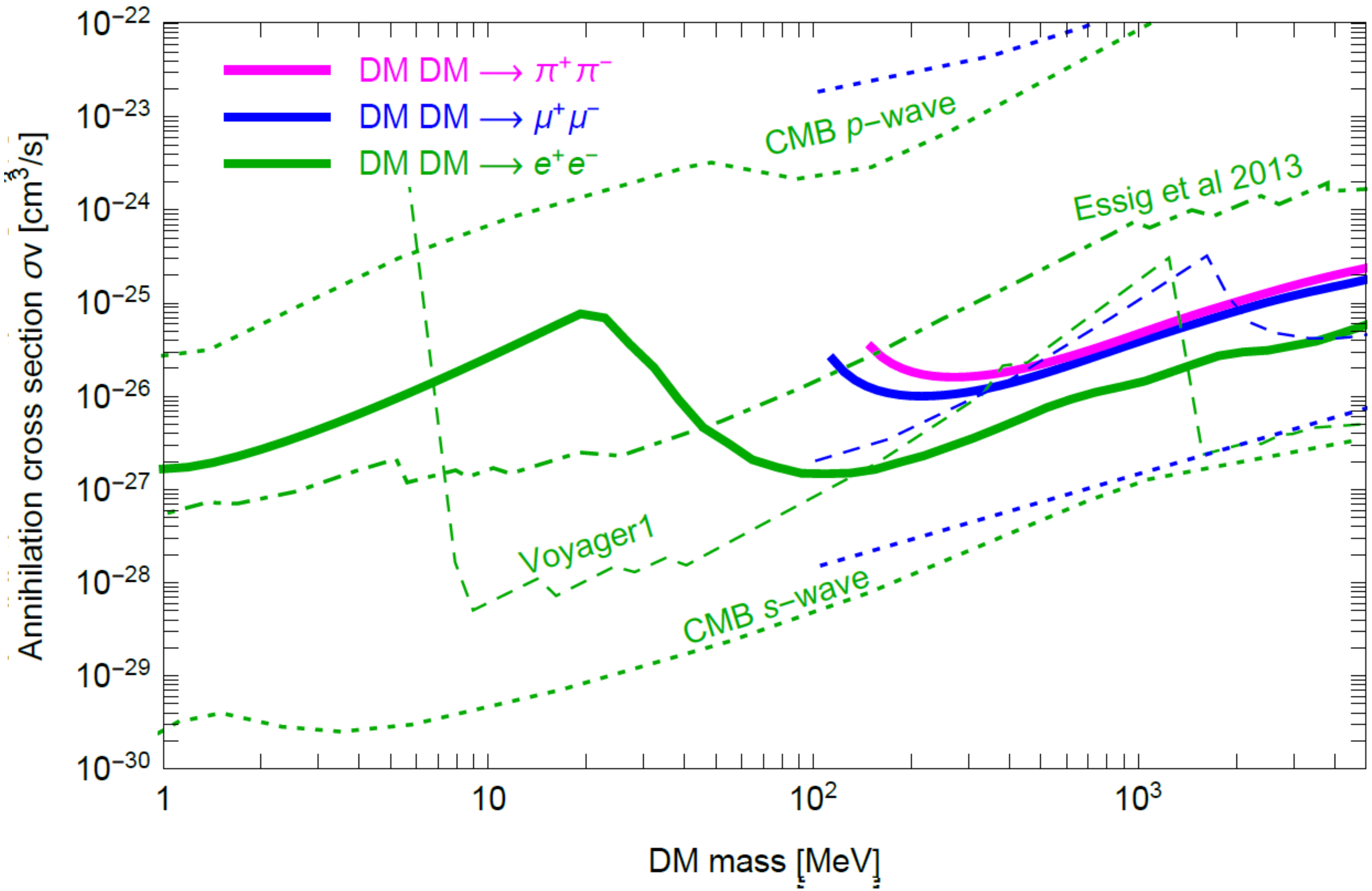



Boudaud et al., Phys. Rev. Lett. 119 (2017) 021103

# 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

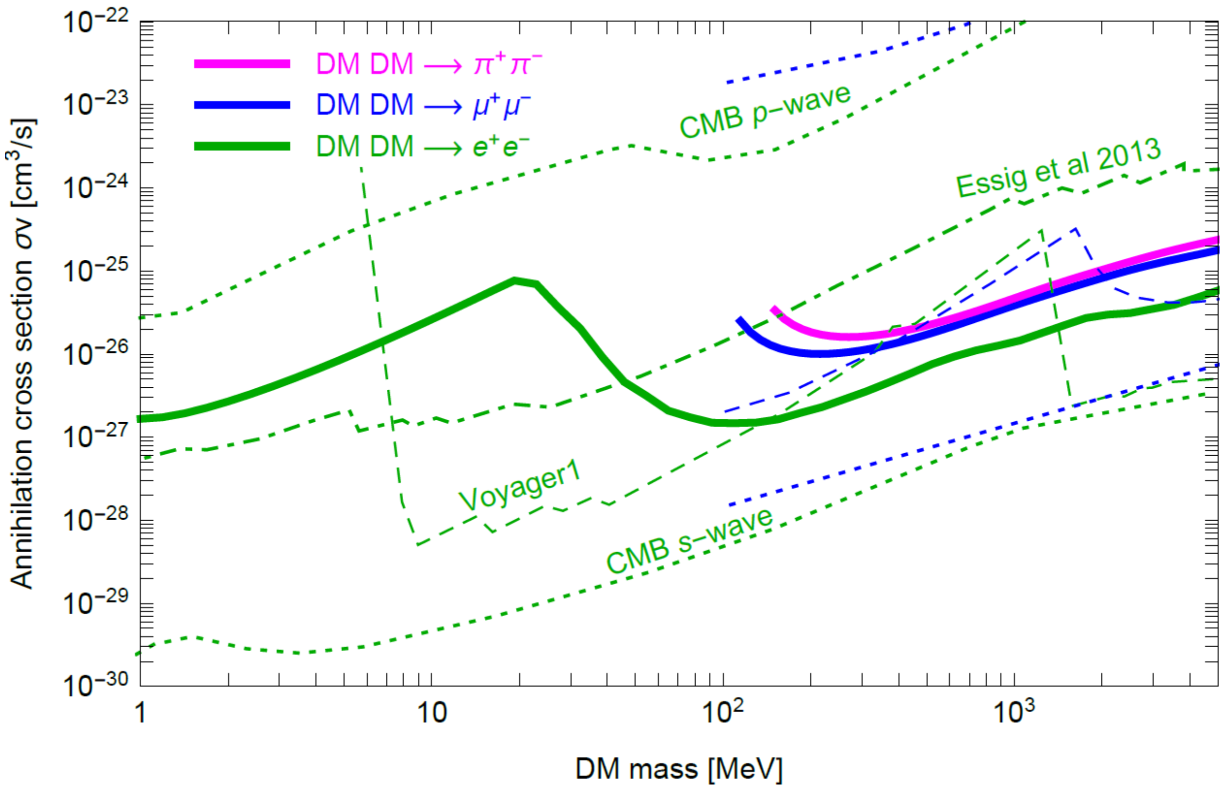
Liu et al., arXiv:2008.01084

# 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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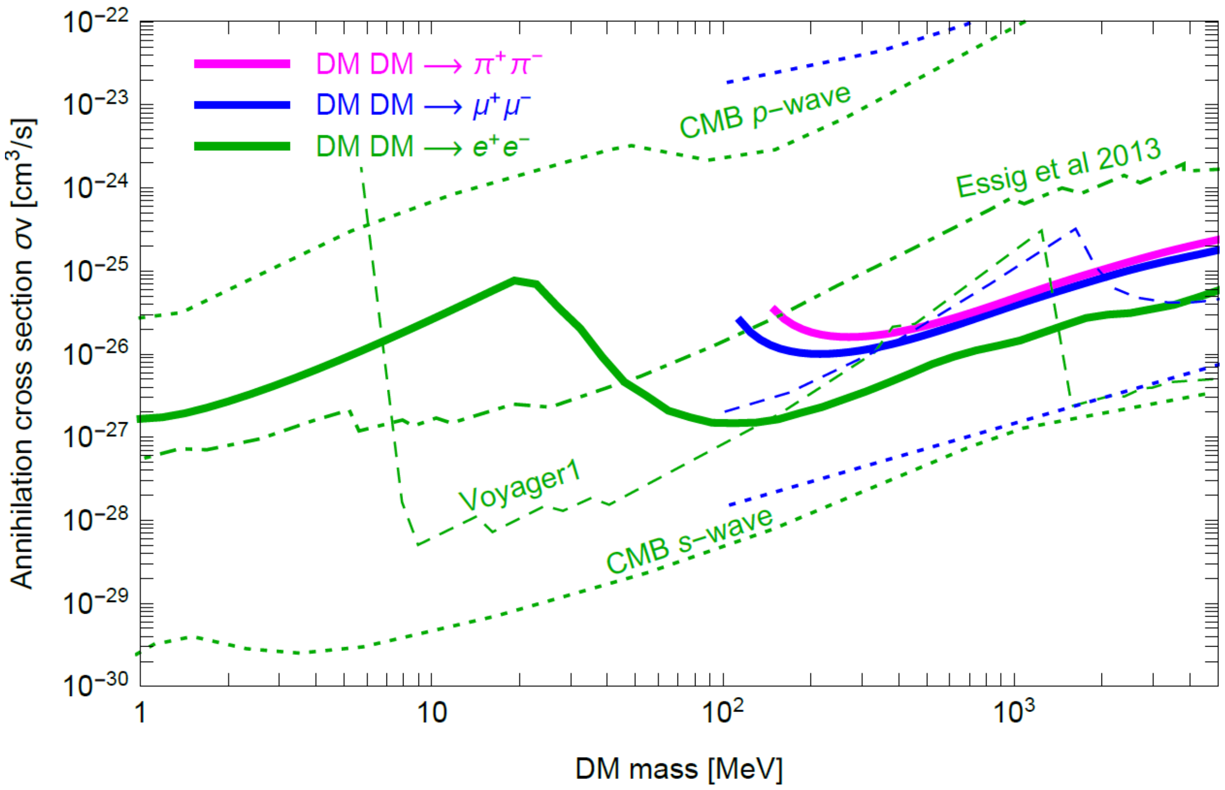


**Thank you for your attention!**