Fermilab

All the X in one basket:
X-ray constraints on sub-GeV dark matter

Elena Pinetti

Cosmology from Home 2023

This talk is based on…

INTEGRAL X-ray constraints on sub-GeV Dark Matter

Marco Cirelli [a], Nicolao Fornengo [b],
Bradley J. Kavanagh [c], Elena Pinetti [a,b]

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Phys.Rev.D 103 (2021) 6, 063022

Putting all the X in one basket: Updated X-ray constraints on sub-GeV Dark Matter

Marco Cirelli [a], Nicolao Fornengo [b],
Jordan Koechler [a], Elena Pinetti [c,d], Brandon Roach [e]

arXiv:2303.08854v1, submitted to JCAP

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Av. de Los Castros s/n, 390…

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

Putting all the X in one basket: Updated X-ray constraints on sub-GeV Dark Matter

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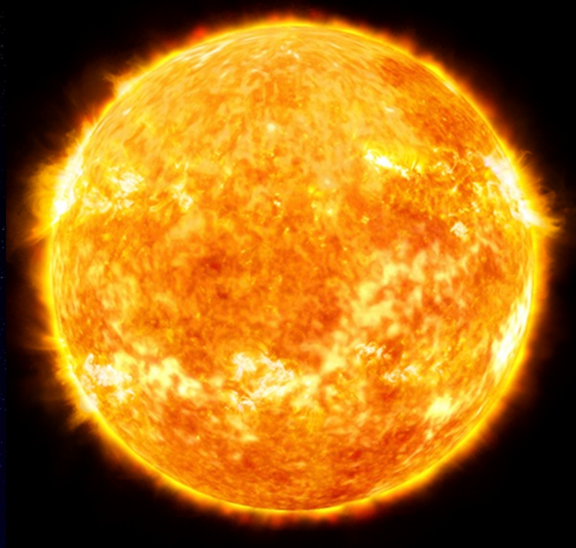
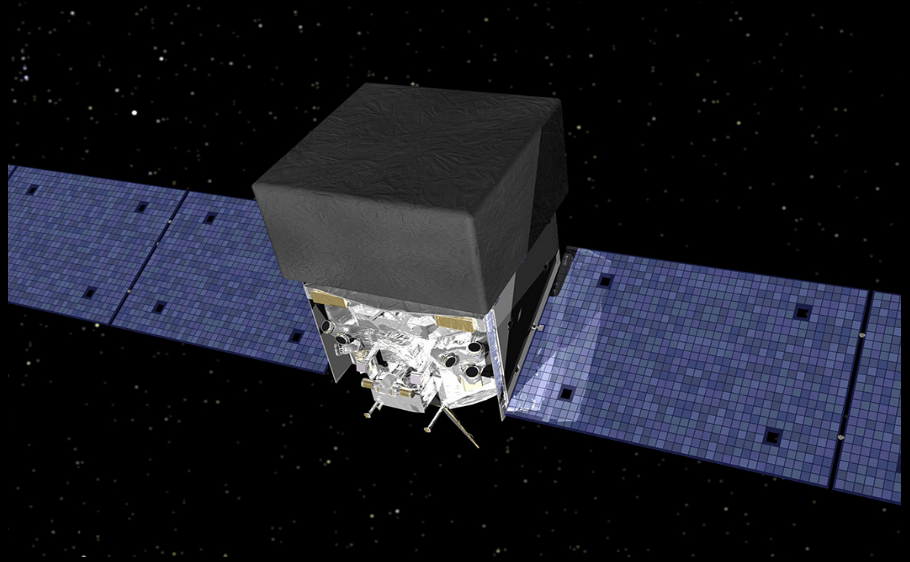
Indirect detection of sub-GeV dark matter

$e^{\pm}$

ν



γ



MeV gap

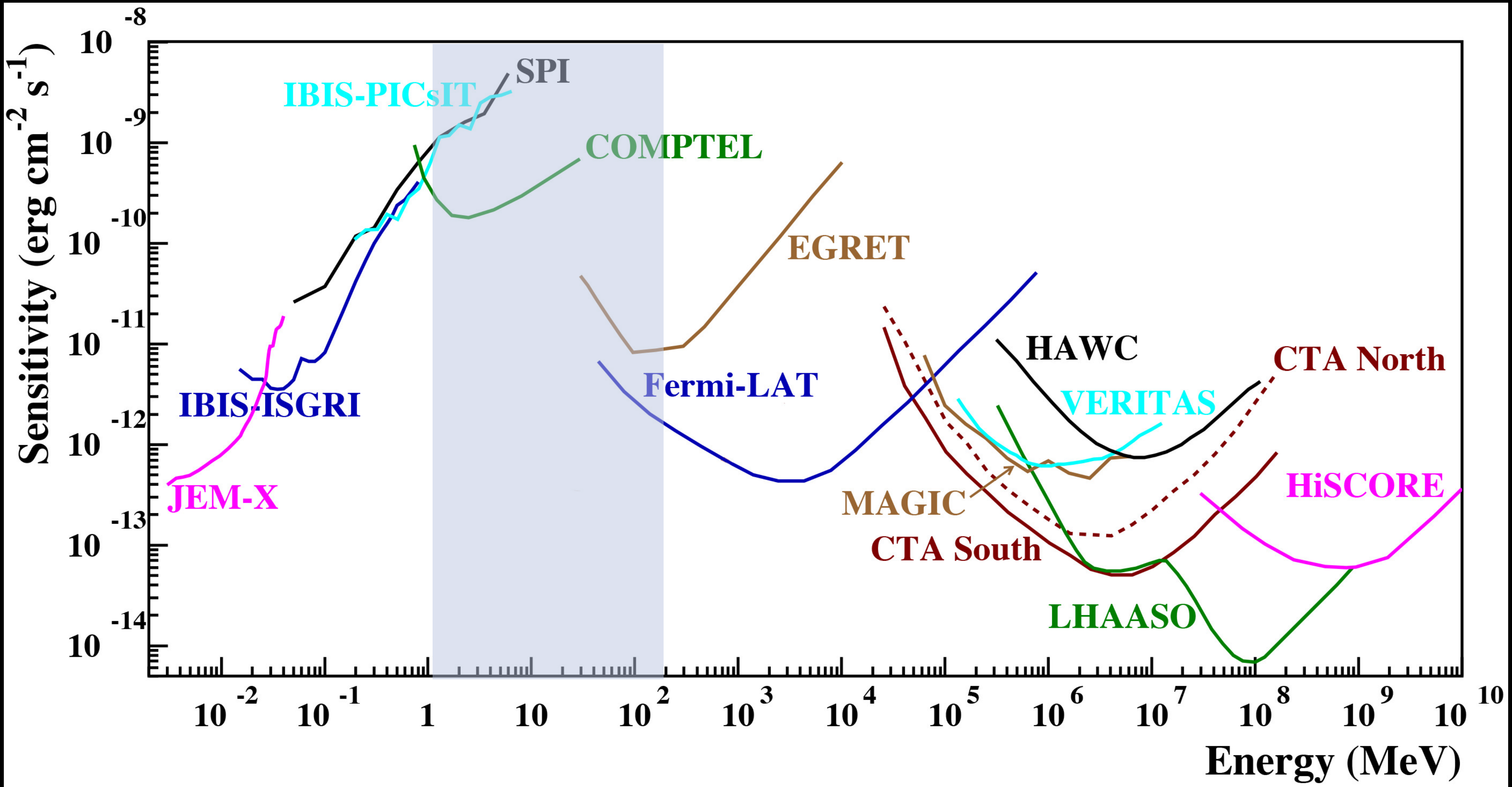


Figure adapted from Tatischeff+ arxiv:1805.06435

MeV gap

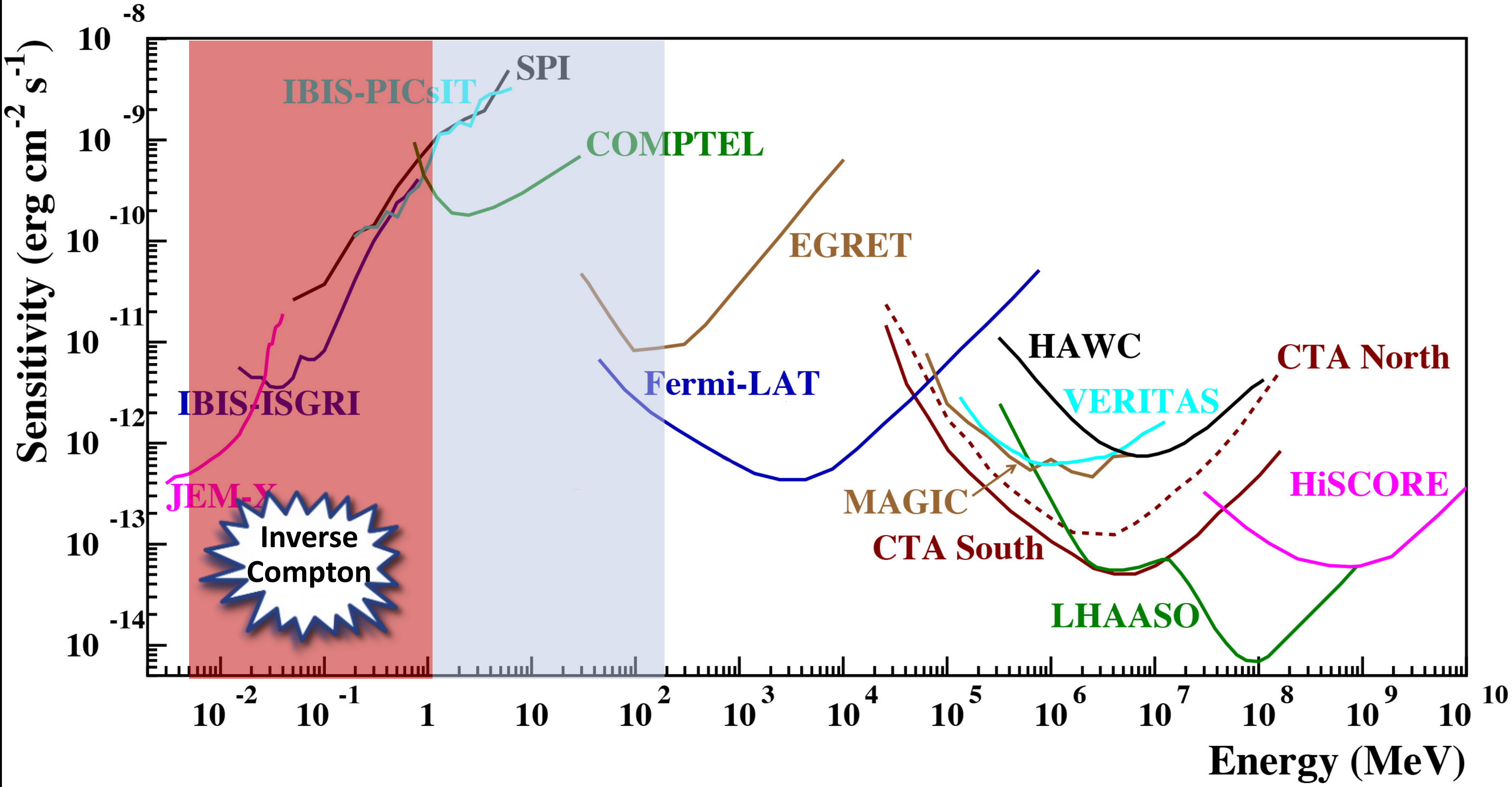


Figure adapted from Tatischeff+ arxiv:1805.06435

Production channels

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

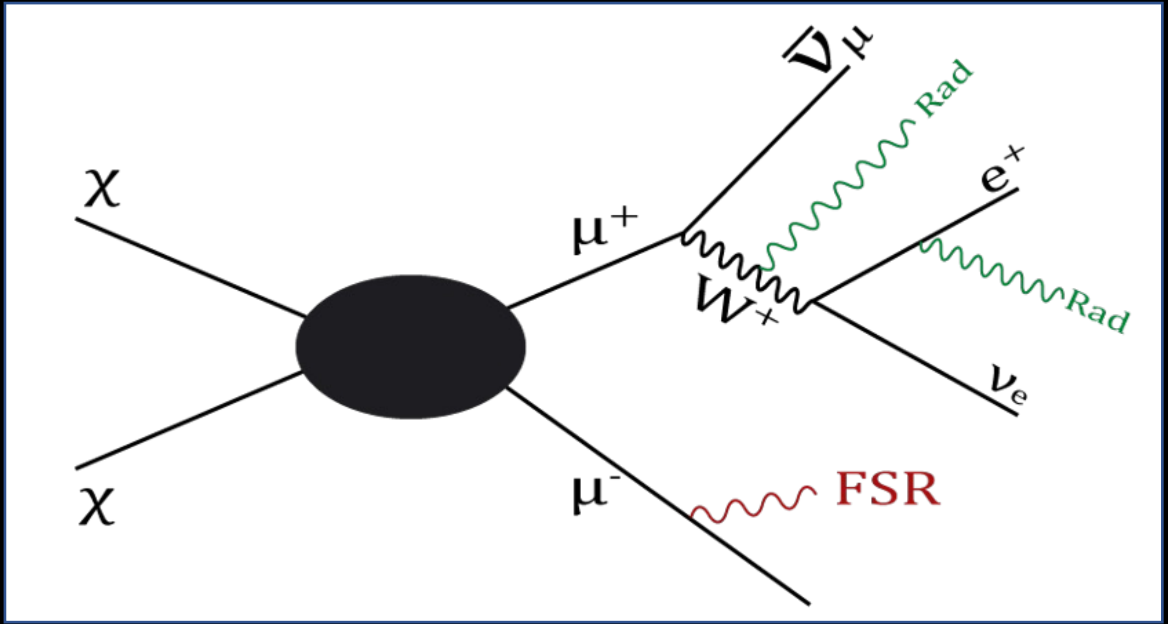
3 decay/annihilation channels:

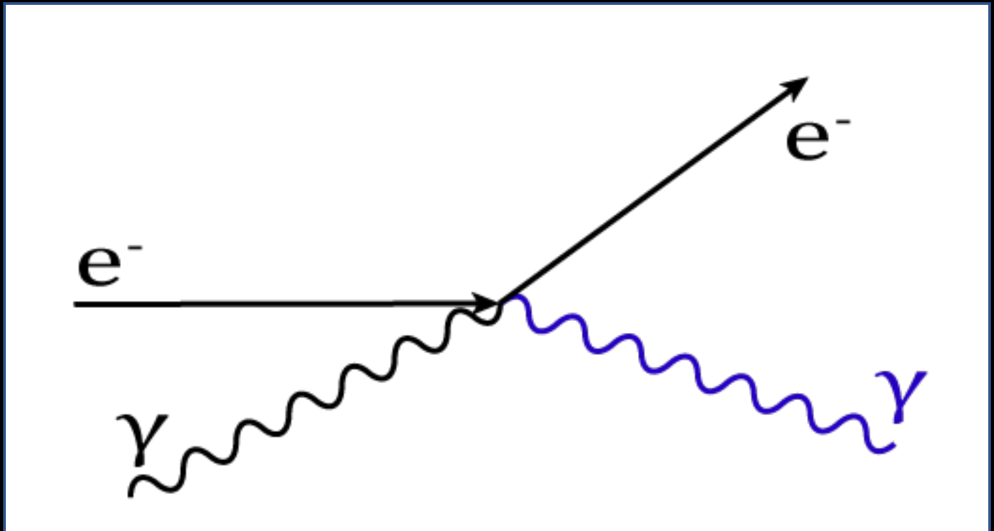
$$\chi(\chi) \longrightarrow e^+e^-$$
$$\chi(\chi) \longrightarrow \mu^+\mu^-$$
$$\chi(\chi) \longrightarrow \pi^+\pi^-$$

Kinematically open: $m_\chi > (2)m_i \quad i = e, \mu, \pi$

Total Flux

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





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

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

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

$\chi\chi \longrightarrow (\dots) \to e^+ e^-$

$e^- + \gamma \to e^- + \gamma$

Prompt components

Decaying dark matter:

$$\frac{d\phi}{dE_\gamma\, d\Omega}(E_\gamma,\theta) = \frac{1}{4\pi}\frac{1}{\tau\, m_{\mathrm{DM}}}\frac{dN}{dE_\gamma}(E_\gamma)\, D(\theta)$$

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

Particle properties

Energy spectrum

D-factor

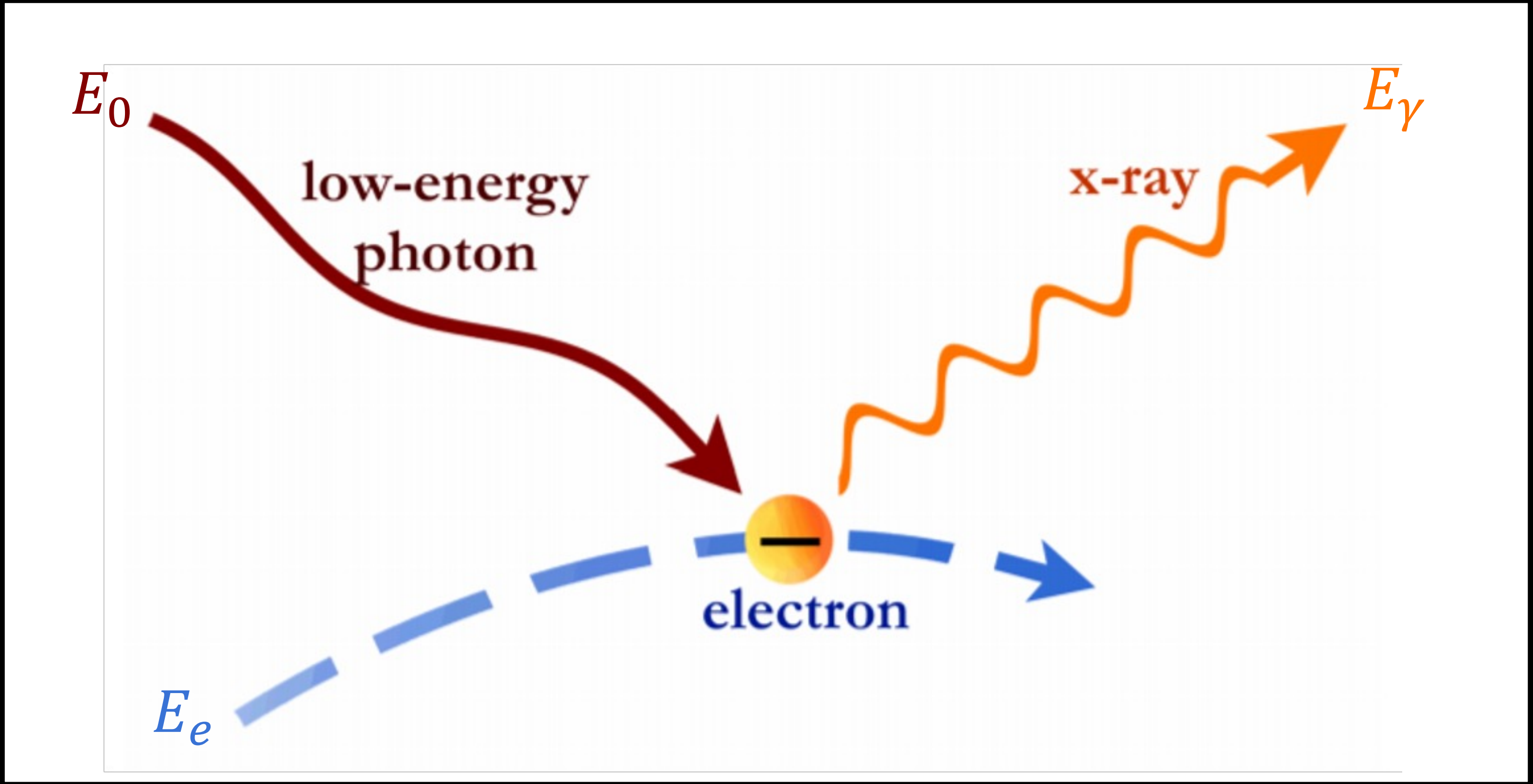
Annihilating dark matter:

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

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

Inverse Compton scattering

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



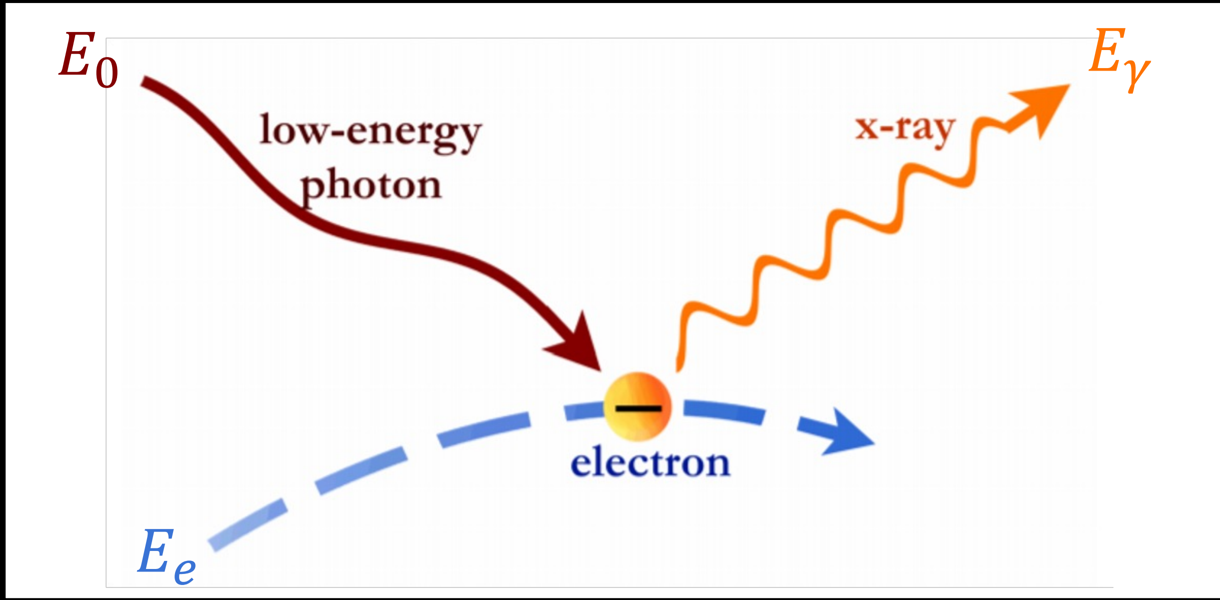
3 kind of photons:

- CMB
- IR (dust)
- Optical (starlight)

Inverse Compton scattering

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

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



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

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

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

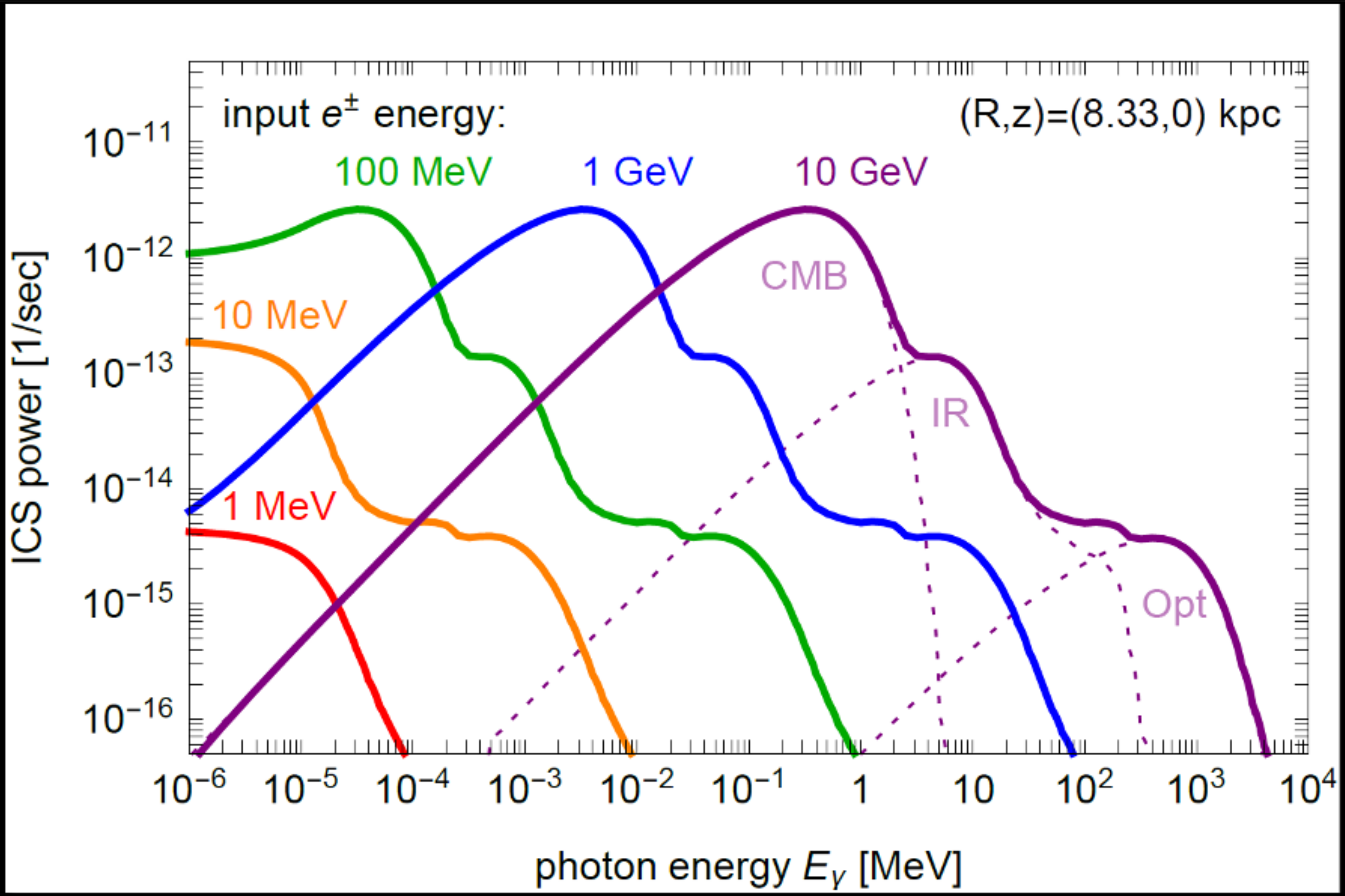
Emissivity

$e^{\pm}$

Differential Power

Number density

ICS Power



input $e^{\pm}$ energy:
(R,z)=(8.33,0) kpc
100 MeV
1 GeV
10 GeV
10 MeV
1 MeV
CMB
IR
Opt
ICS power [1/sec]
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4}
photon energy E_{γ} [MeV]

Electron number density

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

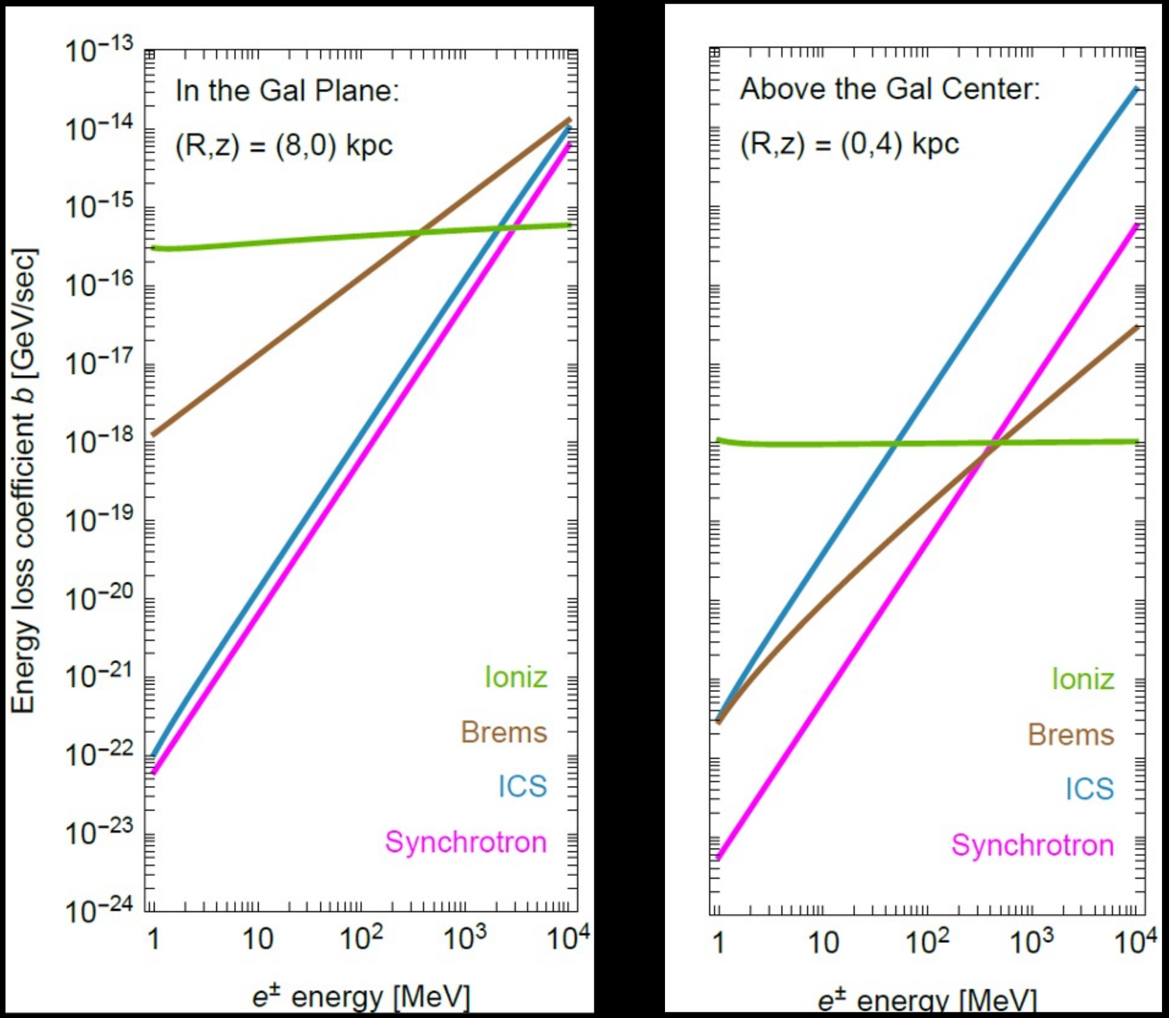
$$Q_e(\tilde{E}_e,\vec{x}) = \frac{\langle\sigma_{ann}v\rangle}{2\,m_{DM}^2}\frac{dN_{e^\pm}}{d\tilde{E}_e}\rho_{DM}^2$$

Particle Properties

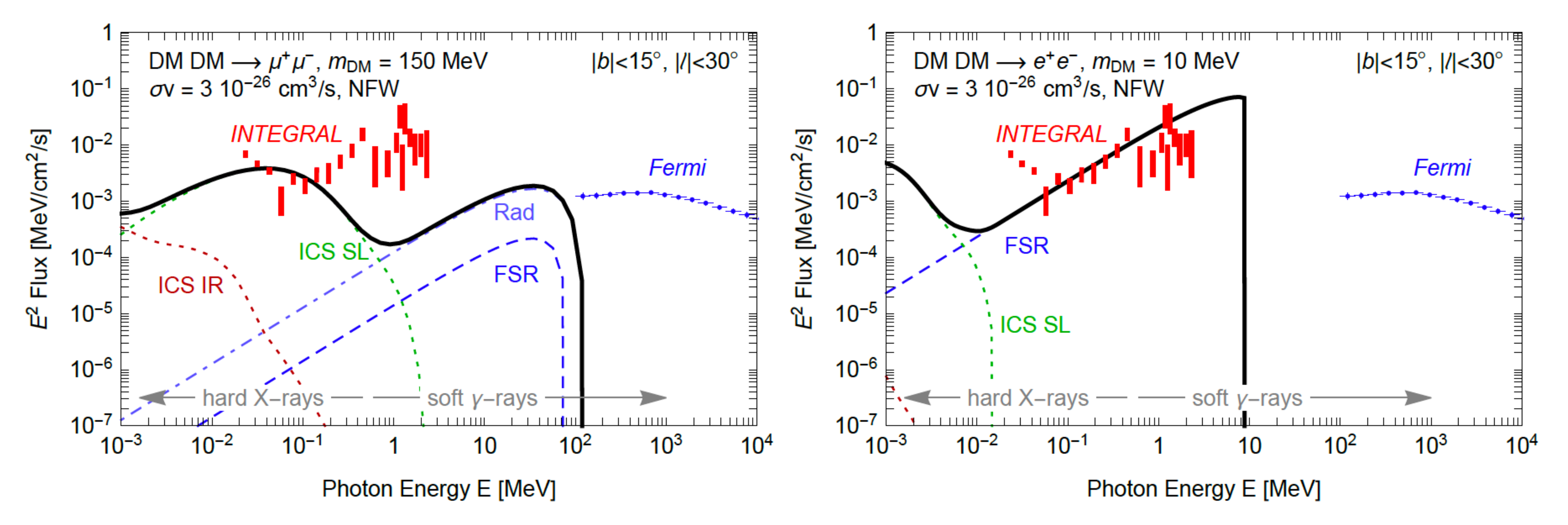
Energy spectrum

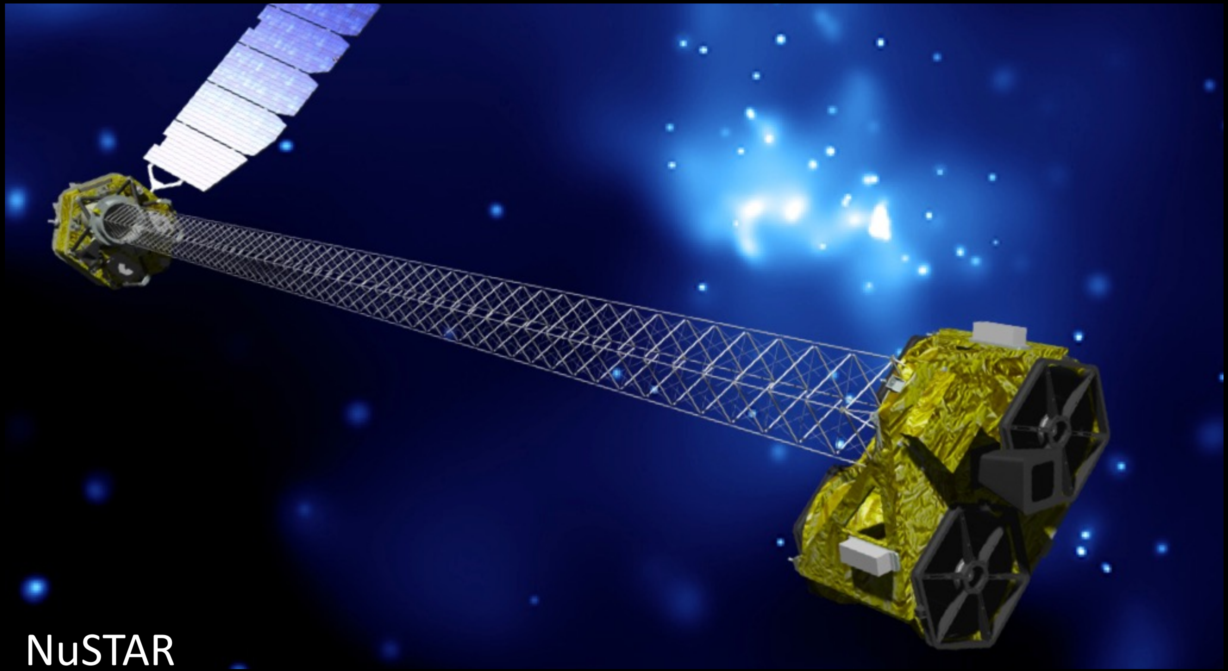
Density distribution

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

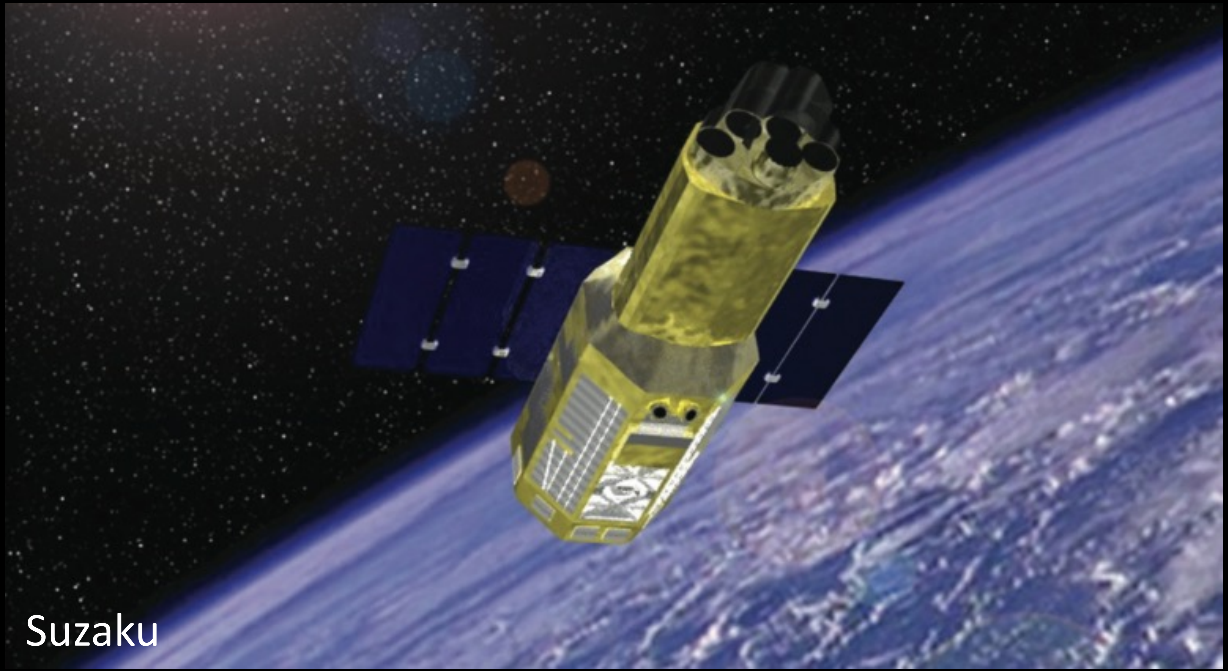


Total flux

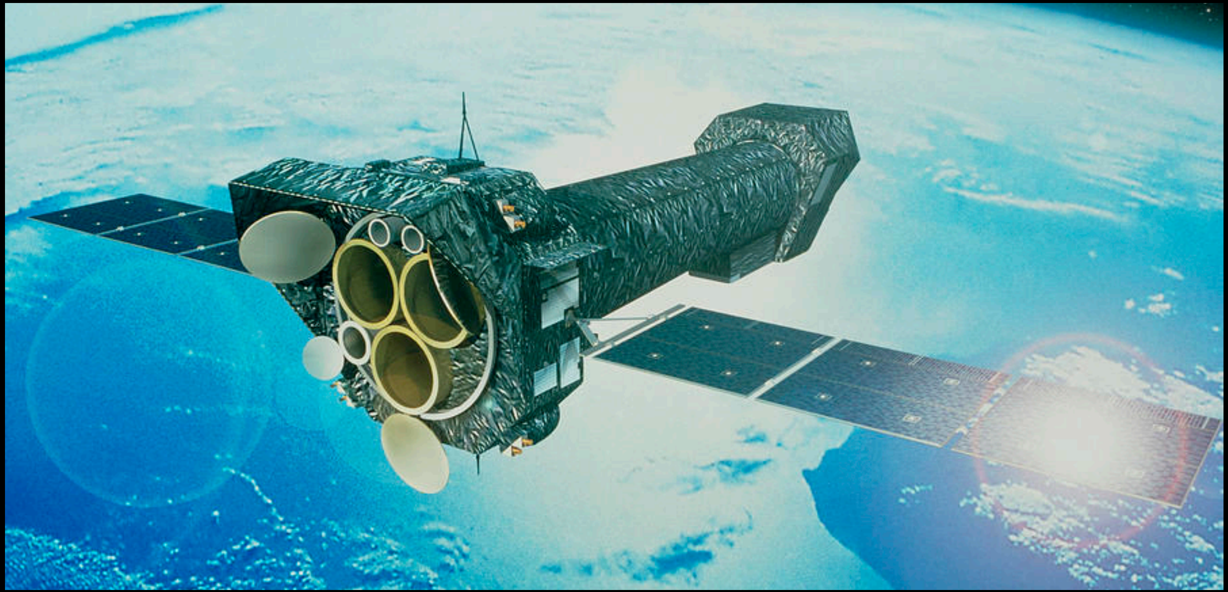

DM DM ⟶ μ⁺μ⁻, m_{DM} = 150 MeV
σv = 3 10⁻²⁶ cm³/s, NFW
|b|<15°, |l|<30°
INTEGRAL
Fermi
Rad
ICS SL
ICS IR
FSR
hard X–rays
soft γ–rays
E² Flux [MeV/cm²/s]
Photon Energy E [MeV]
DM DM ⟶ e⁺e⁻, m_{DM} = 10 MeV
σv = 3 10⁻²⁶ cm³/s, NFW
|b|<15°, |l|<30°
INTEGRAL
Fermi
FSR
ICS SL
hard X–rays
soft γ–rays
E² Flux [MeV/cm²/s]
Photon Energy E [MeV]



NuSTAR



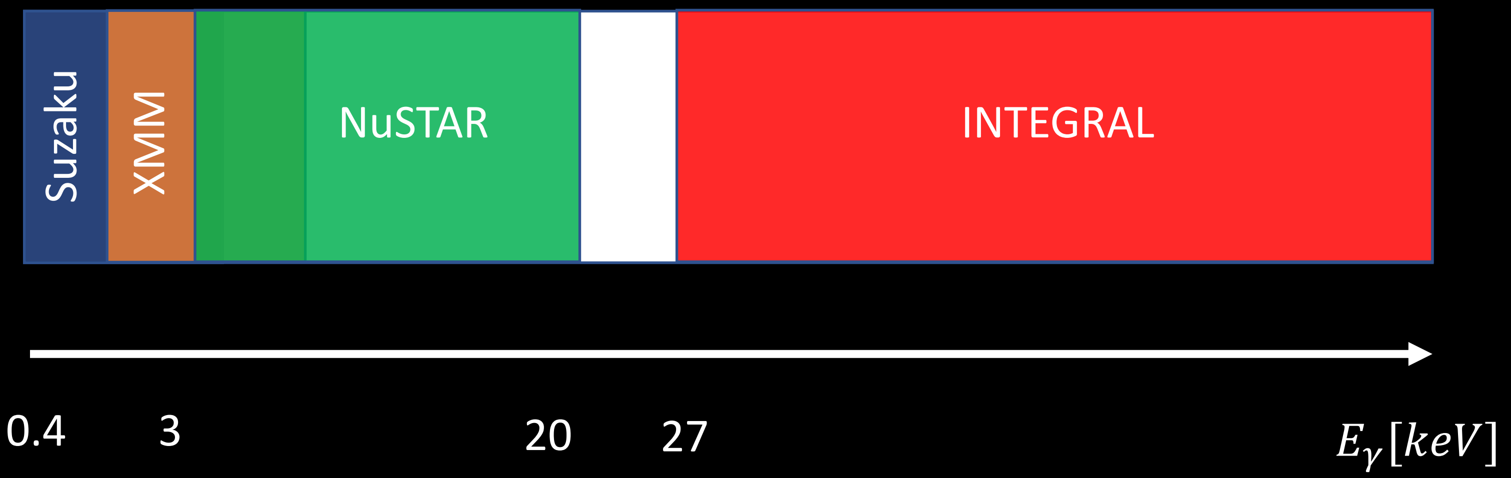
Suzaku



XMM-Newton

INTEGRAL

Energy range



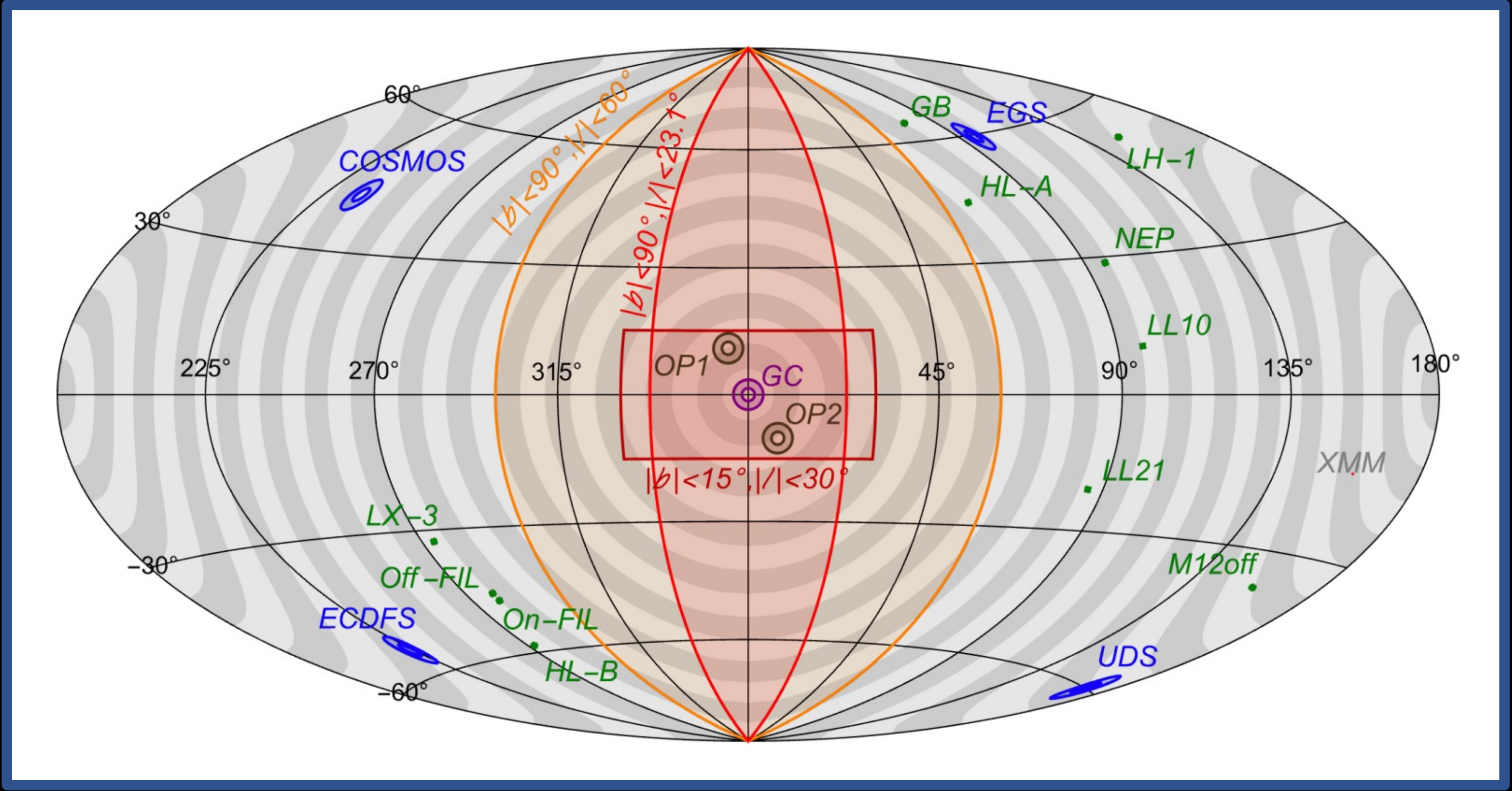
Suzaku: 0.4 keV – 5 keV

NuSTAR: 3 keV – 20 keV

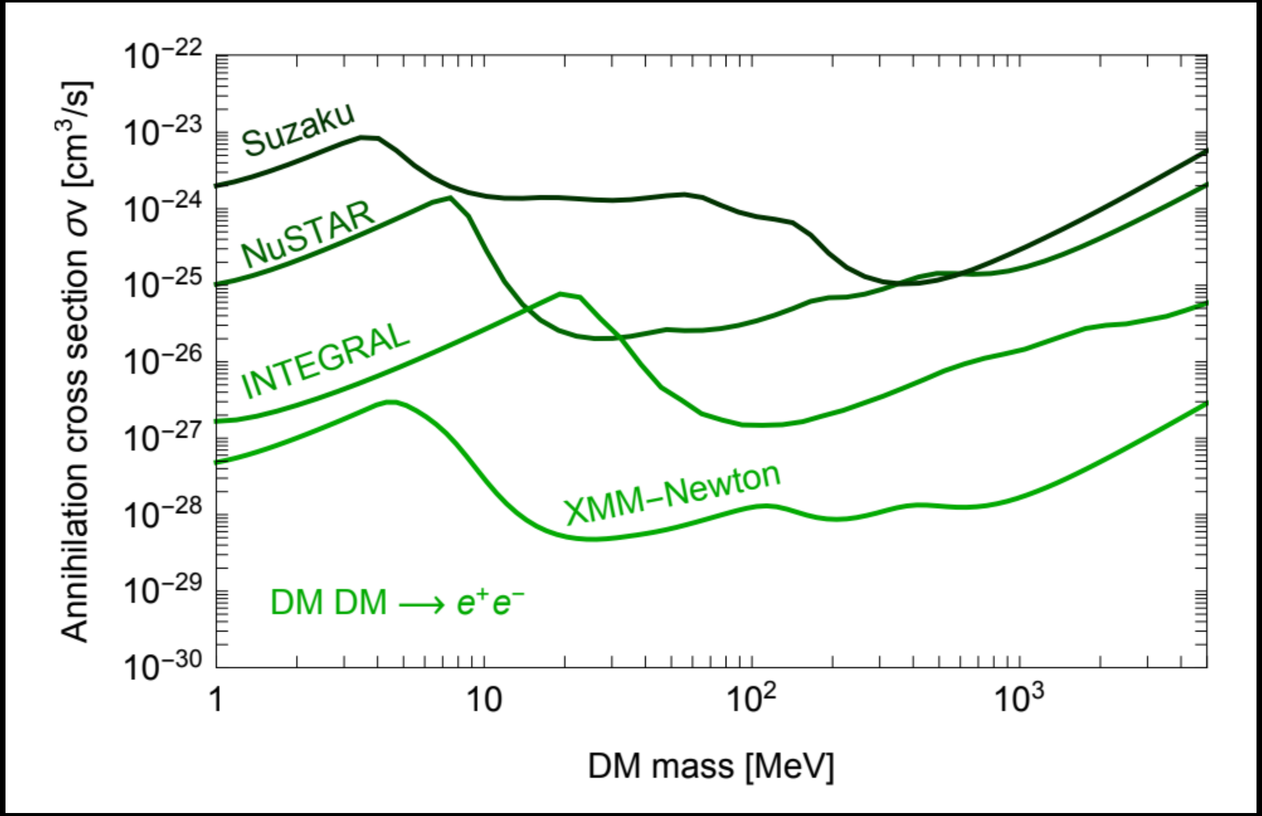
XMM-Newton: 2.5 keV – 8 keV

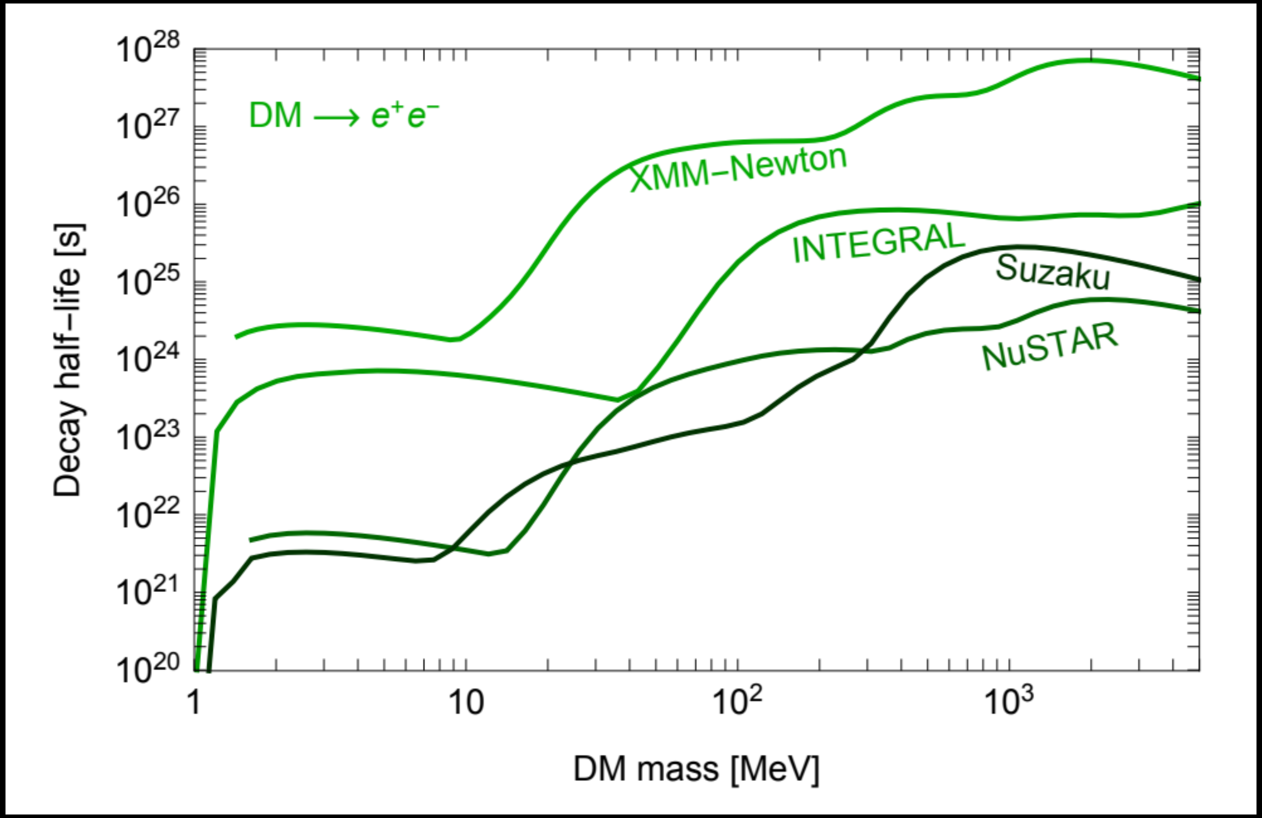
INTEGRAL: 27 keV – 1.8 MeV

Observations



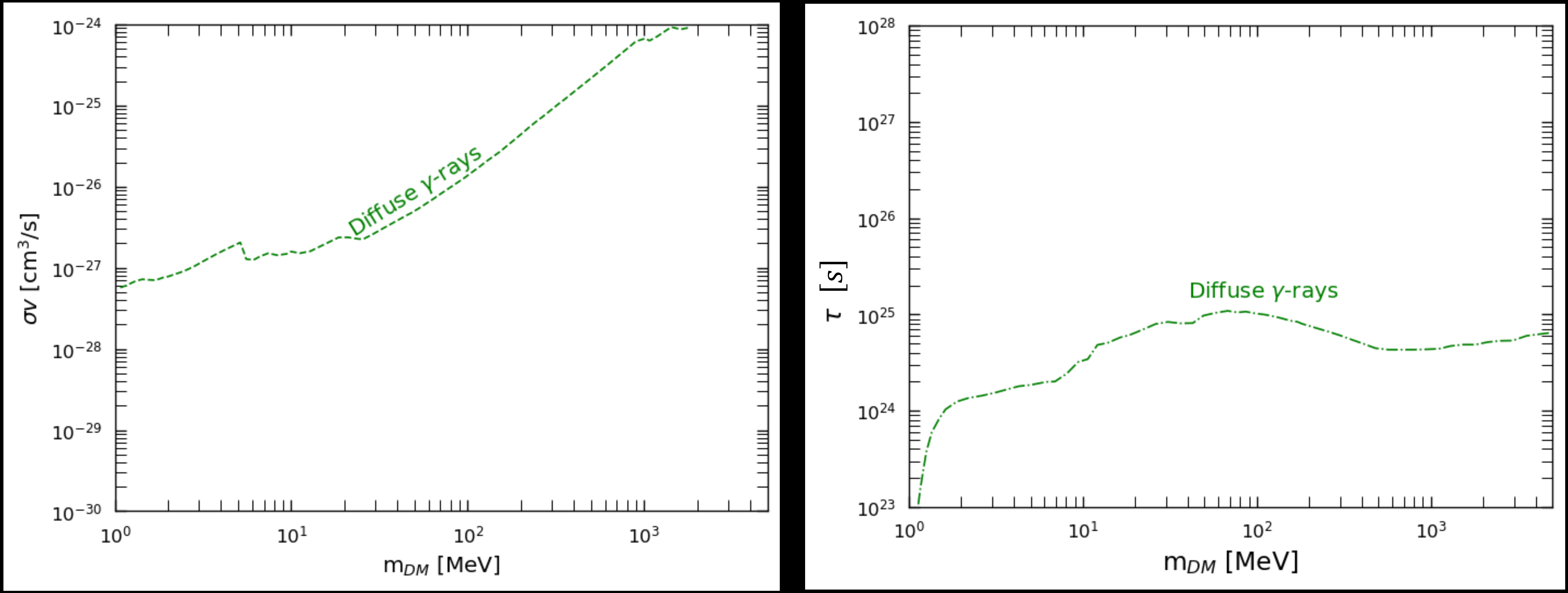
Constraints on electron channel





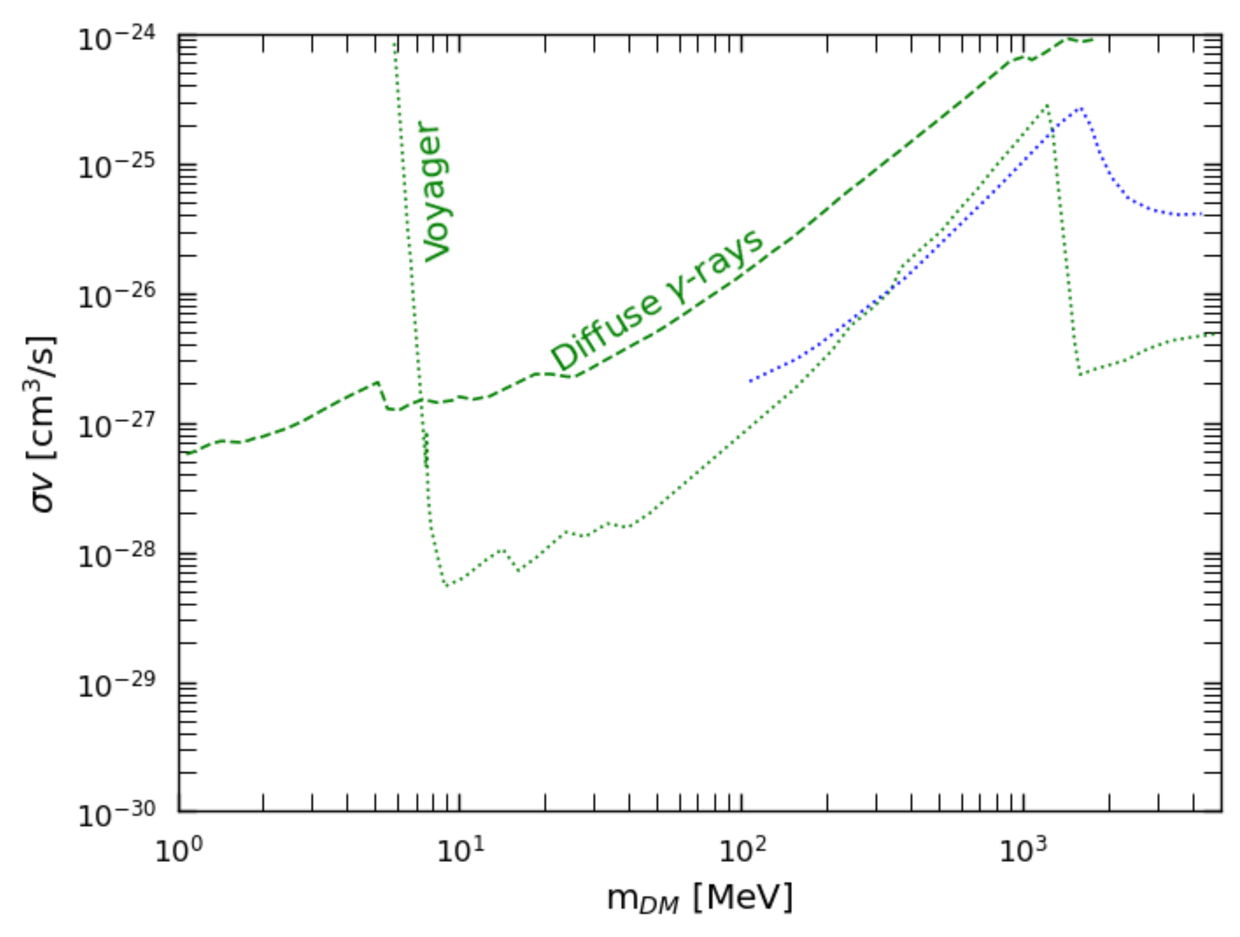
Comparison with the literature

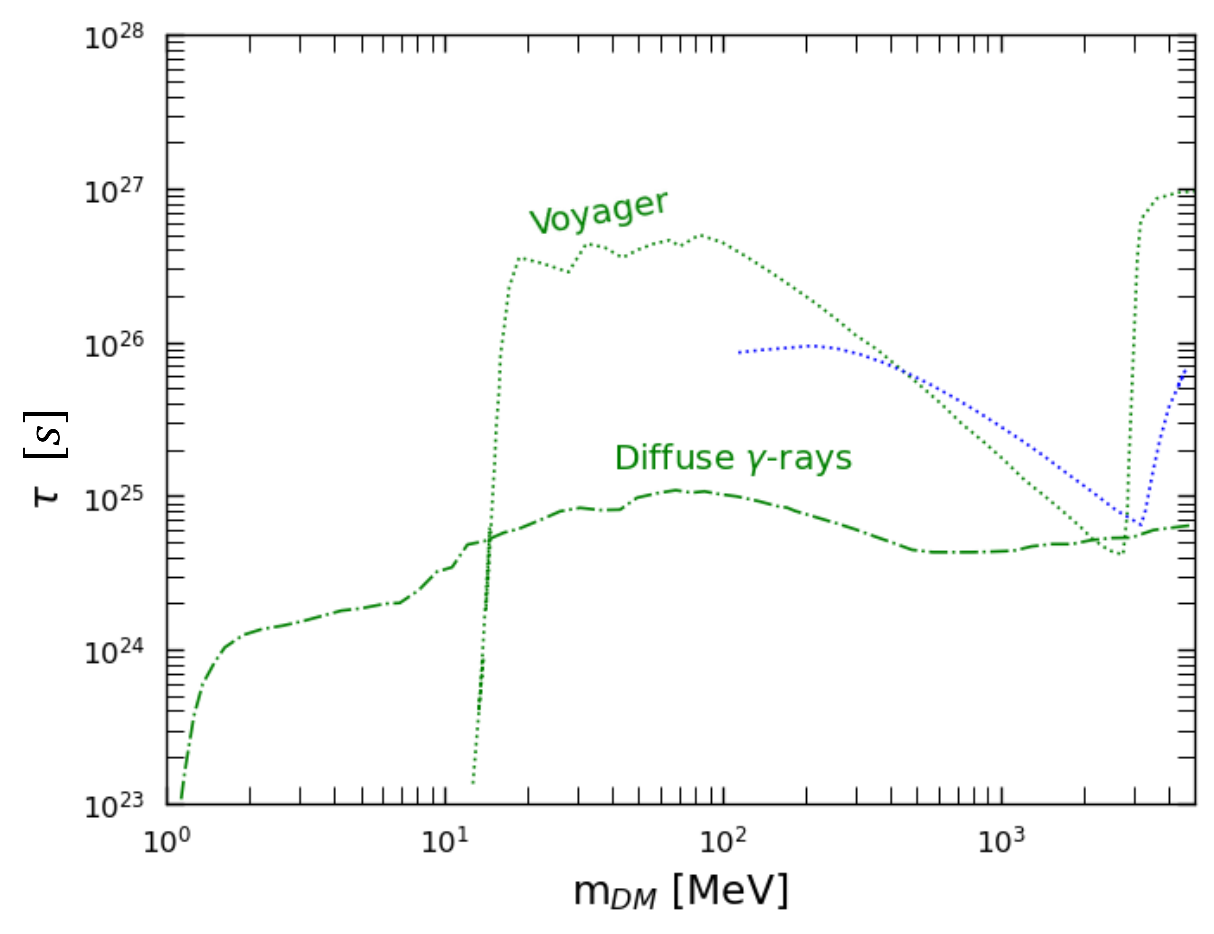
Diffusive gamma-ray constraints



Essig+, JHEP 11 (2013) 193

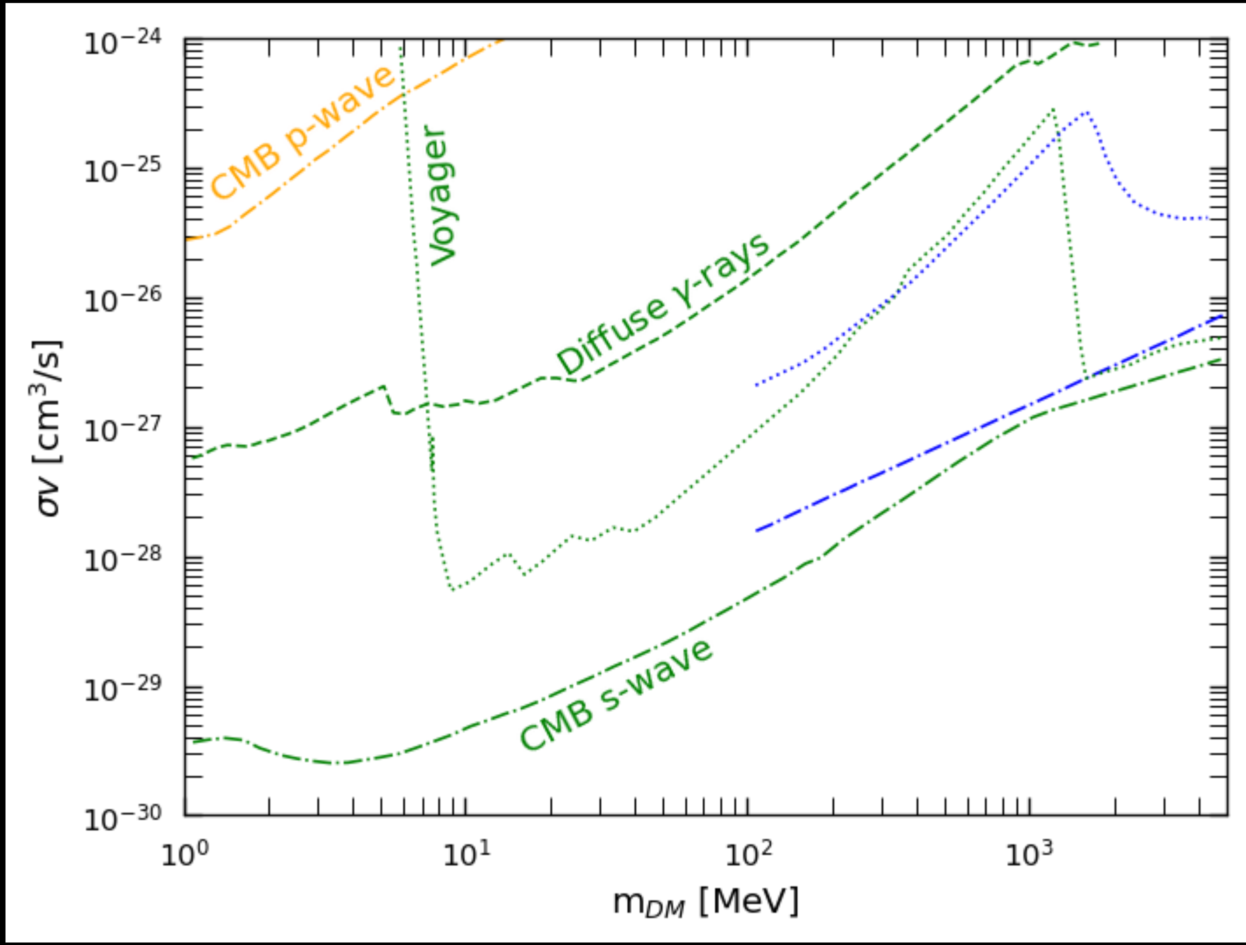
Voyager constraints

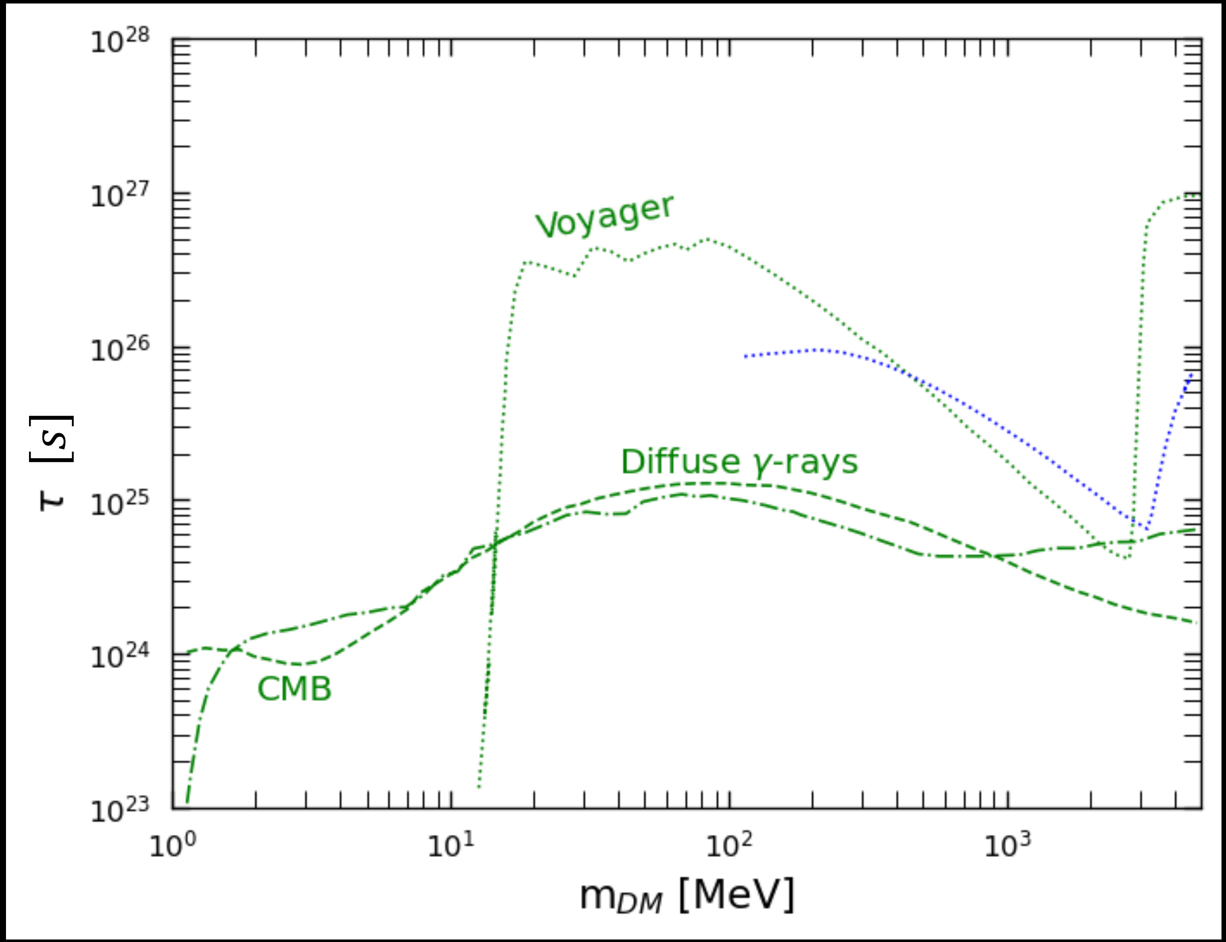




Boudaud et al., Phys. Rev. Lett. 119 (2017) 021103

CMB constraints

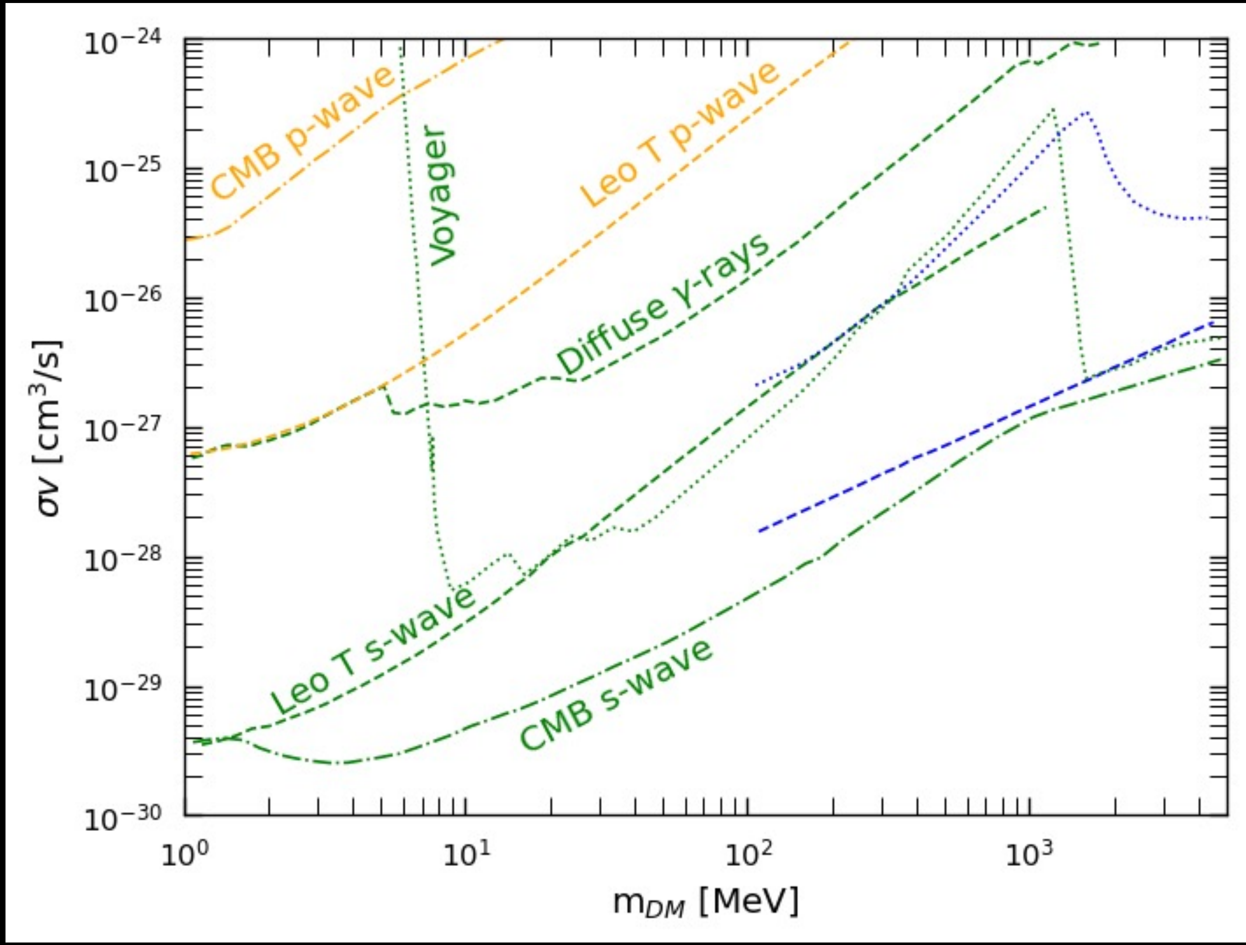


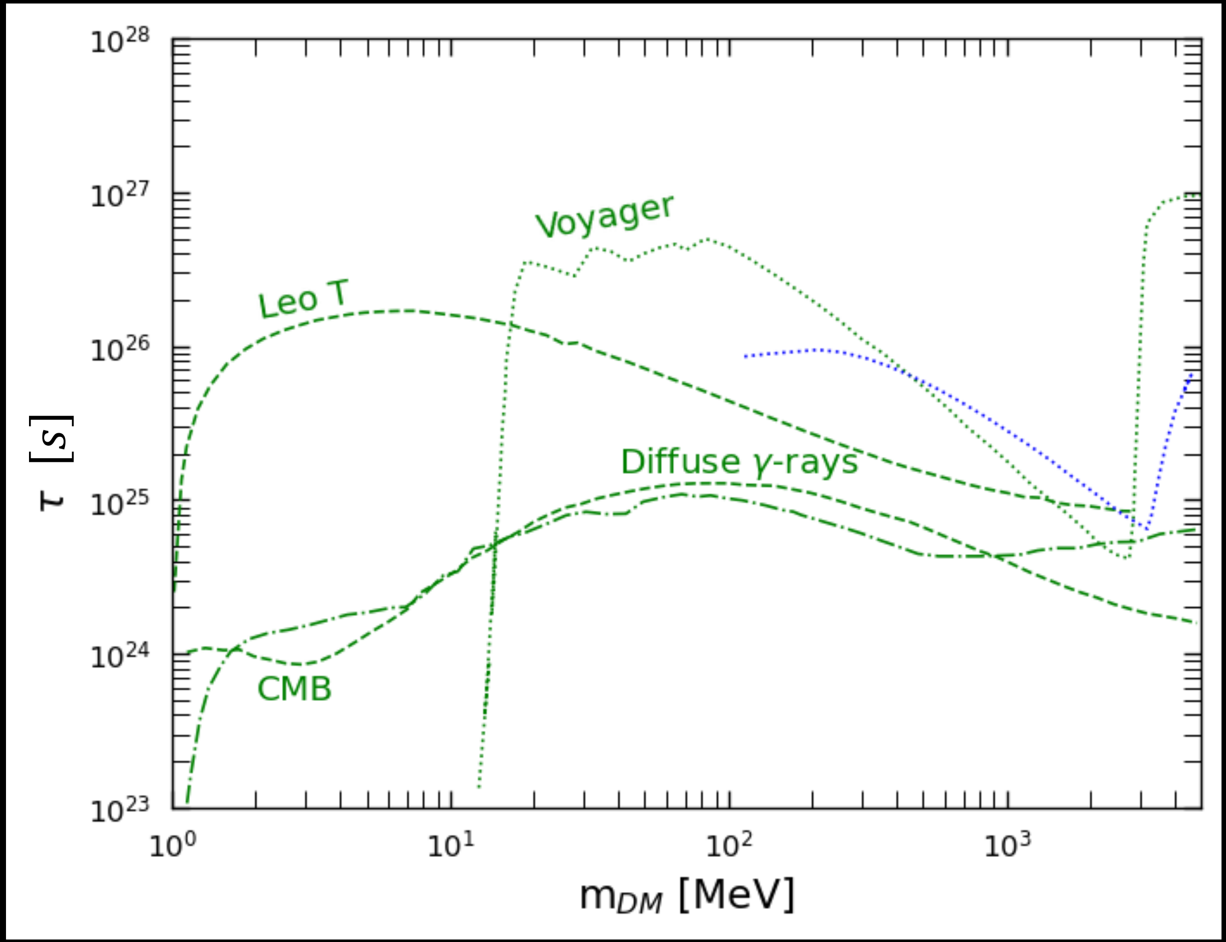


Slatyer, Phys. Rev. D 93 (2016) 023527 Lopez-Honorez et al., JCAP 07 (2013) 046

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

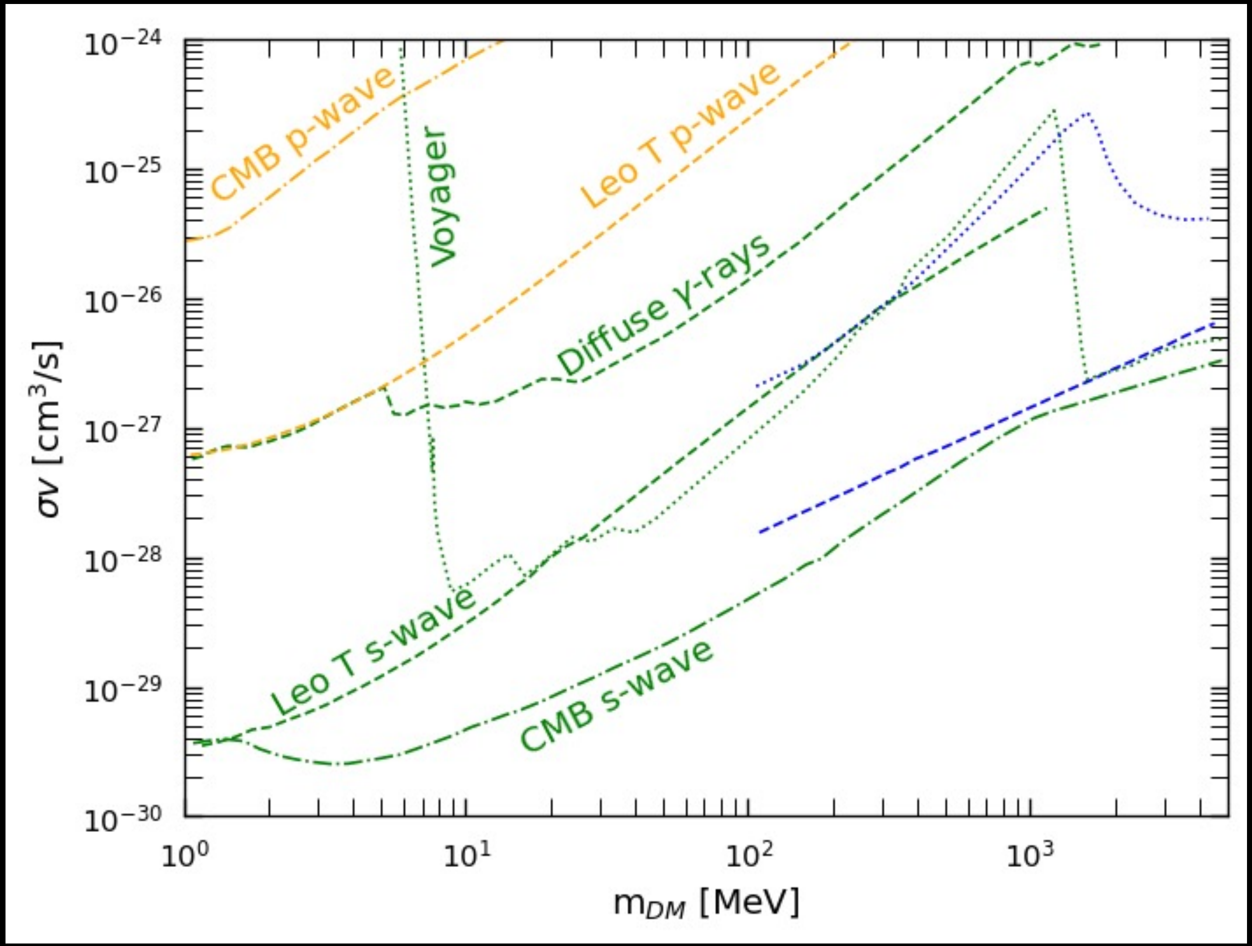
Leo T constraints

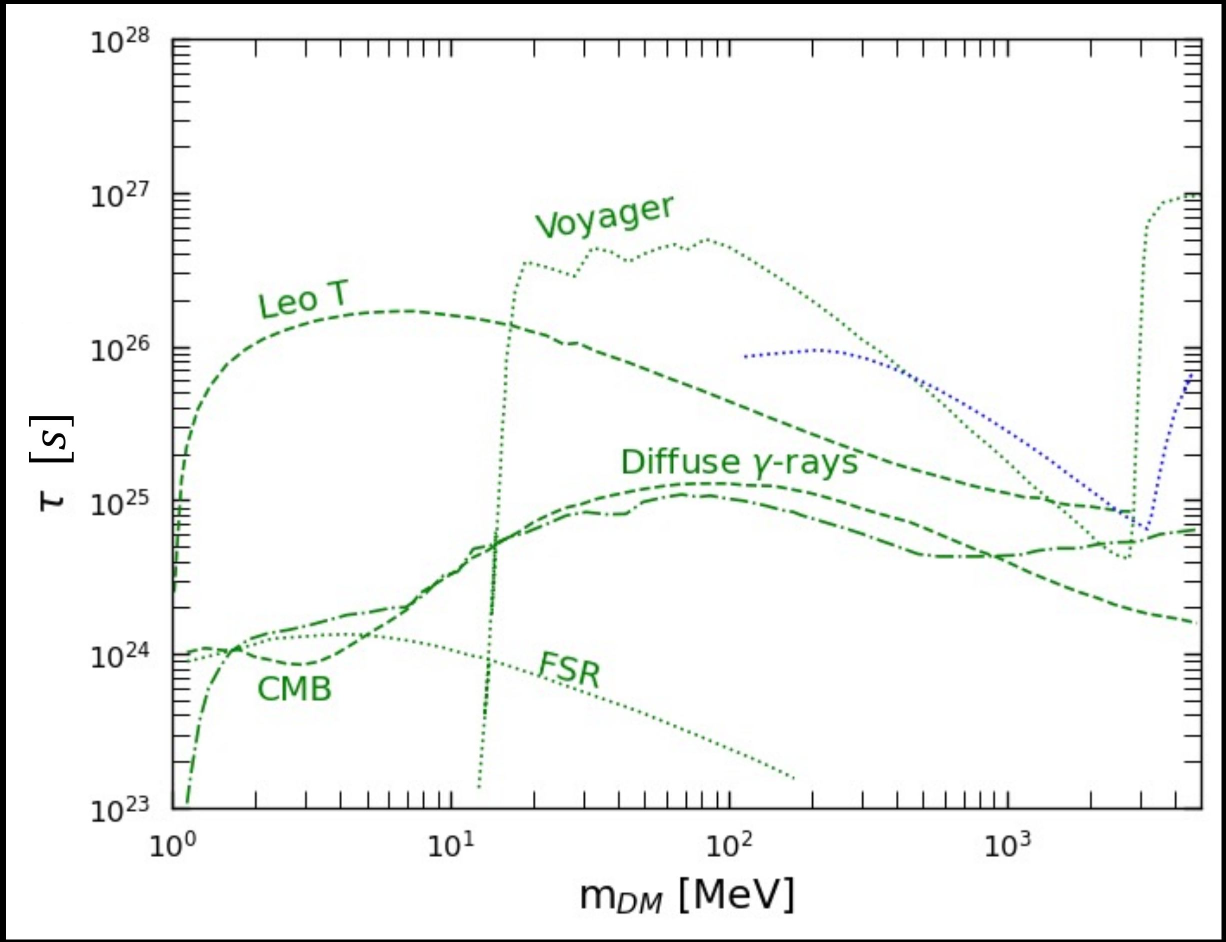




Wadekar and Wang, *Phys.Rev.D* 106 (2022) 7, 075007

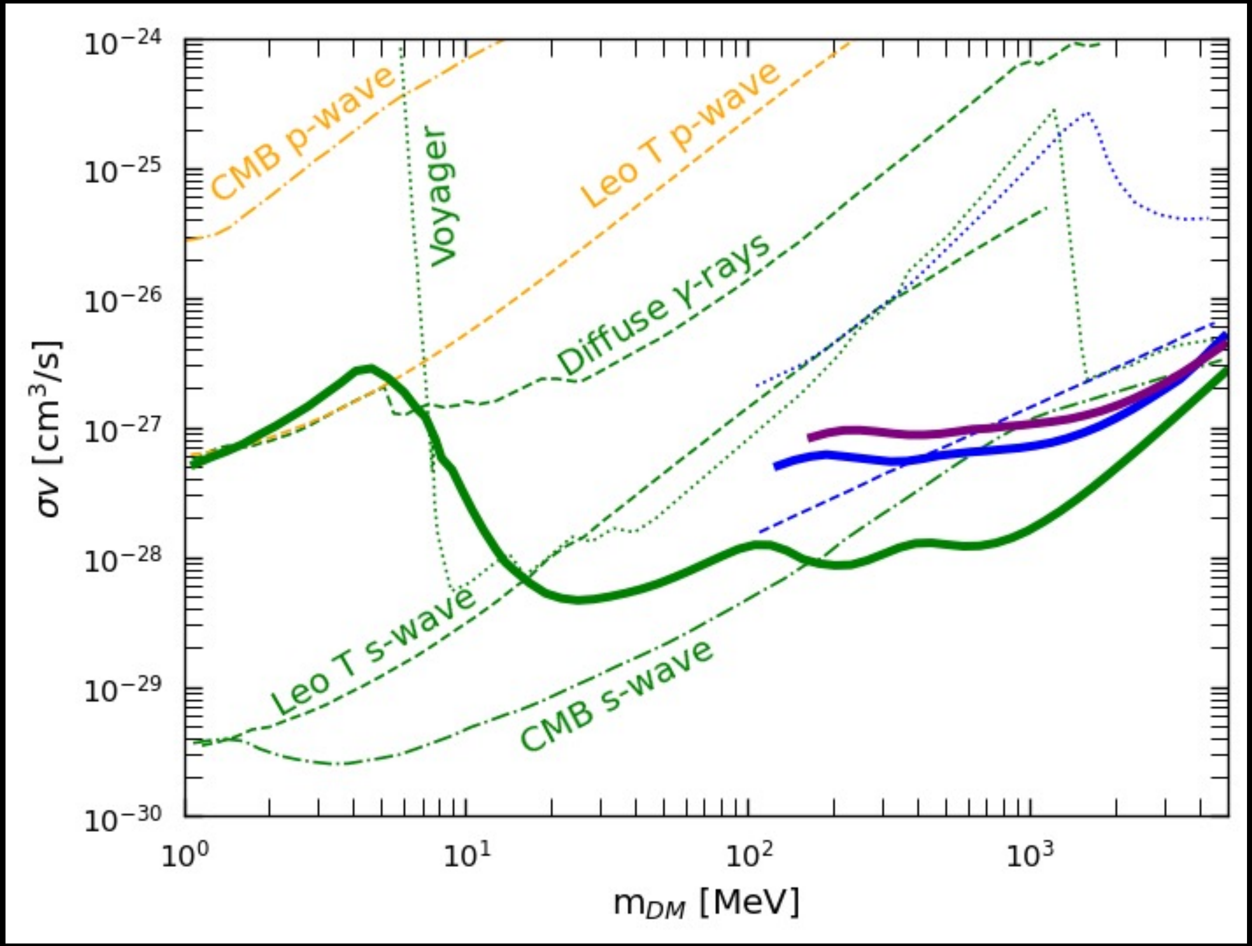
Final state radiation with INTEGRAL

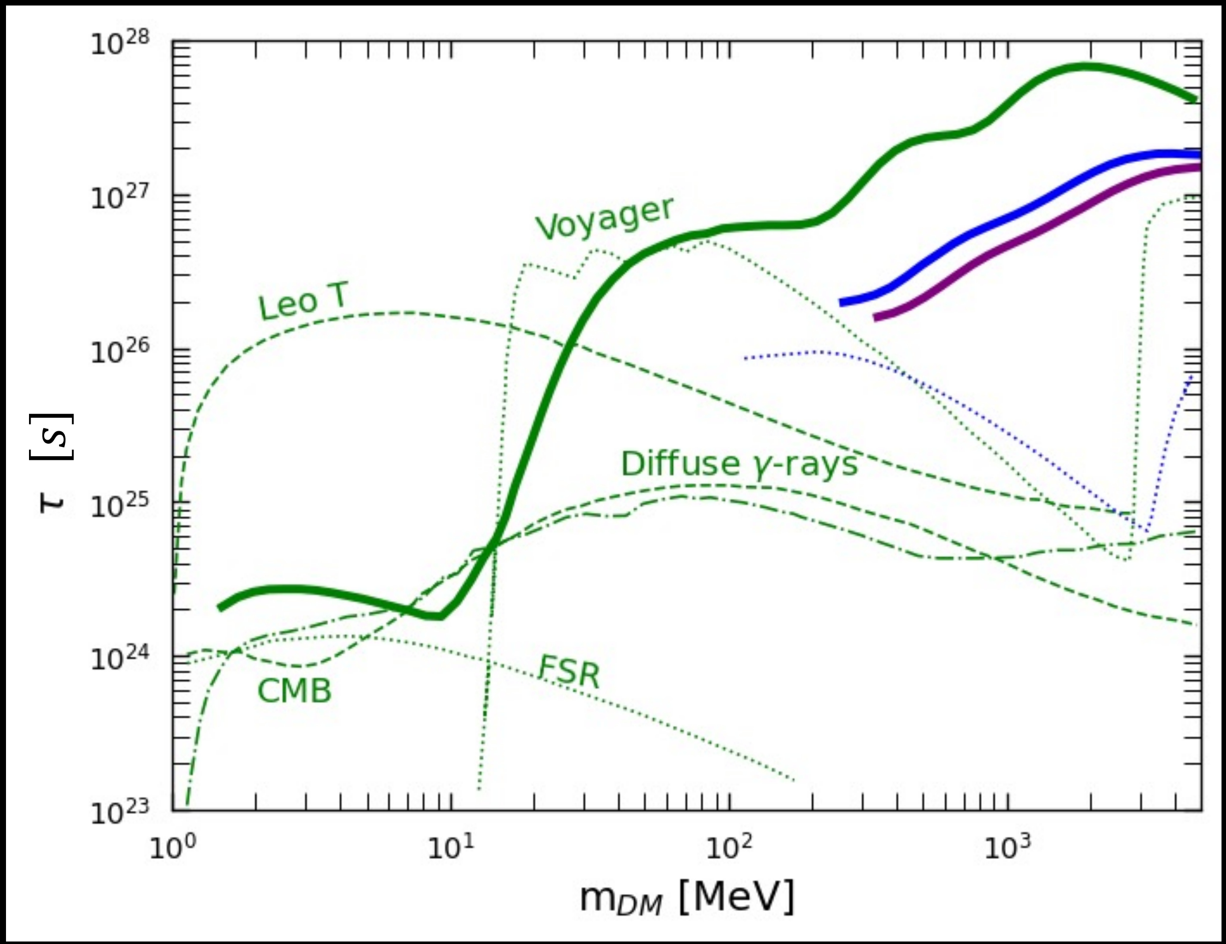




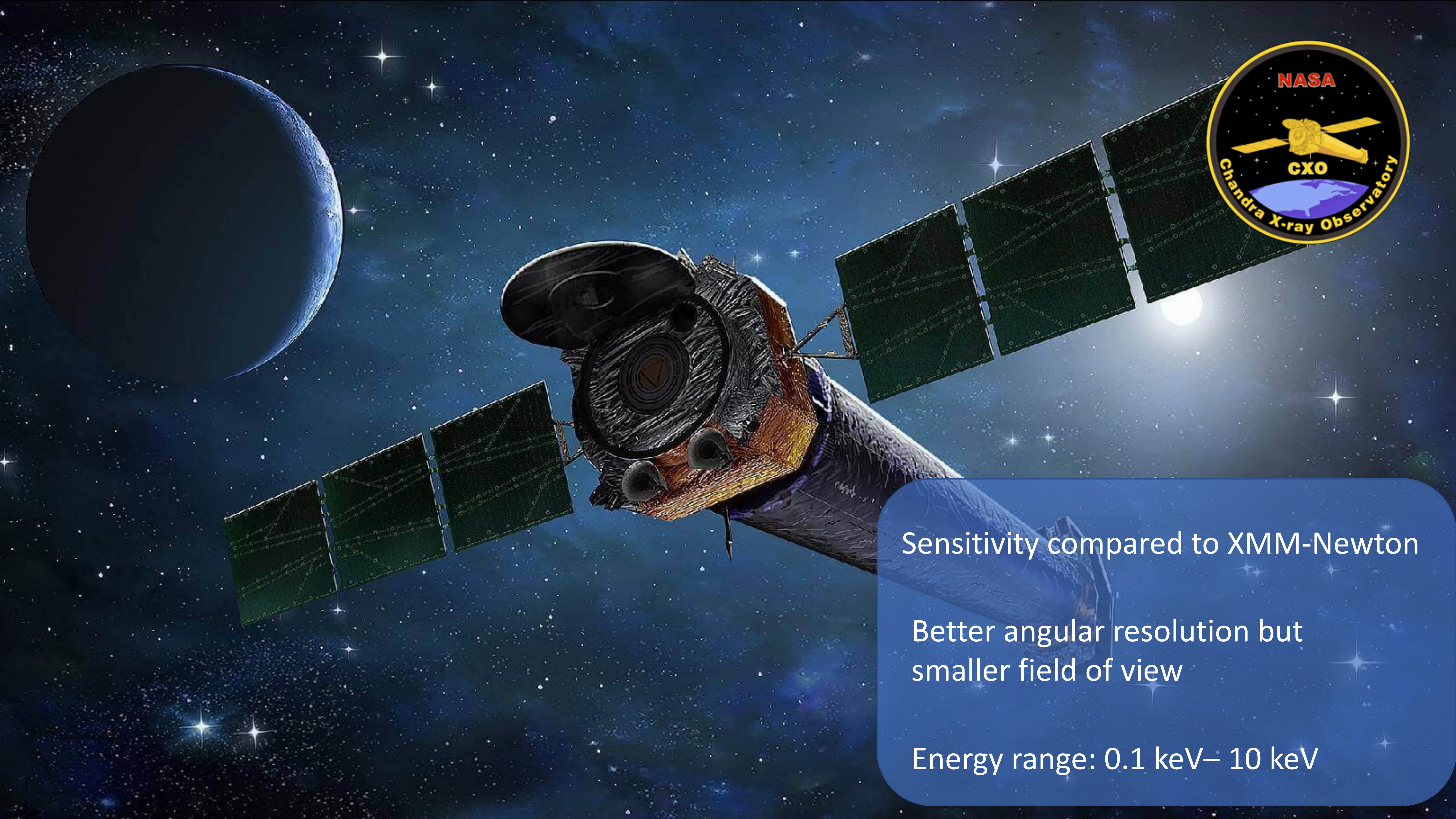
Calore+, Mon. Not. Roy. Astron. Soc. 520 (2023) 4167–4172

Comparison with bounds





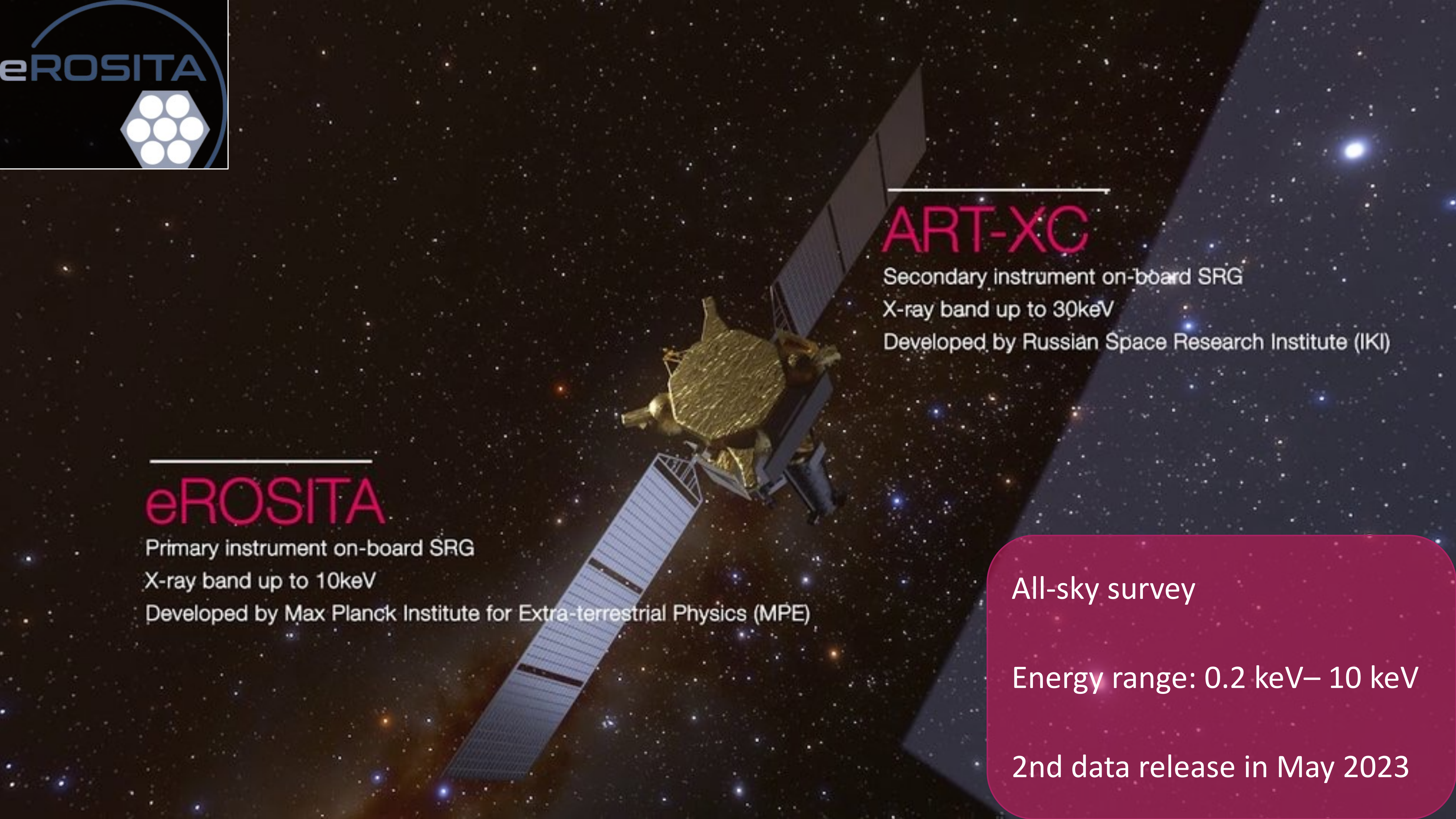
An eye toward the future



Sensitivity compared to XMM-Newton

Better angular resolution but smaller field of view

Energy range: 0.1 keV– 10 keV



All-sky survey

Energy range: 0.2 keV– 10 keV

2nd data release in May 2023

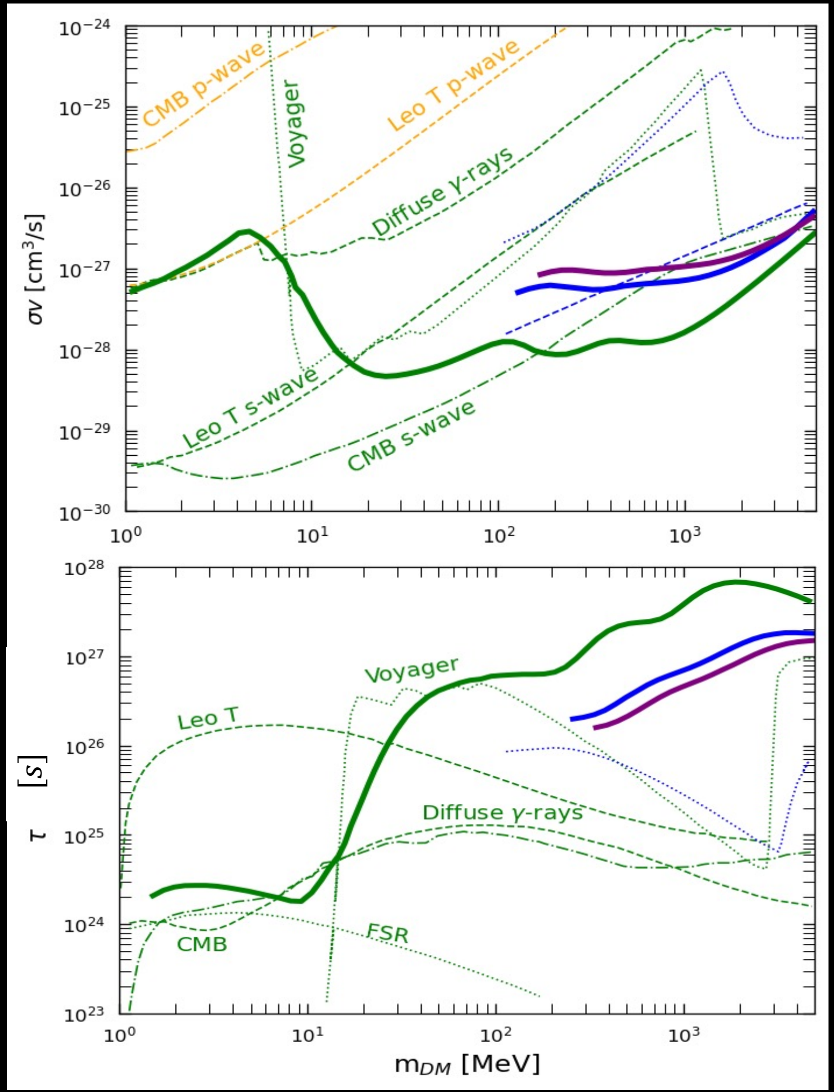
Beyond the Milky Way

Conclusions

1. X-ray telescopes can help in closing the MeV gap

2. Inverse-Compton scattering on the photon bath is a powerful tool to study sub-GeV dark matter

3. Strongest bounds on
   - Annihilating DM (if p-wave): $m_{DM} \geq 20$ MeV
   - Decaying DM: $m_{DM} \geq 100$ MeV



Conclusions

Thank you for your attention!

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