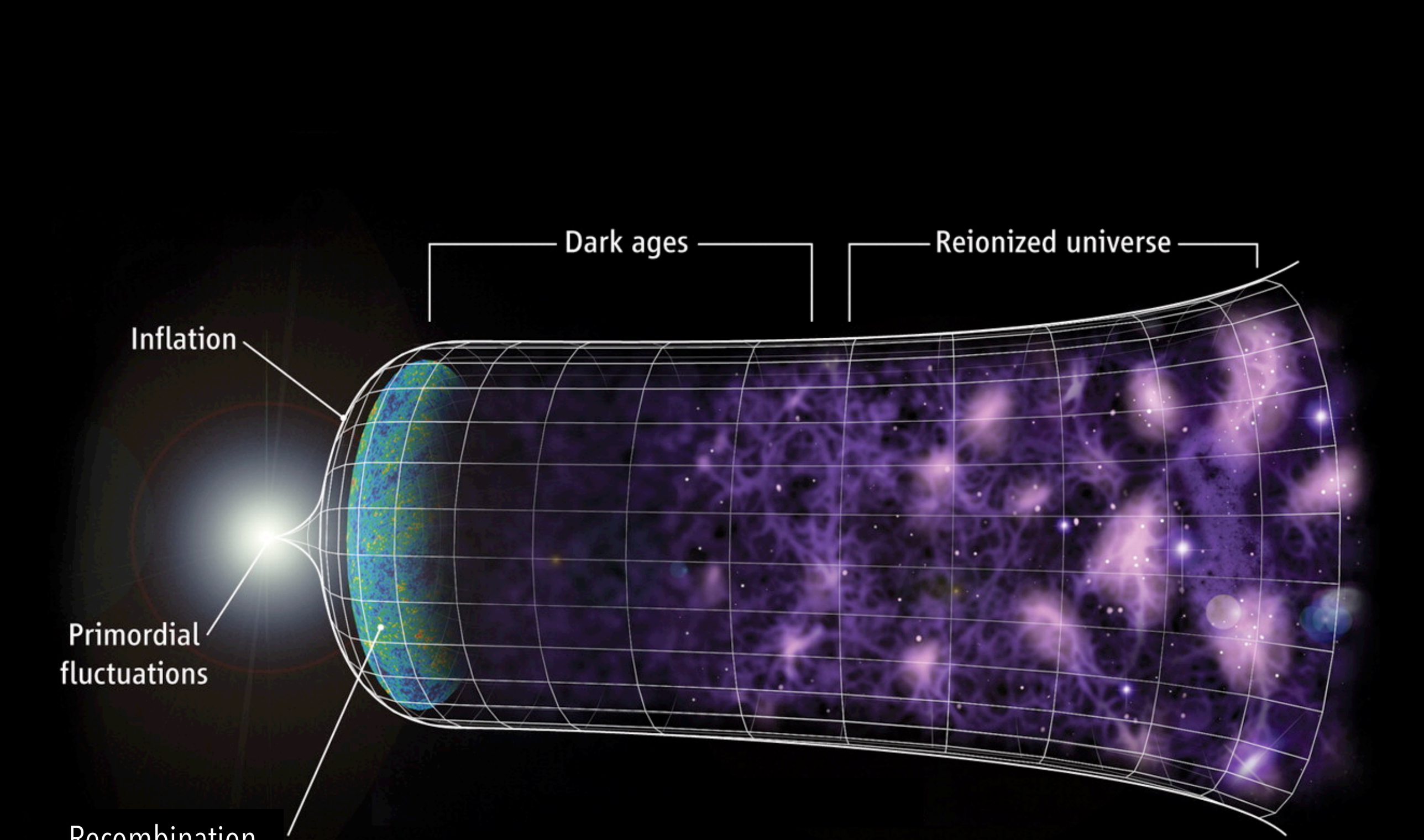
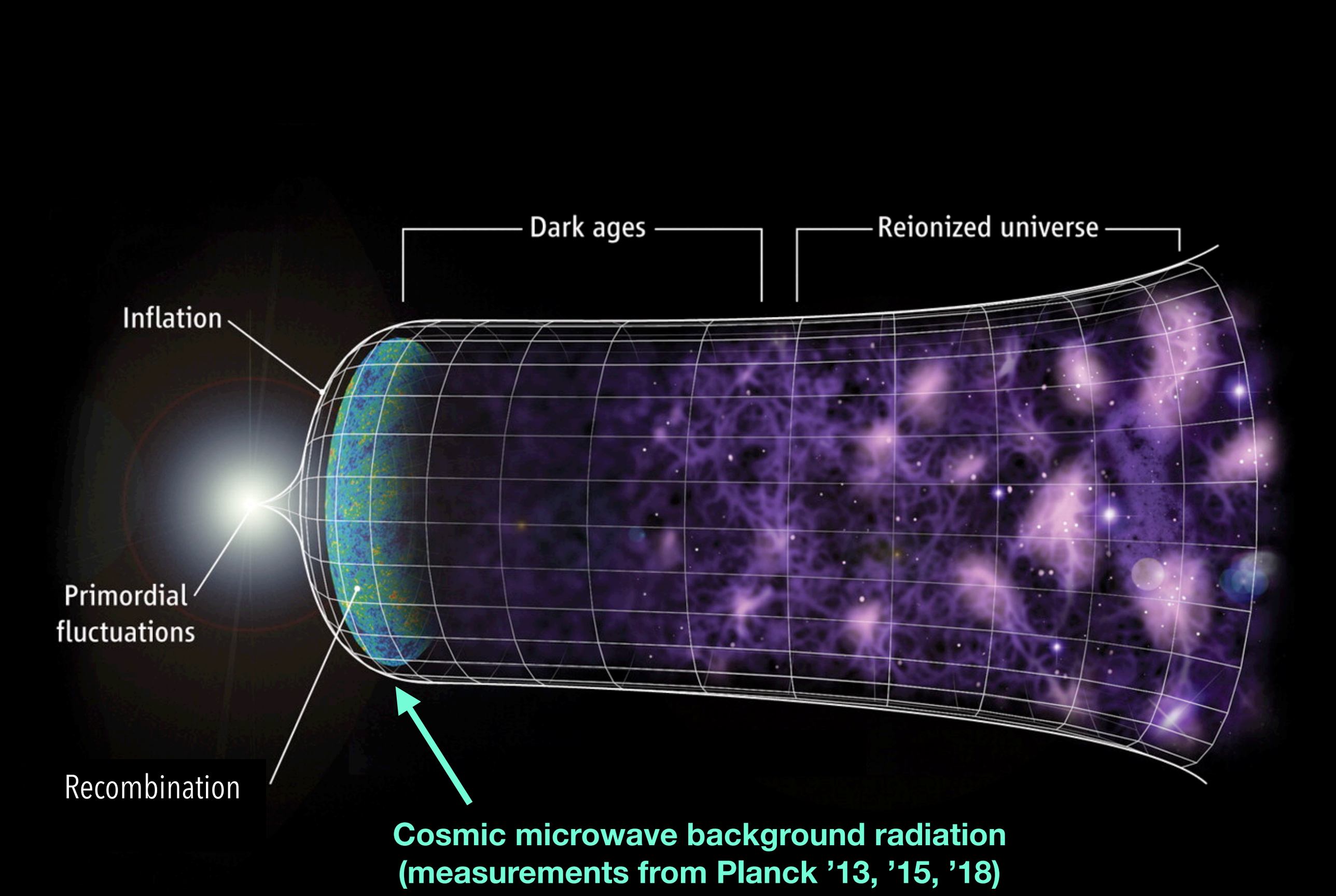
Constraining Dark Matter with the CMB

Kimberly Boddy
Johns Hopkins University

IPA, Cincinnati

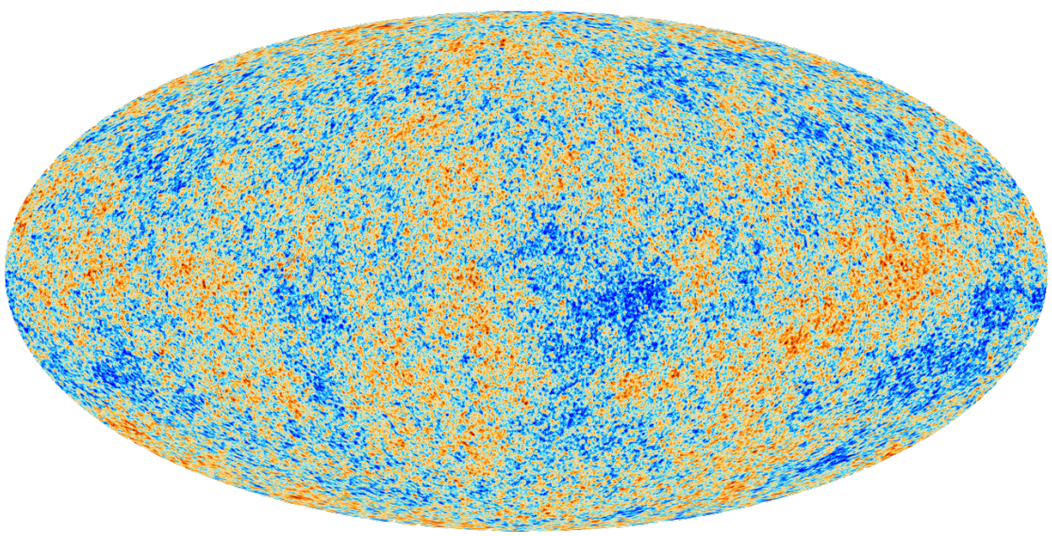
10 October 2018


Dark ages
Reionized universe
Inflation
Primordial fluctuations
Recombination

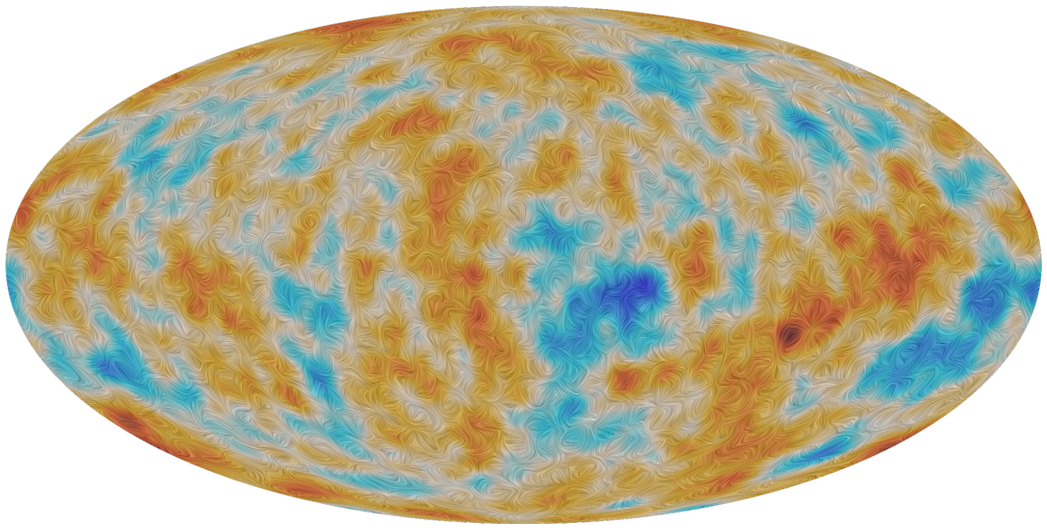

Dark ages
Reionized universe
Inflation
Primordial fluctuations
Recombination
Cosmic microwave background radiation
(measurements from Planck ’13, ’15, ’18)

Planck 2015

Temperature anisotropy



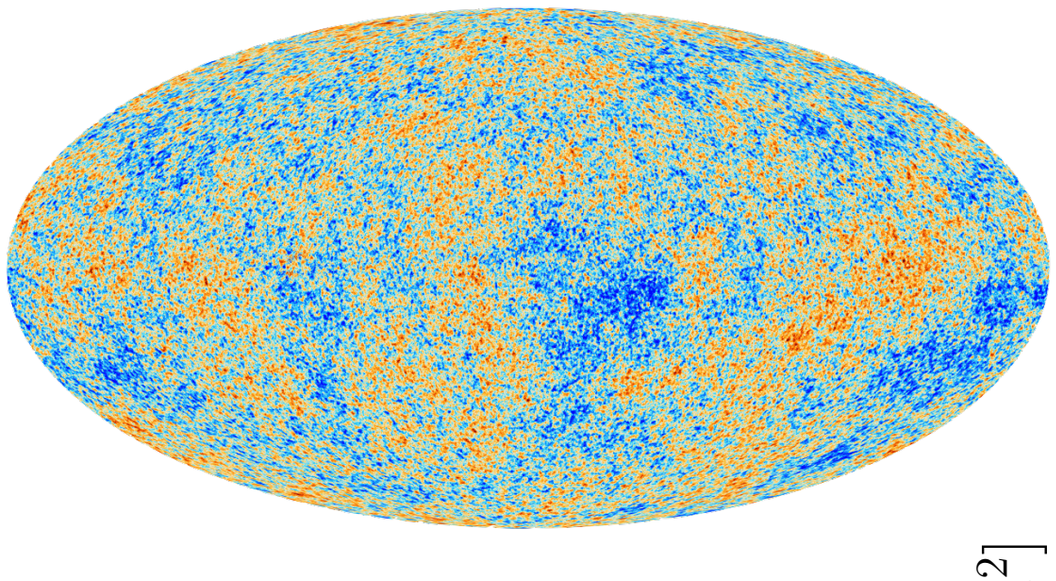
Polarization anisotropy



ESA and Planck Collaboration

Planck 2015

Temperature anisotropy



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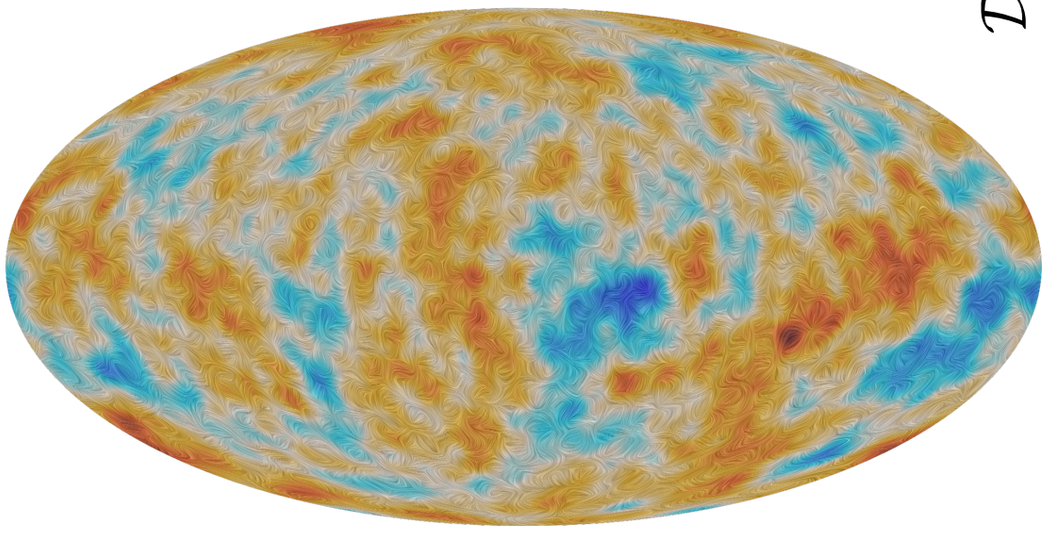
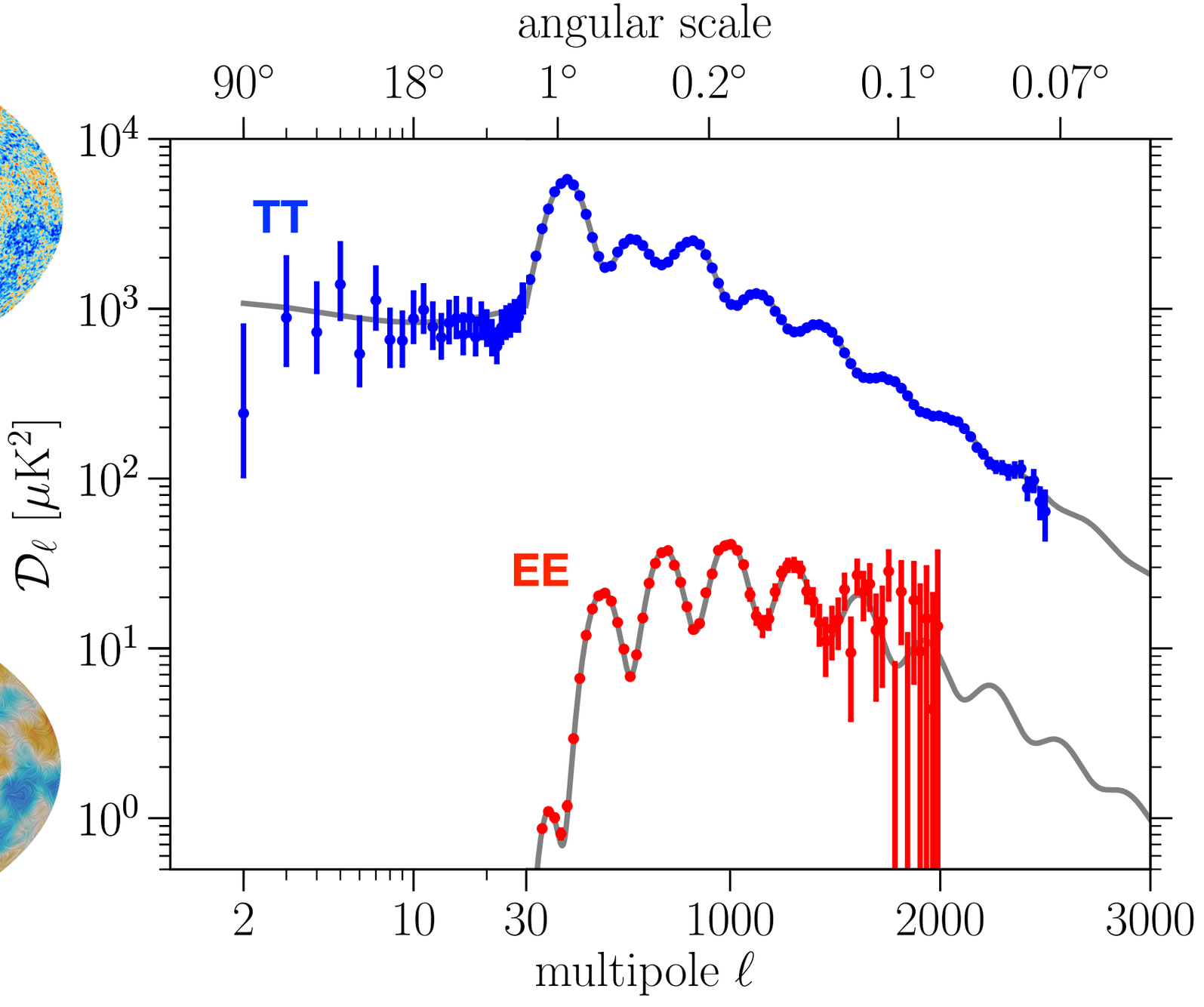
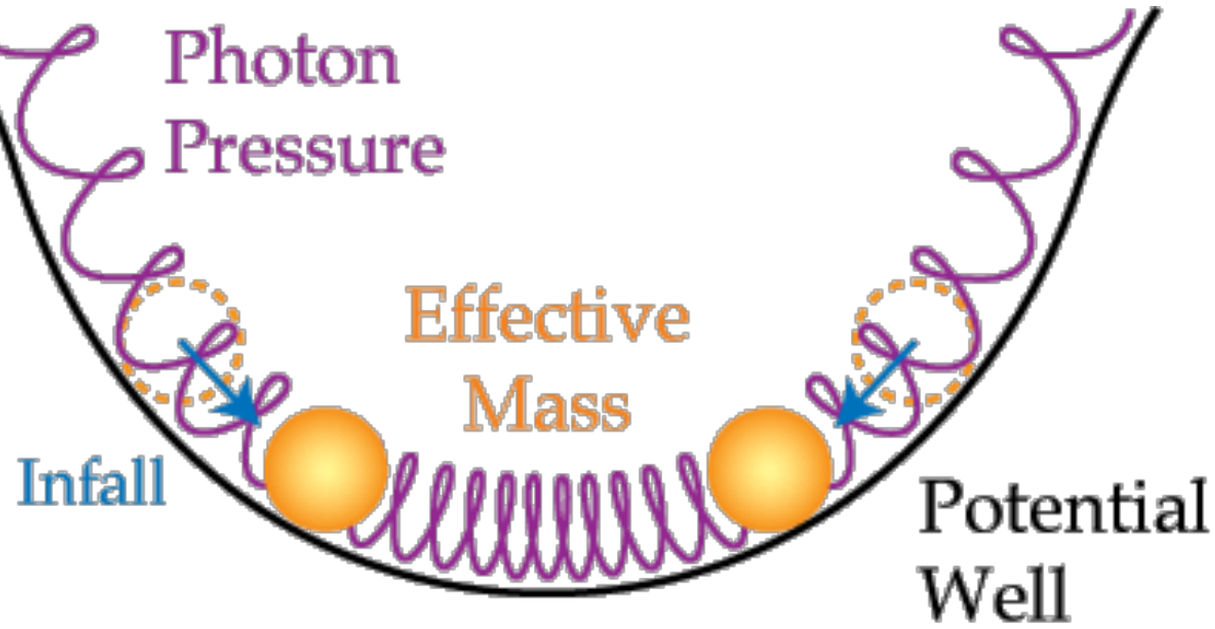




ESA and Planck Collaboration

Baryon Acoustic Oscillations



W. Hu, http://background.uchicago.edu/~whu/index.html

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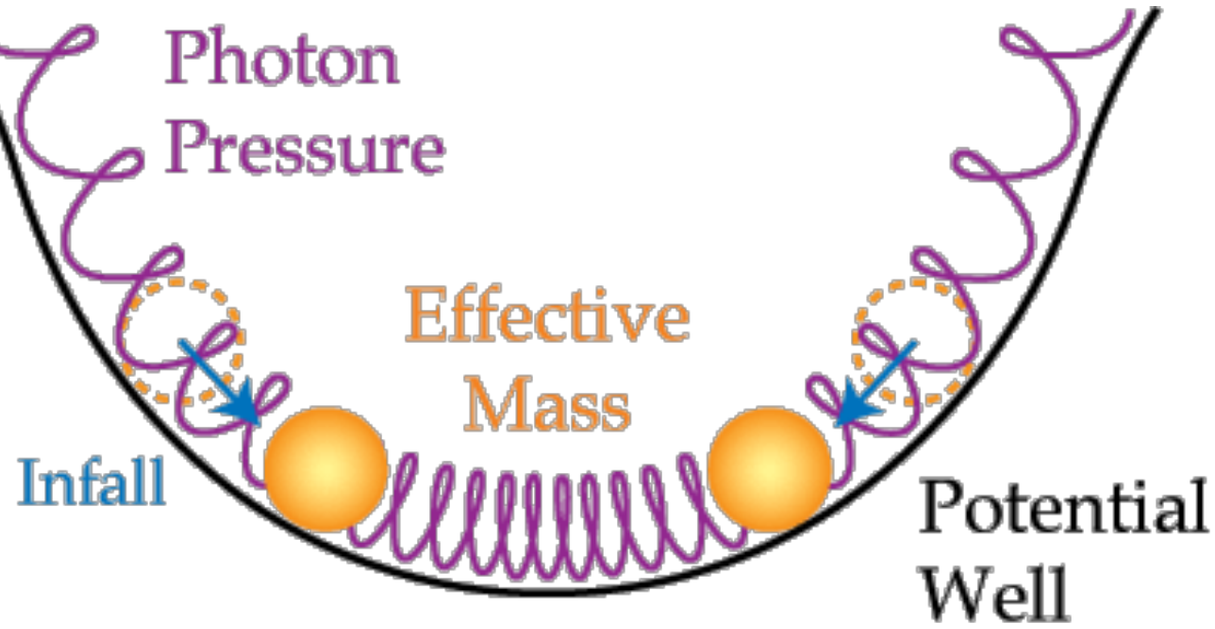
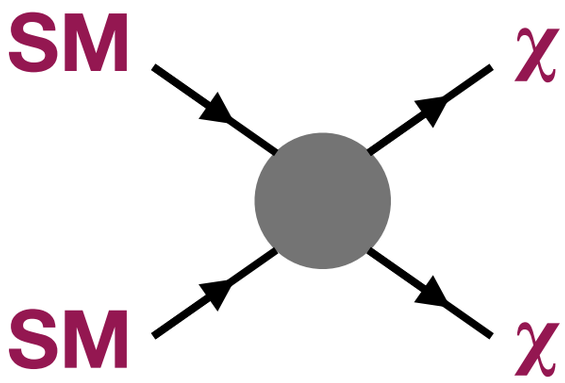


W. Hu, http://background.uchicago.edu/~whu/index.html

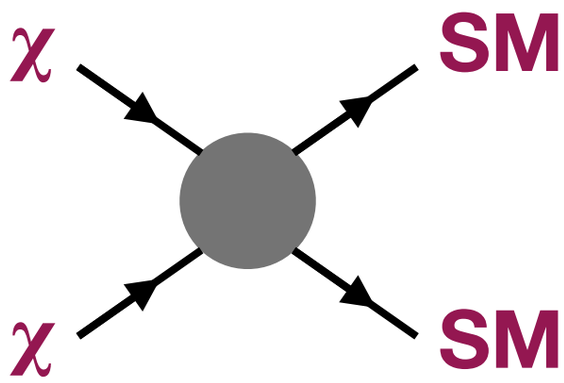
How does this picture change with non-gravitational dark matter interactions?

Search Channels

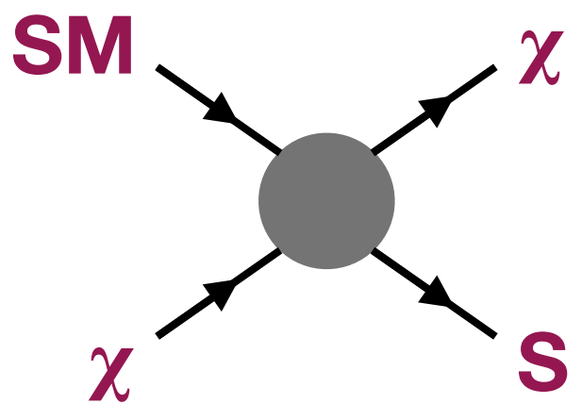
Production



Annihilation



Scattering



in particle physics

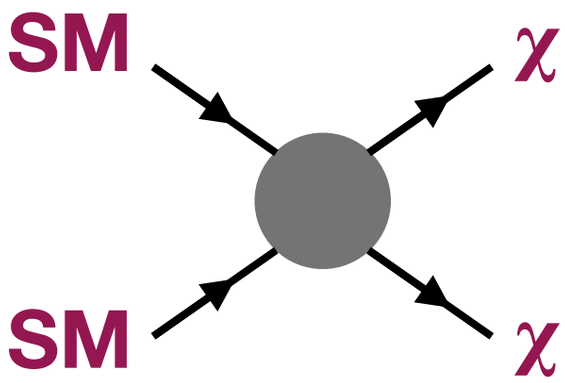
Collider **Indirect detection** **Direct detection**

in cosmology

Relic abundance **Energy injection** **Momentum transfer**

Search Channels

Production



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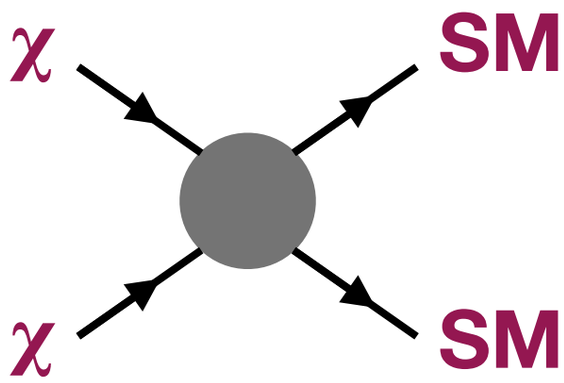

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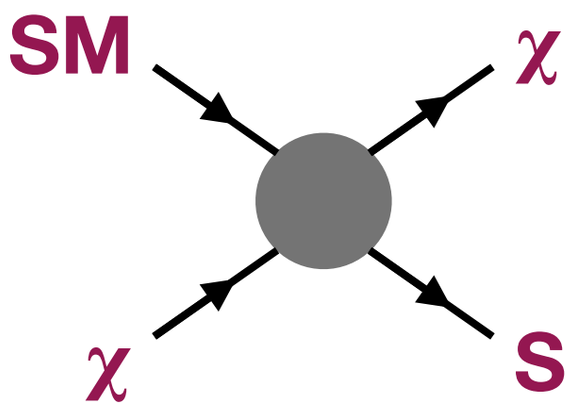

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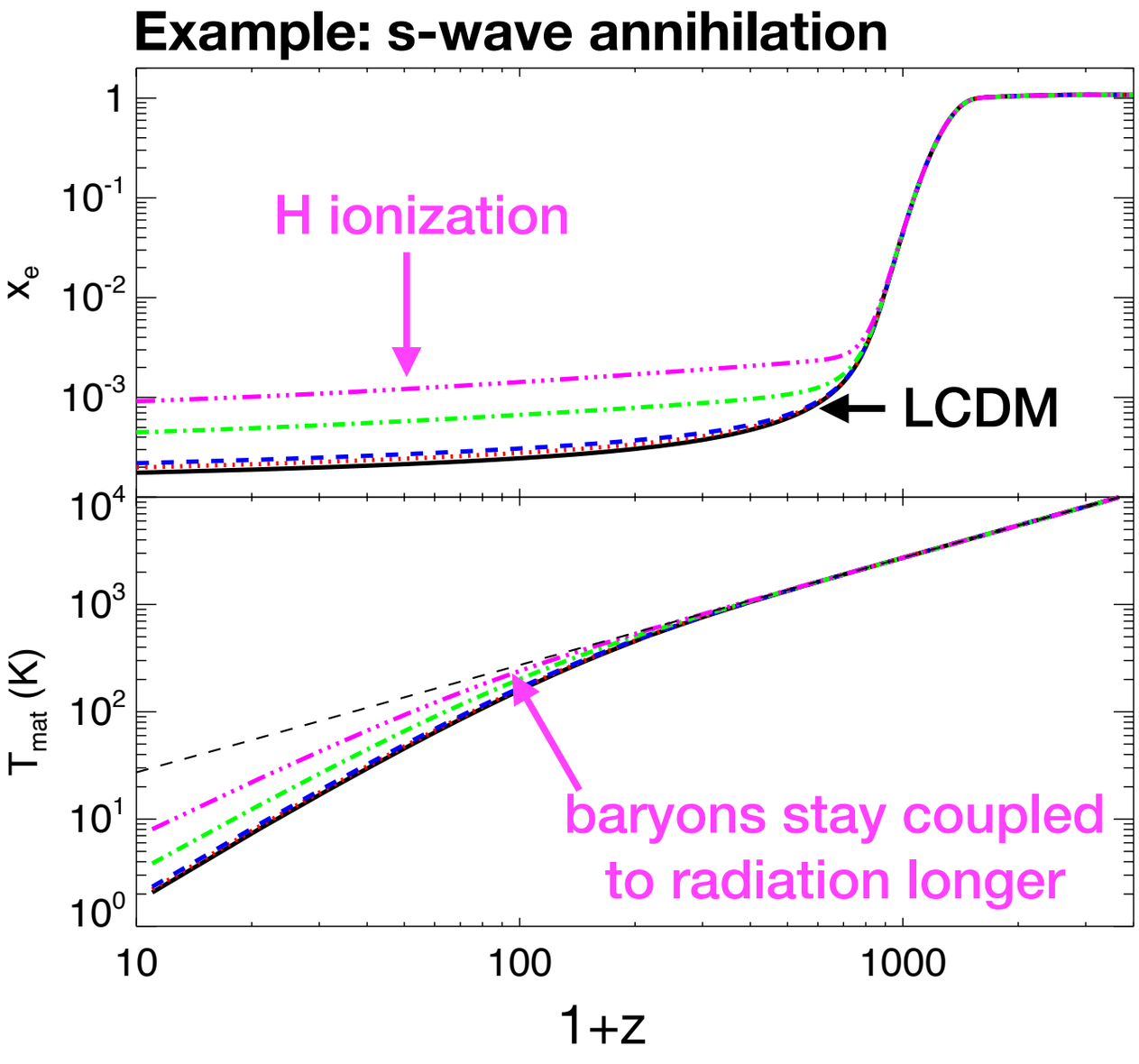
Energy Injection

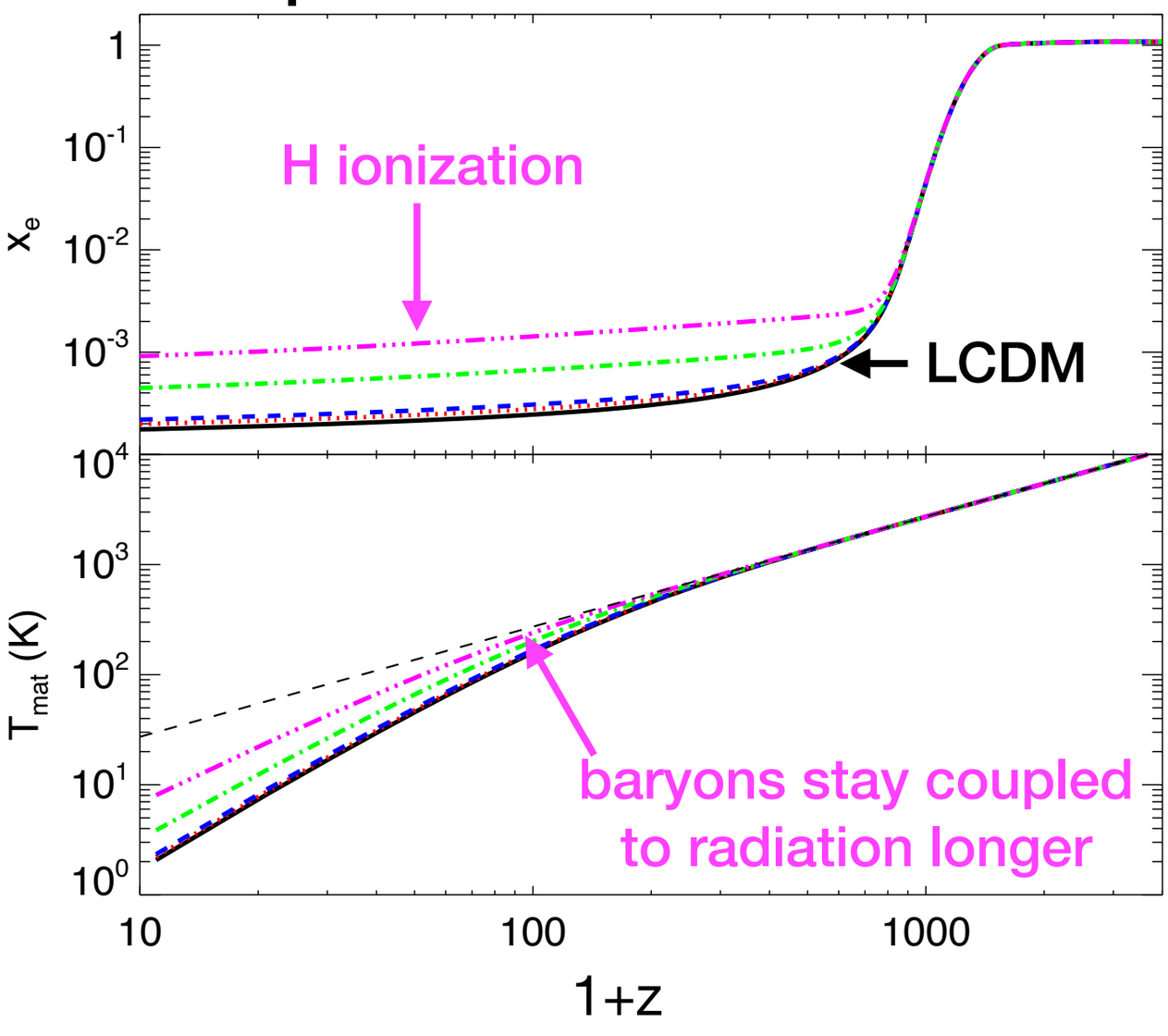


Padmanabhan and Finkbeiner (2005)

see also Galli+ (2009, 2013), Finkbeiner (2011), Slatyer (2016)

Energy Injection

Example: s-wave annihilation



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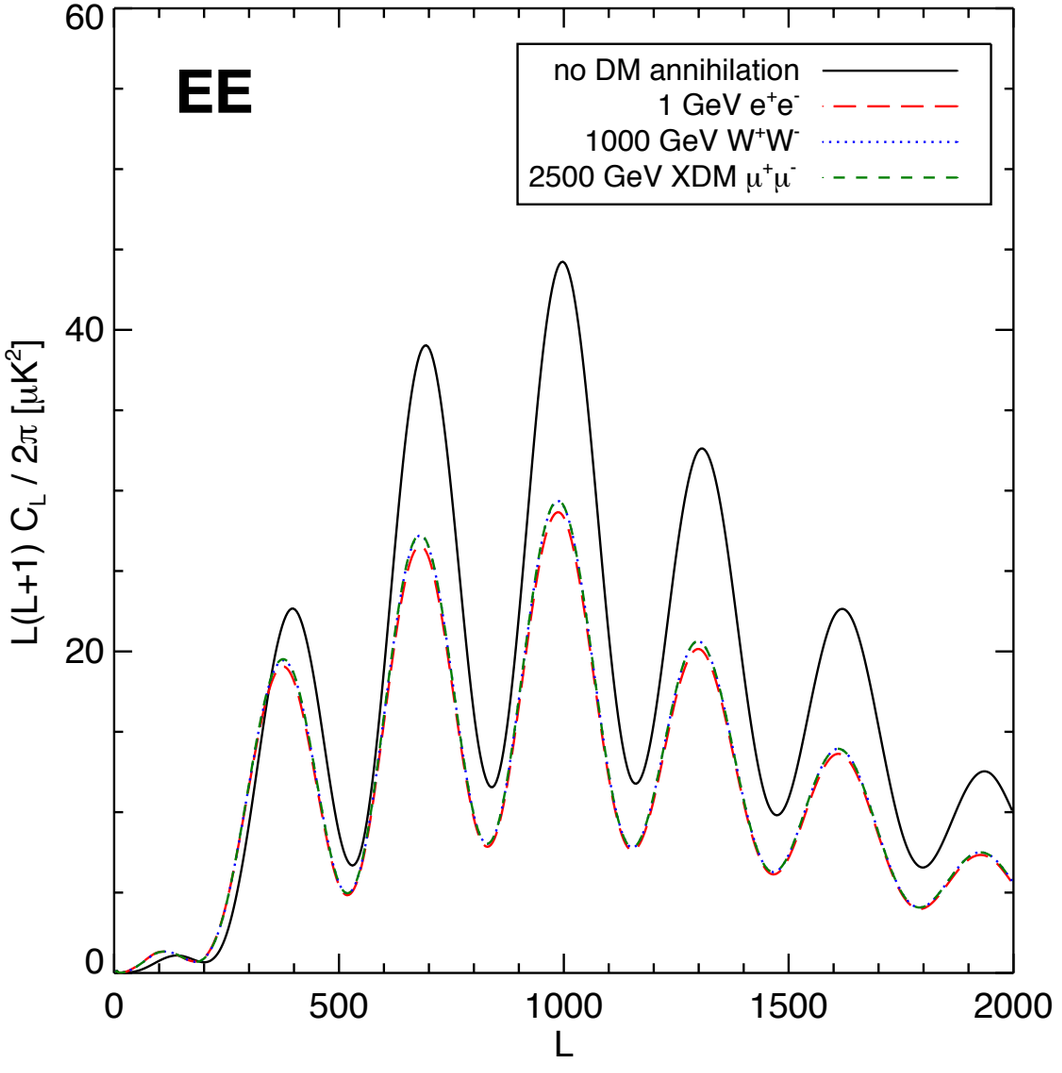

Slatyer+ (2009)

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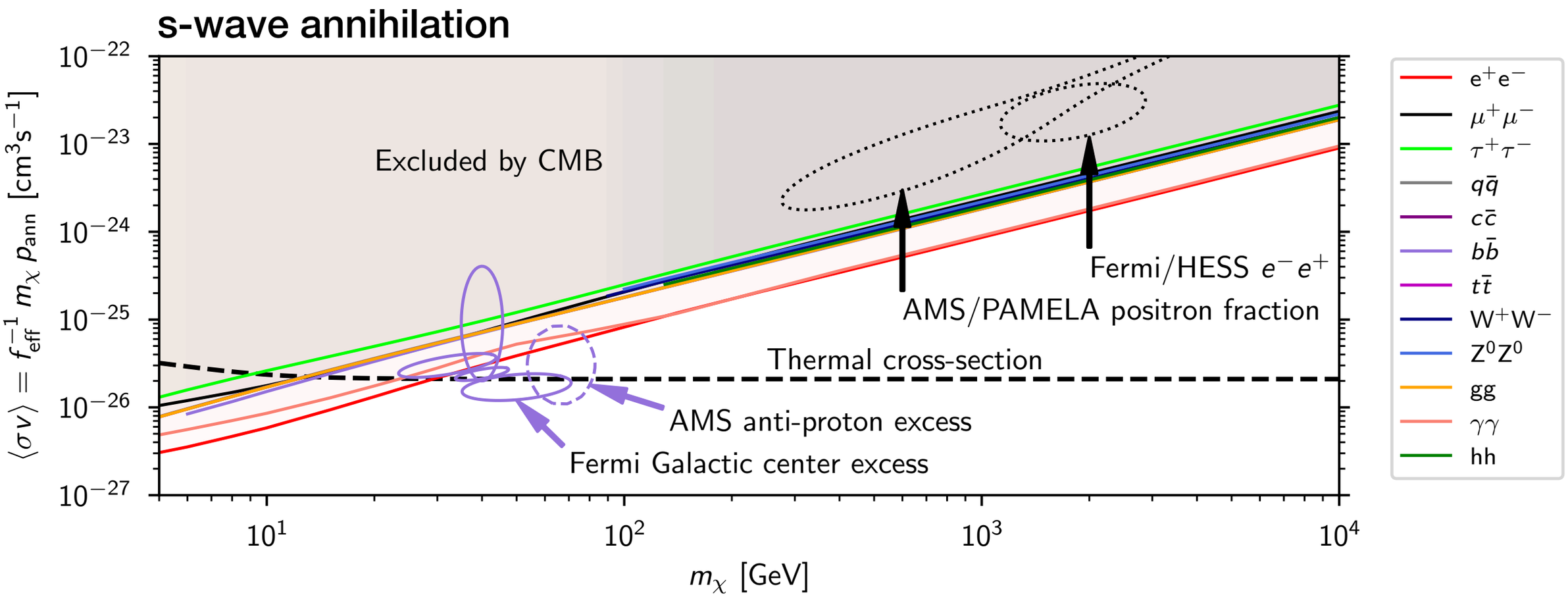
CMB Annihilation Limits



~20% improvement over Planck 2015

Planck Collaboration (2018)

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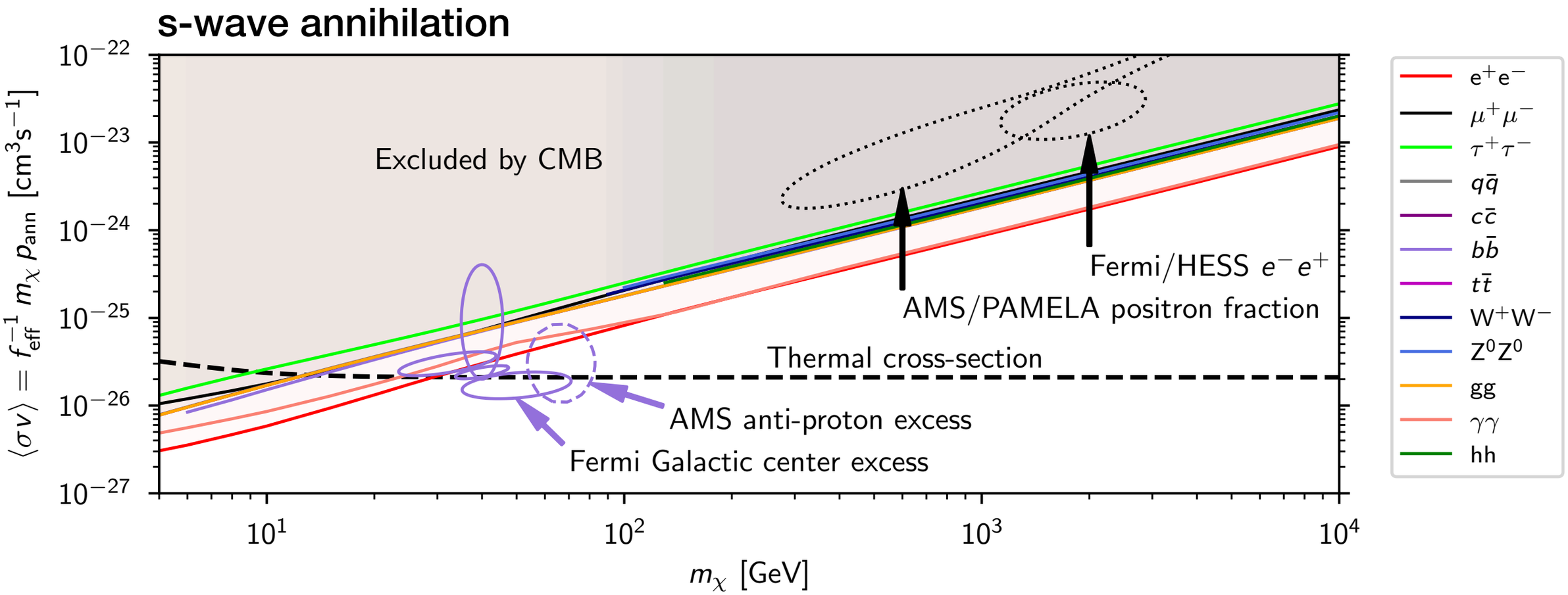

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For decay, see Poulin+ (2017), Slatyer and Wu (2017)

Search Channels

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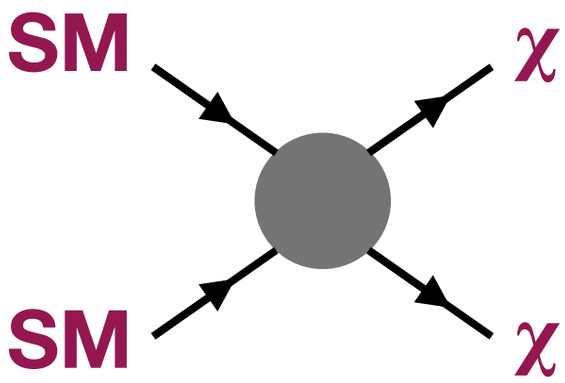

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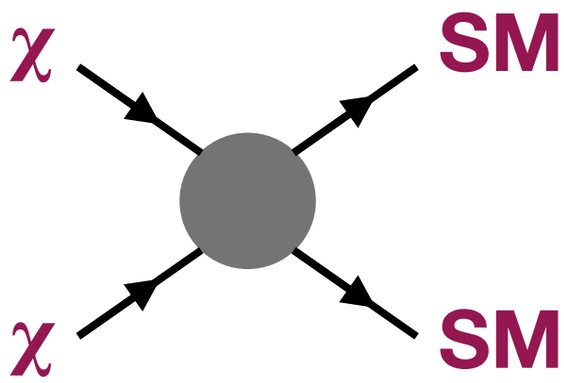

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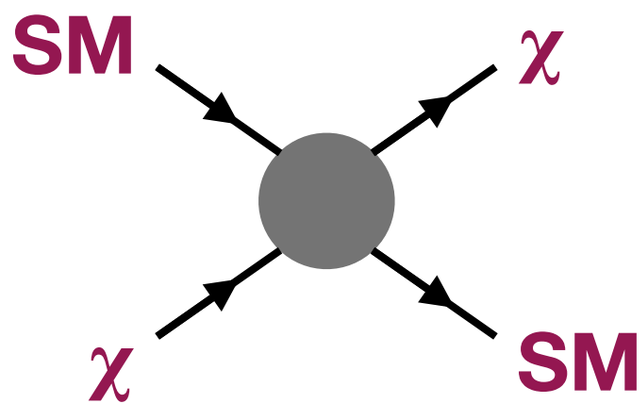

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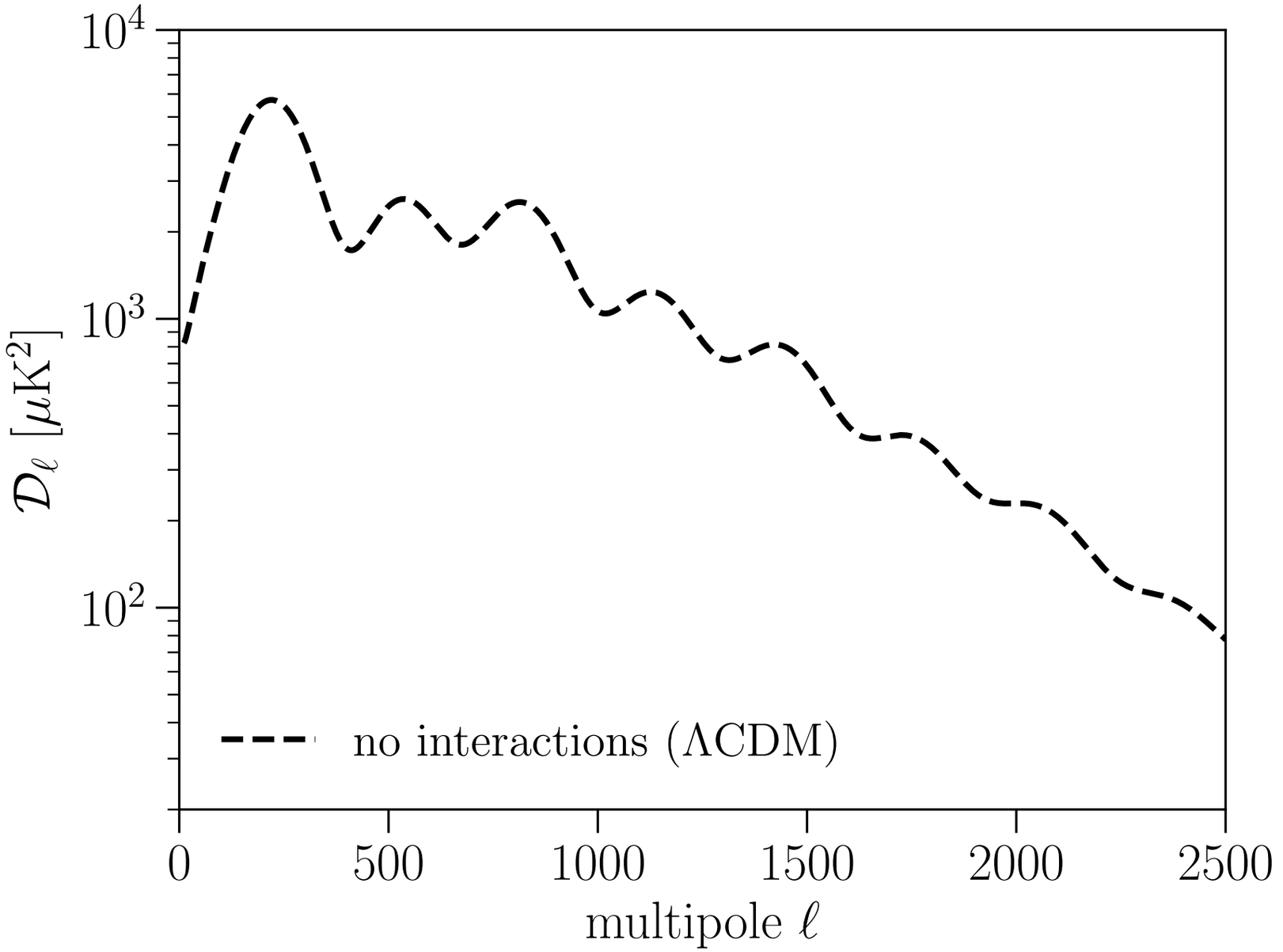
Elastic Scattering

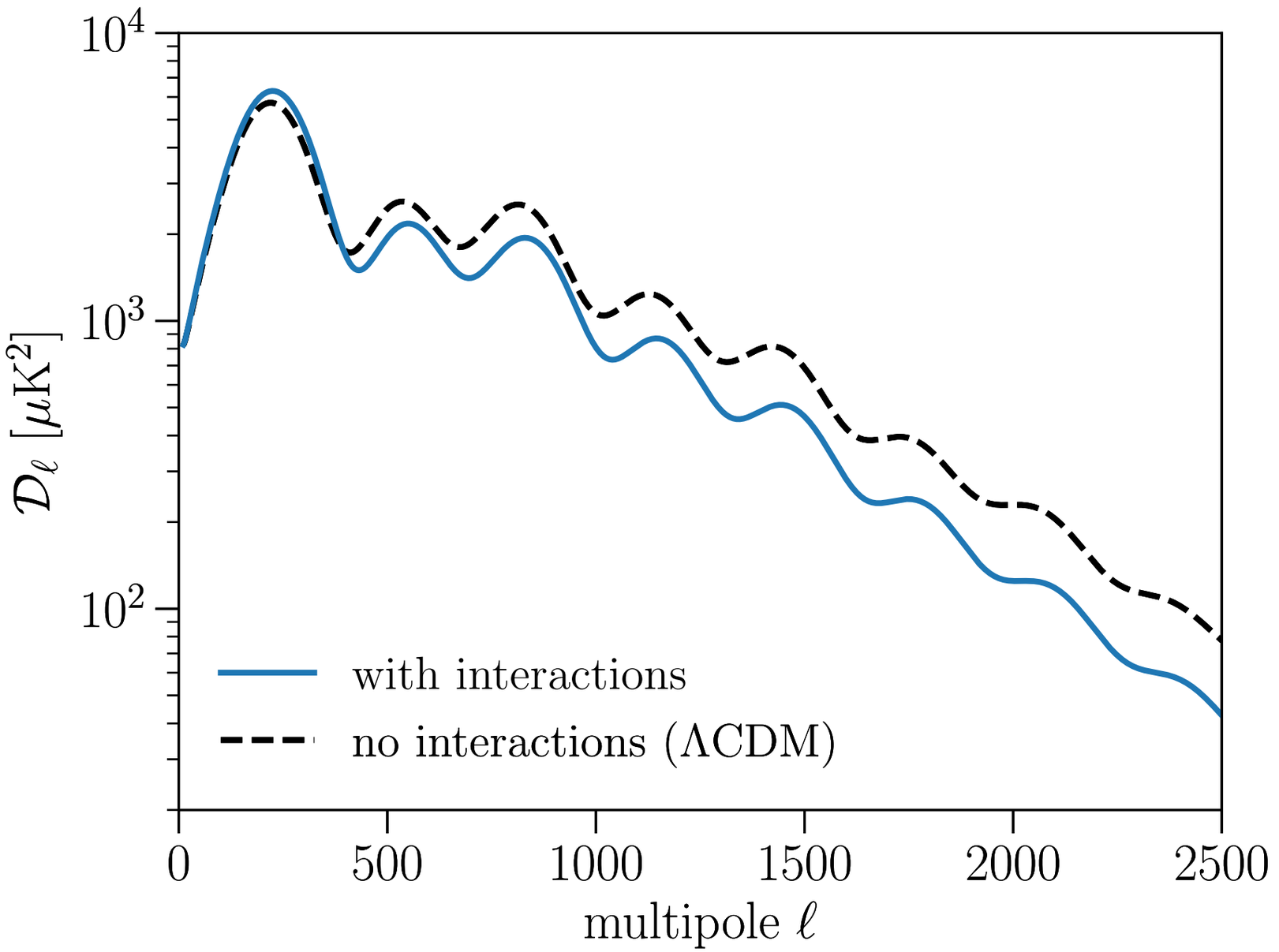


KB and Gluscevic (2018)

Elastic Scattering

DM-baryon scattering:

- **heat exchange**
- **momentum exchange (drag force)**
- **suppression at small scales**



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H, He nuclei

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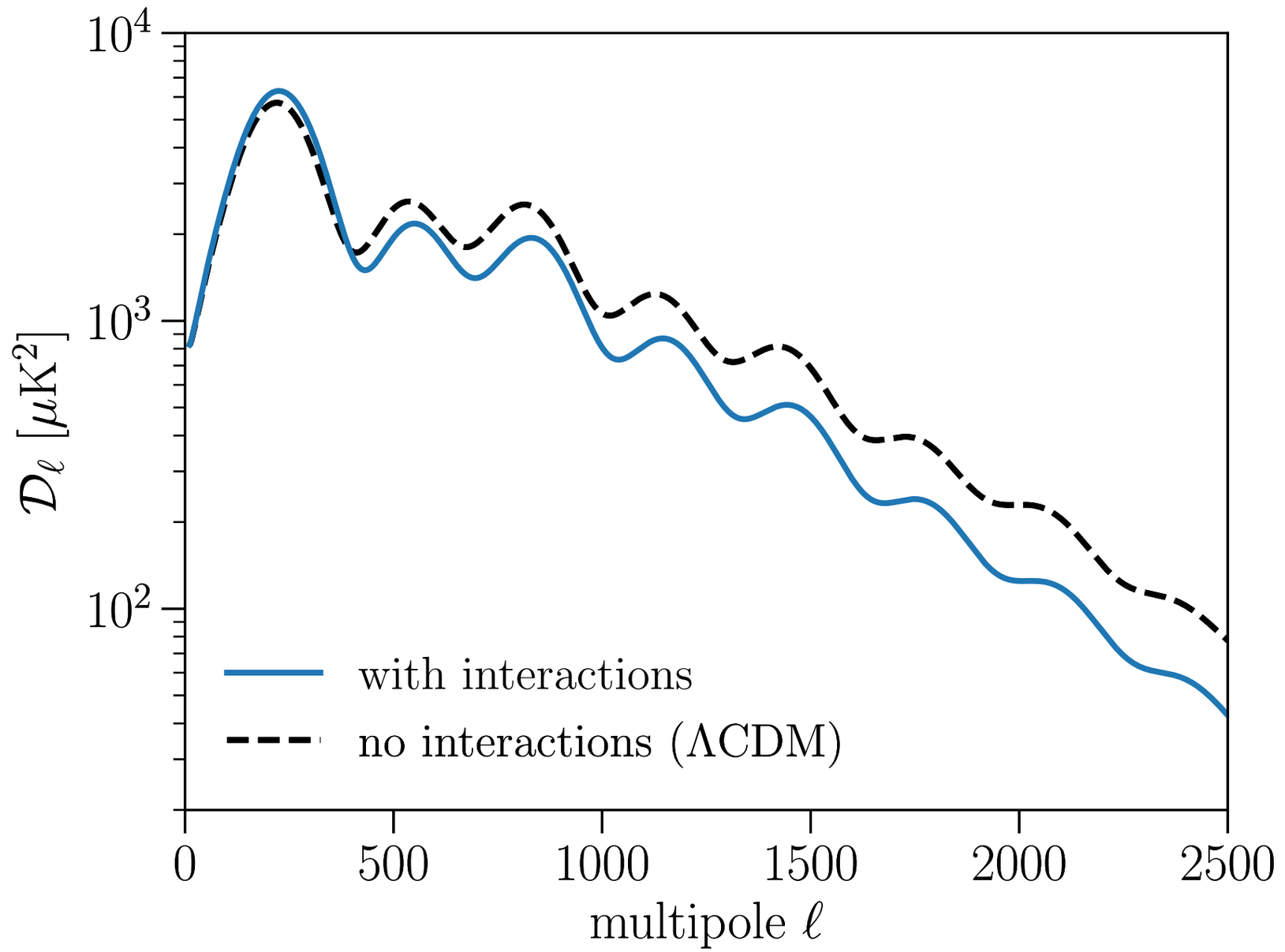

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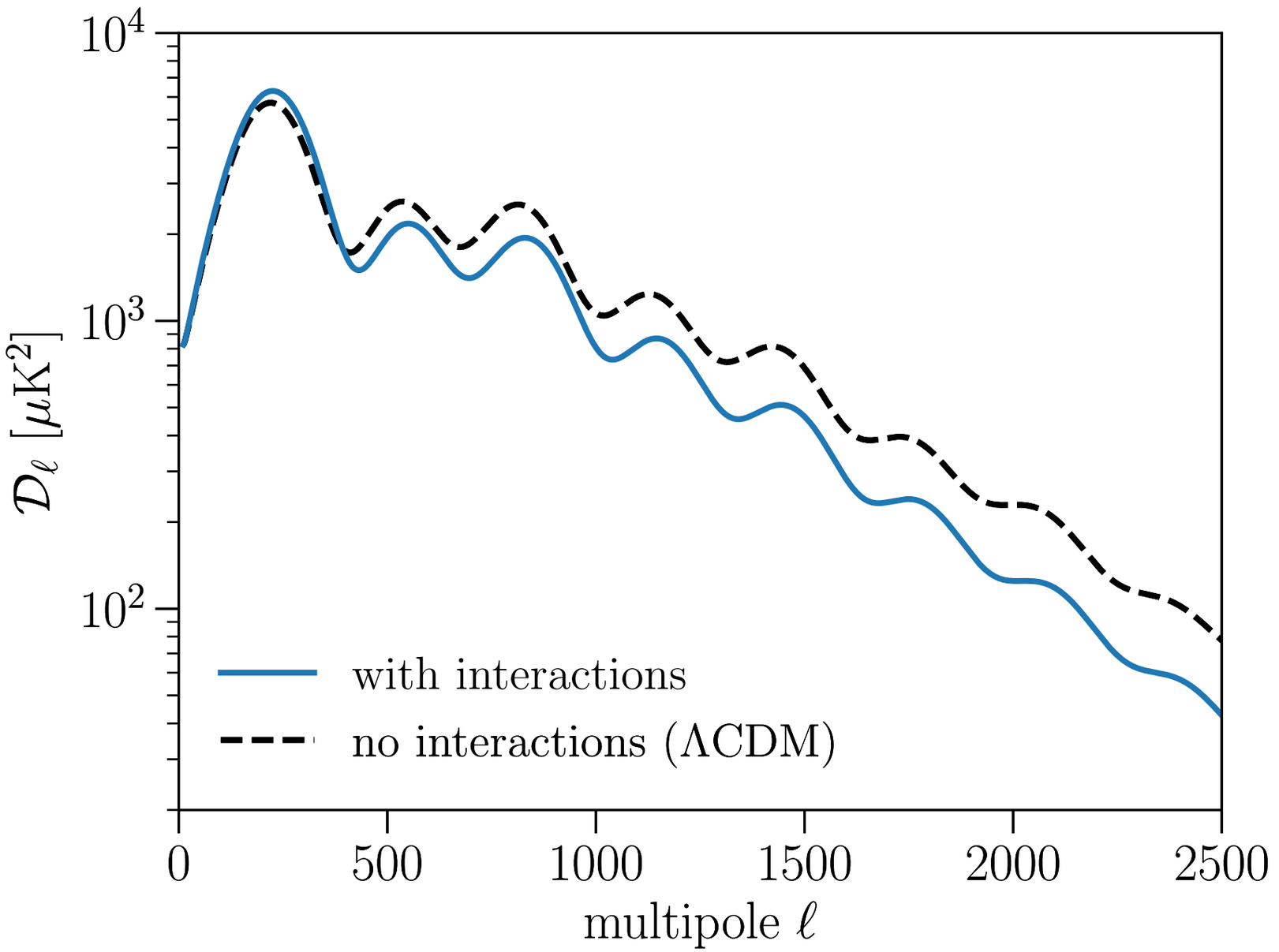
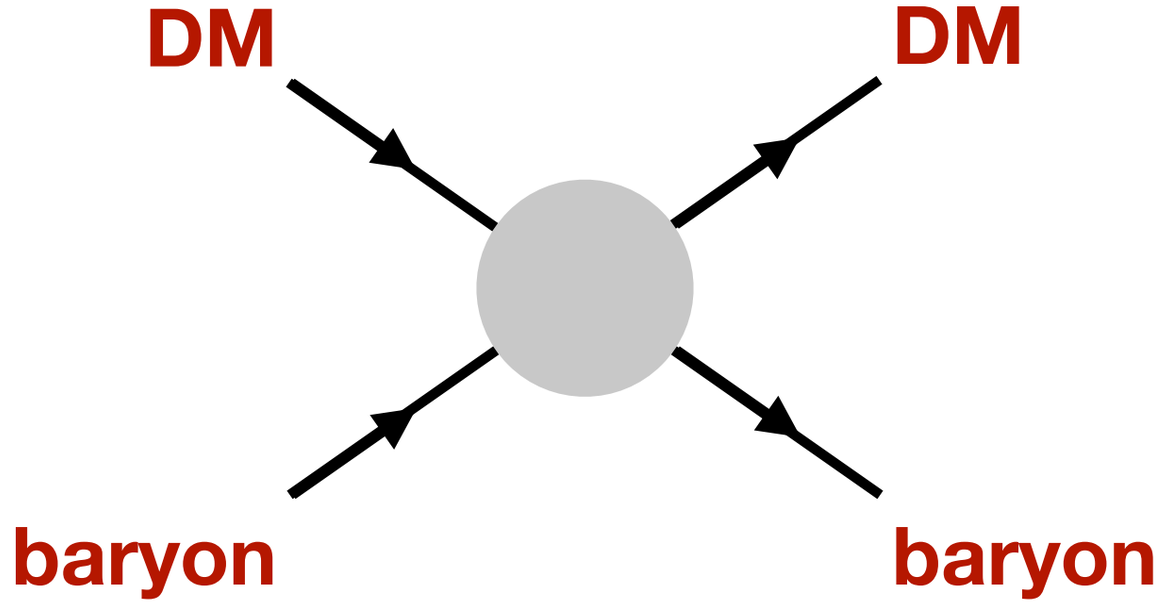
Particle physics input?



KB and Gluscevic (2018)

Interactions via heavy mediators



Non-Relativistic EFT

Fan et al. (2010), Fitzpatrick et al. (2013), Anand et al. (2014), Dent et al. (2015)

Observables

$$\mathcal{O} \sim \left|\vec{v}^{\perp}\right|^{\alpha} \left|\vec{q}\right|^{\beta}$$

- DM and nucleon spins
- Momentum transfer (MT) $\quad |\vec{q}| \sim |\vec{v}|(1-\cos\theta)^{1/2}$
- Perpendicular velocity $\qquad \vec{v}^{\perp}(\vec{v},\vec{q}) \;\rightarrow\; \vec{v}^{\perp}\cdot\vec{q} = 0$

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$$\sigma_{MT}(v) = \sigma_0 v^{2(\alpha+\beta)} \times (v\text{-dependent correction for He})$$

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DM response **nuclear response**

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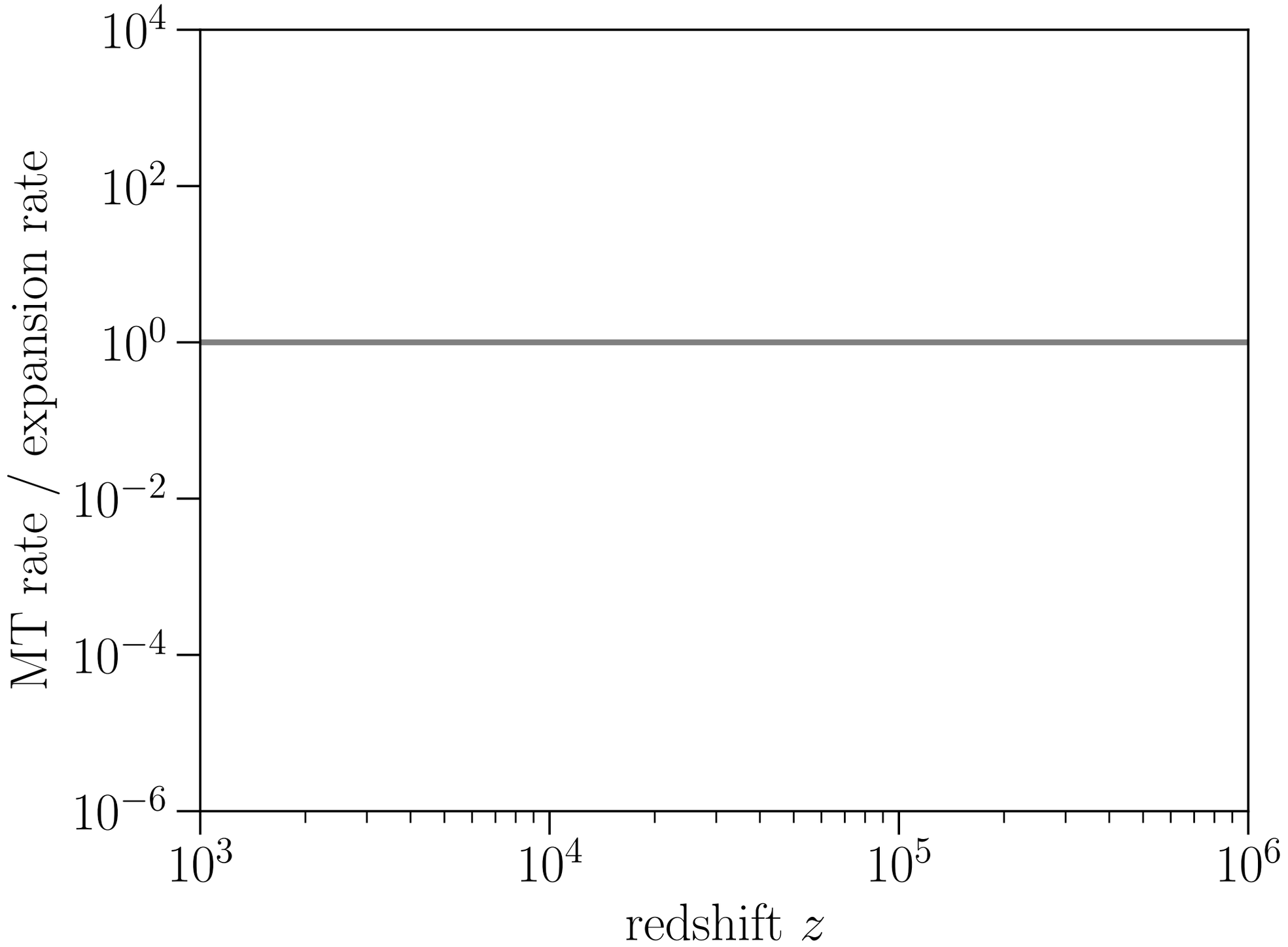
DM response **nuclear response**

CMB is sensitive to rate of momentum transfer (and rate of heat transfer).

rate ~ (cross section)/mass x (number density of target) x (reduced mass)

Rate of Momentum Transfer



KB and Gluscevic (2018)

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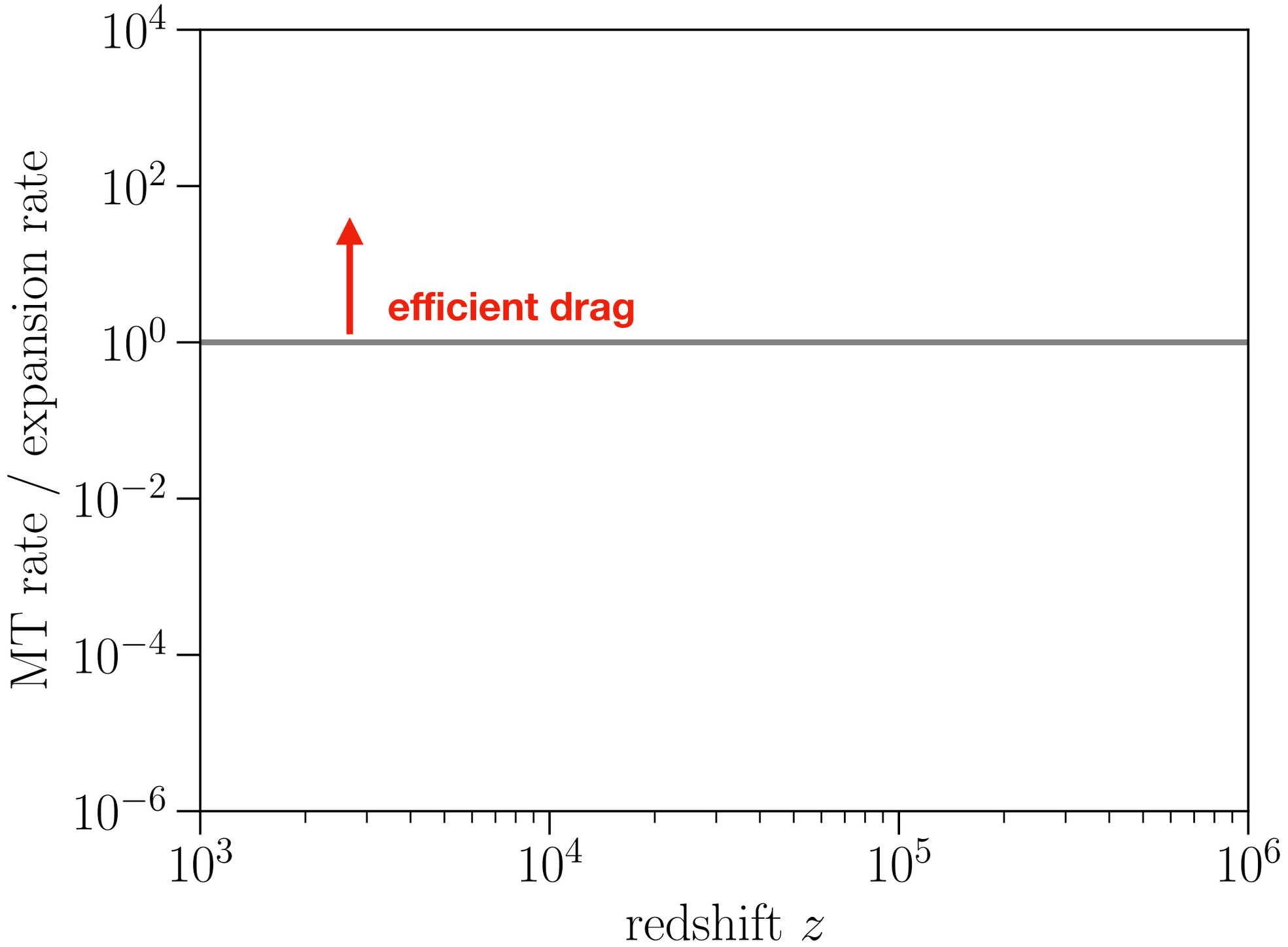

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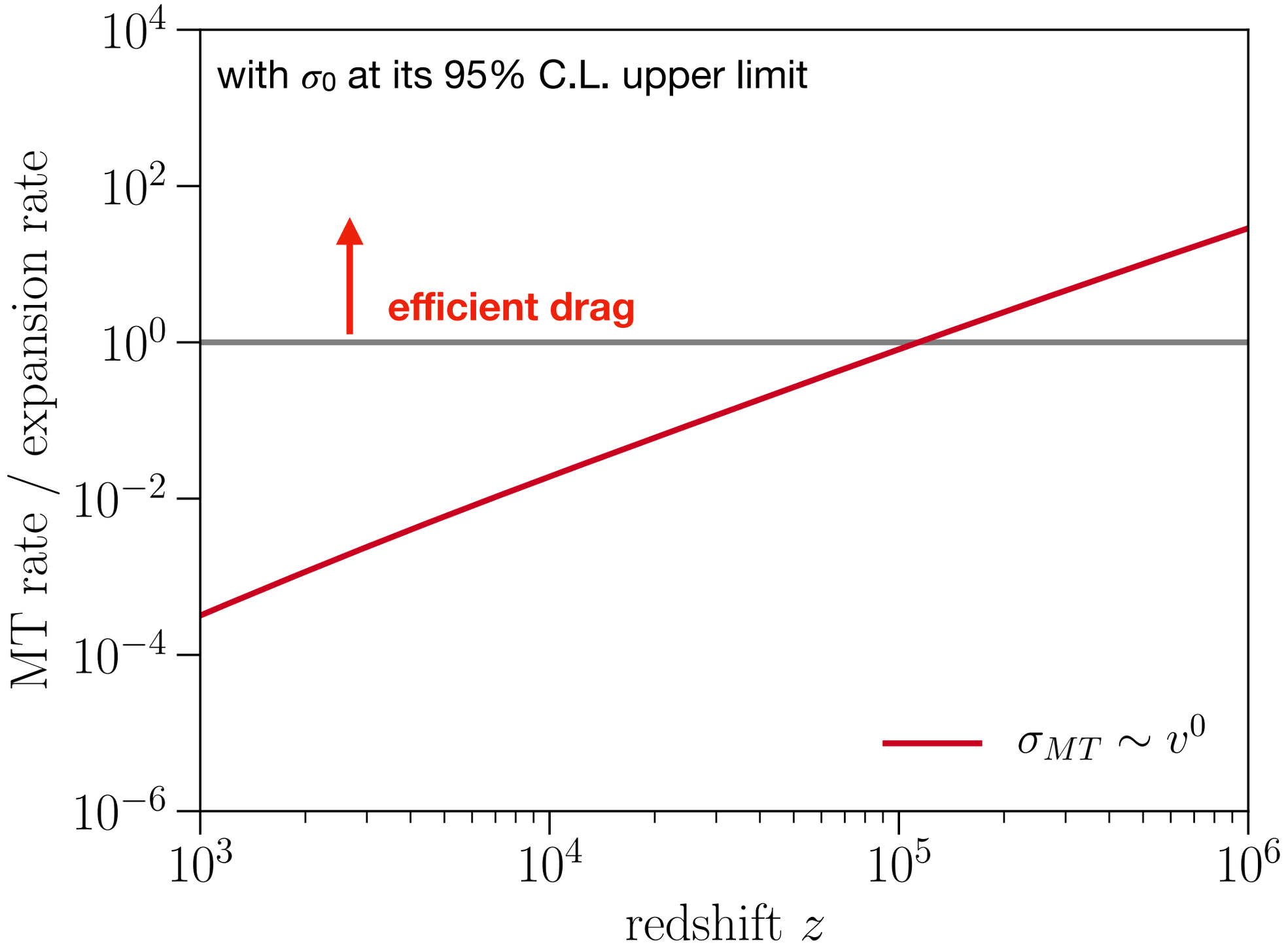

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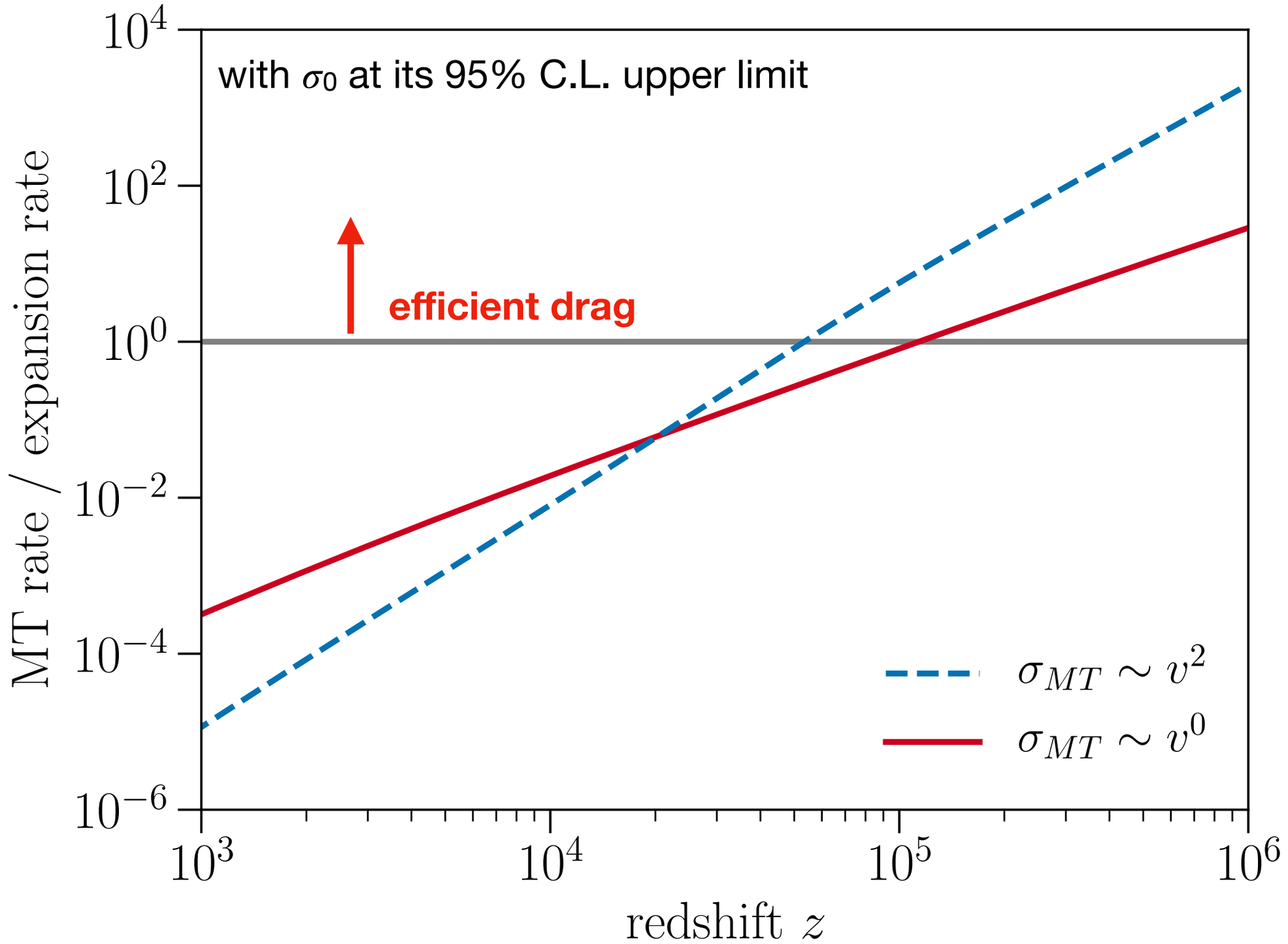

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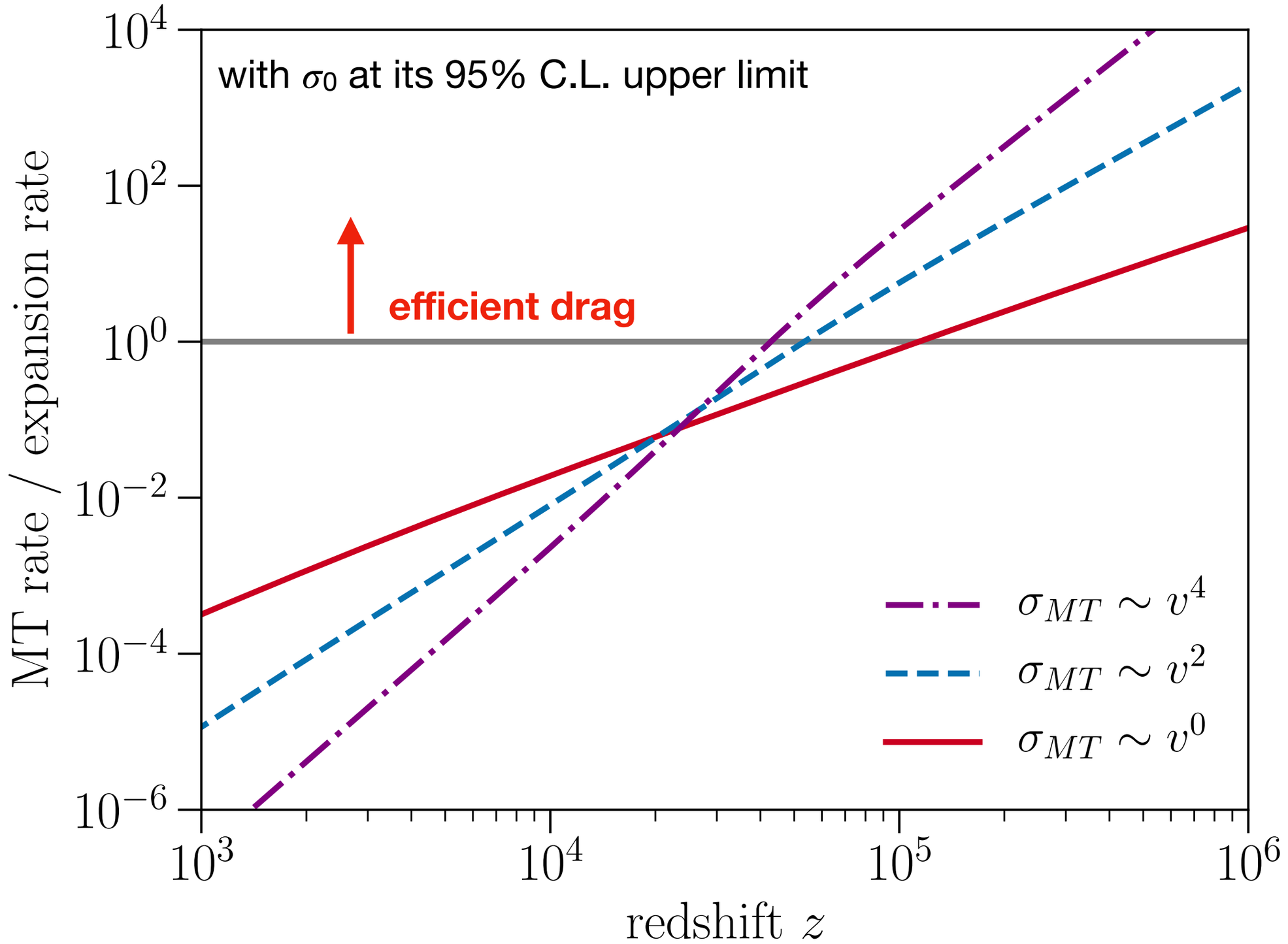

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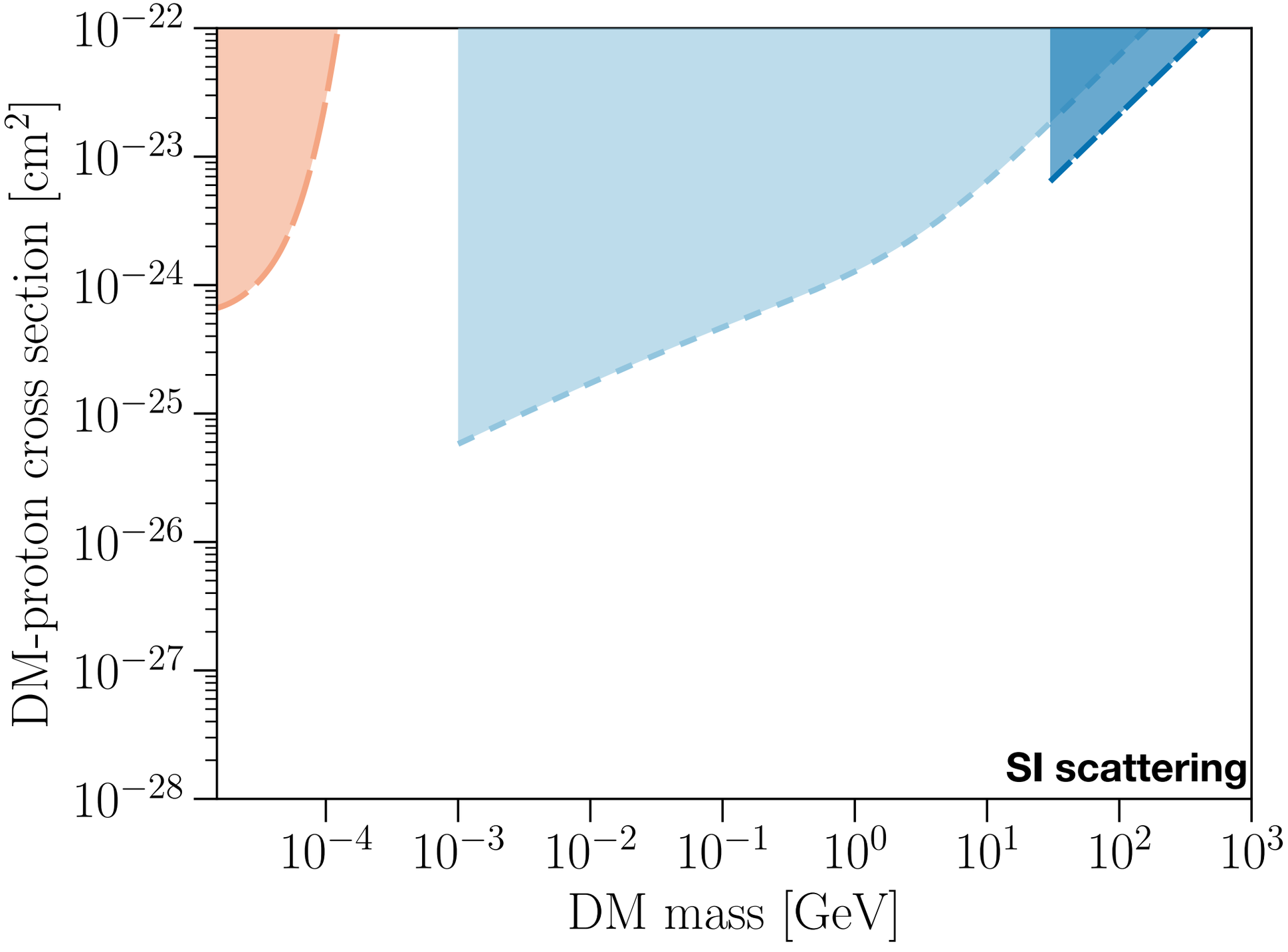
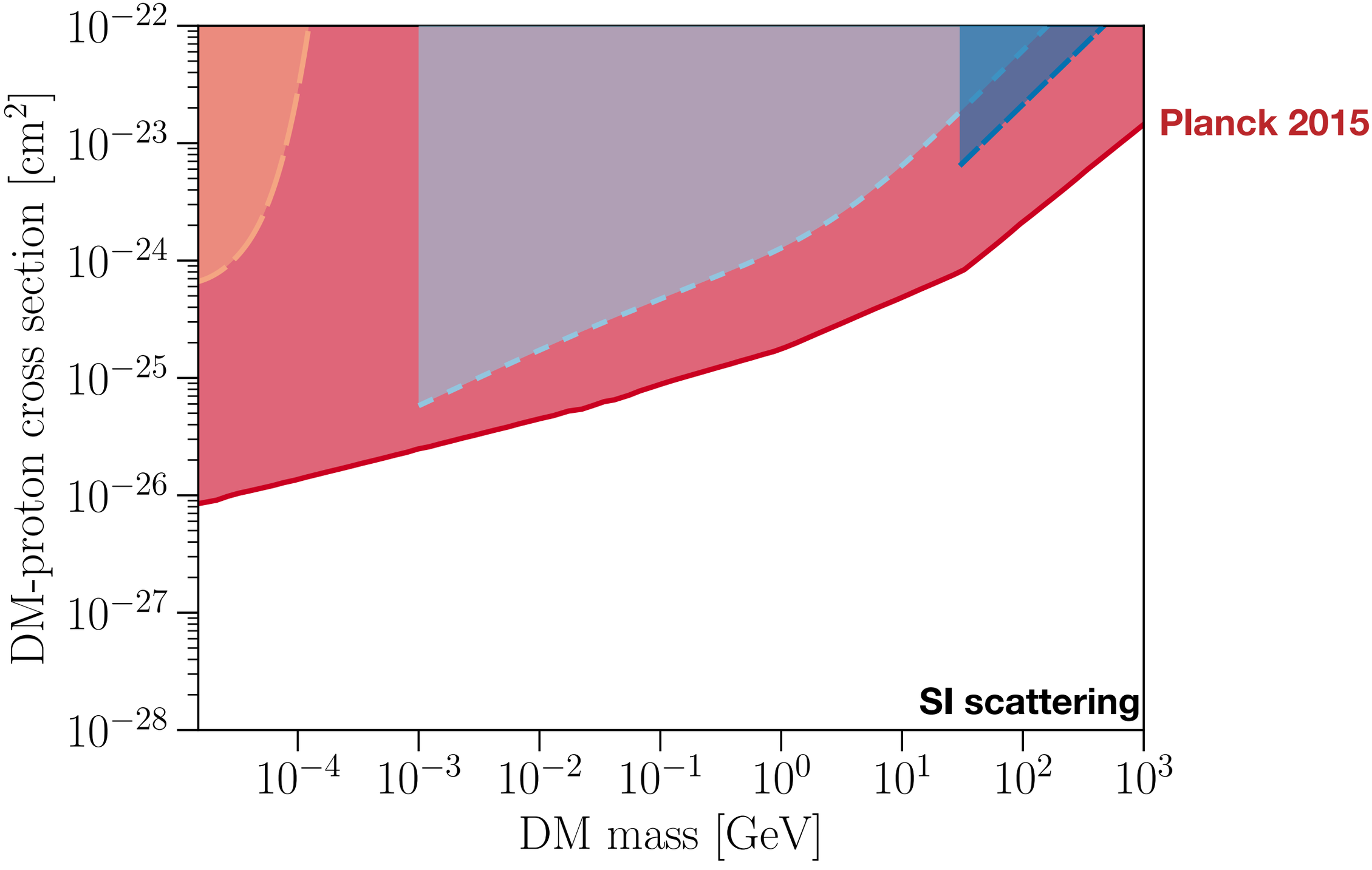


Spectral distortions (Ali-Haïmoud et al, 2015)

COBE+2dF (Chen et al., 2002)

Planck 2013 (Dvorkin et al., 2014)



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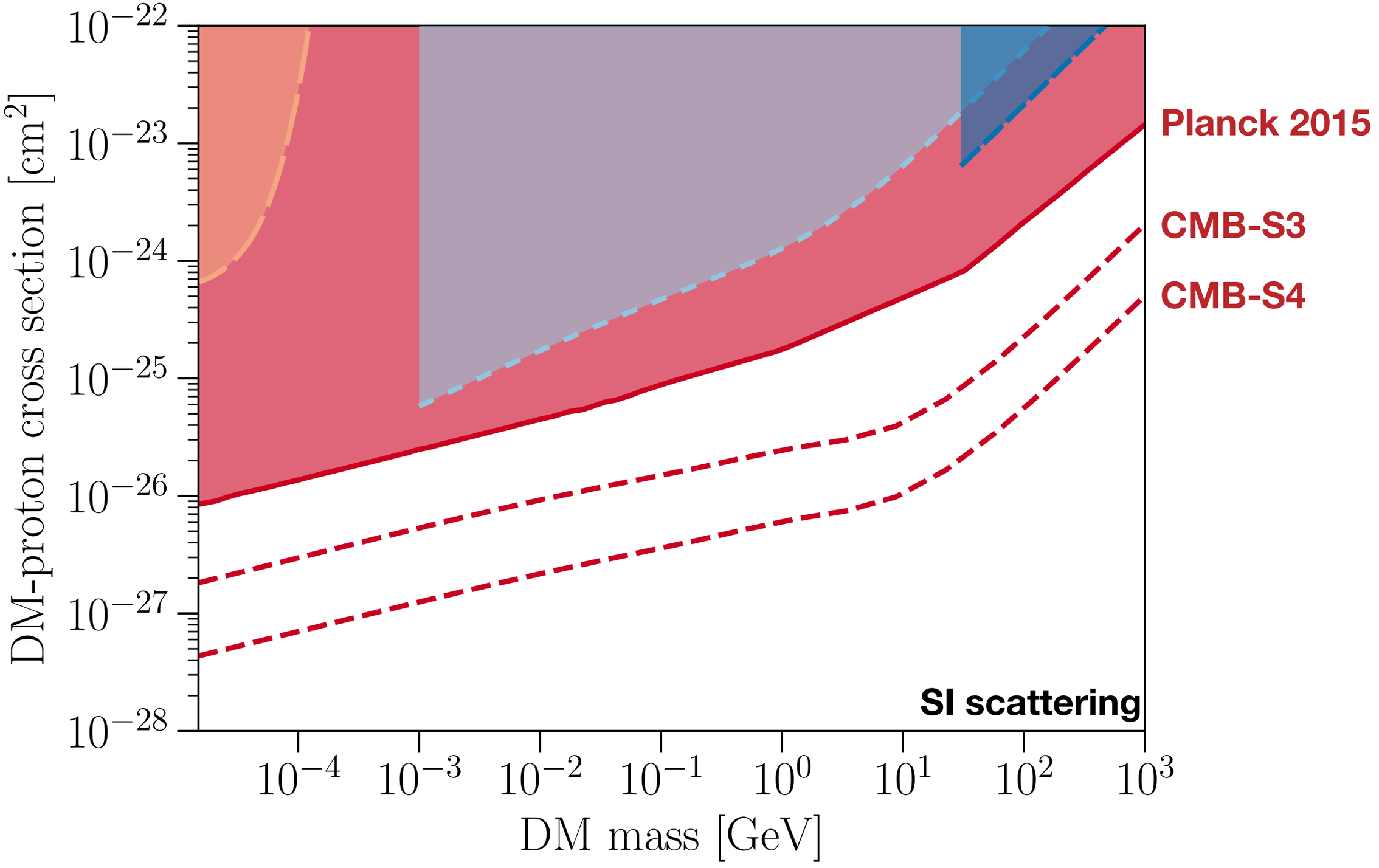

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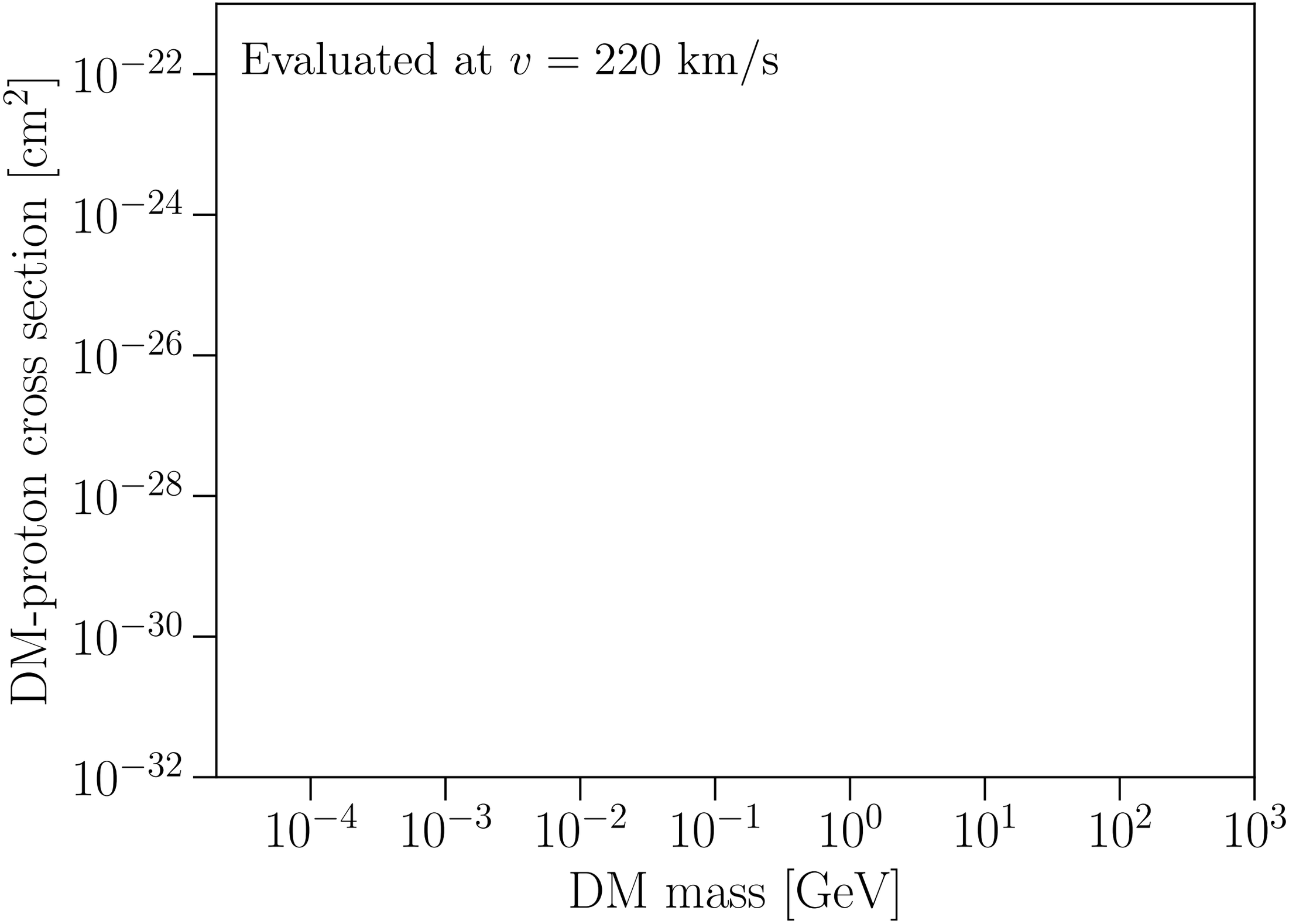
Li, Gluscevic, **KB**, Madhavacheril (2018)



KB and Gluscevic (2018)

Evaluated at $v = 220$ km/s

Planck excluded

DM-proton cross section [cm^2]

10^{-22}
10^{-24}
10^{-26}
10^{-28}
10^{-30}
10^{-32}

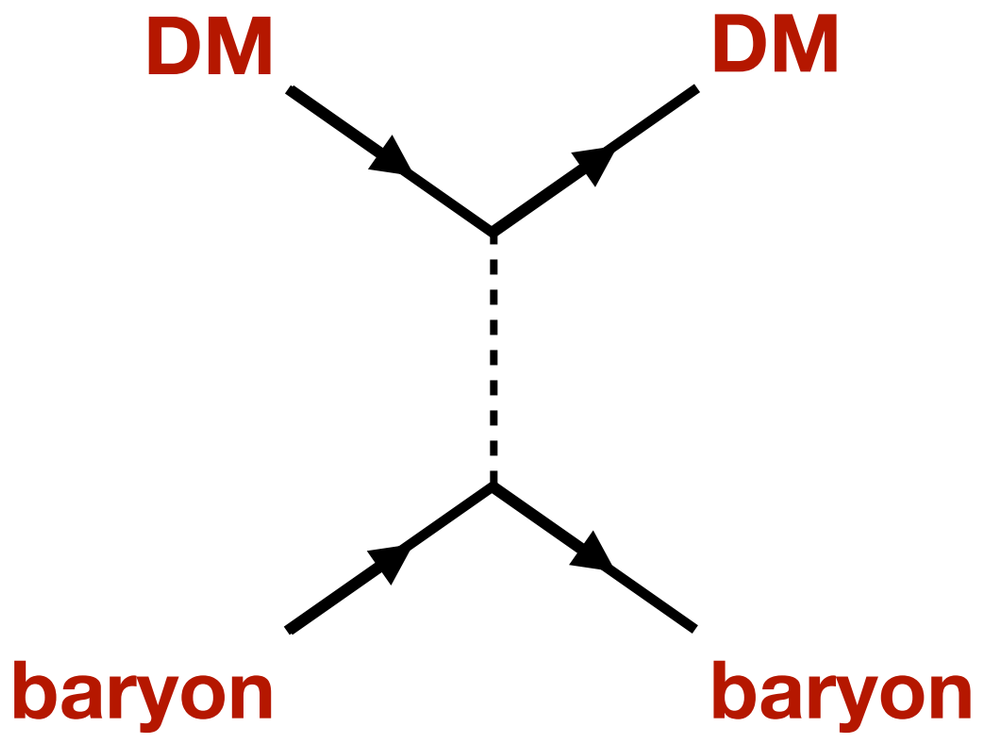
$\sigma_{MT} \simeq v^4$
$\sigma_{MT} \simeq v^2$
$\sigma_{MT} \simeq v^0$

10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}

DM mass [GeV]

KB and Gluscevic (2018)

Interactions via light mediators



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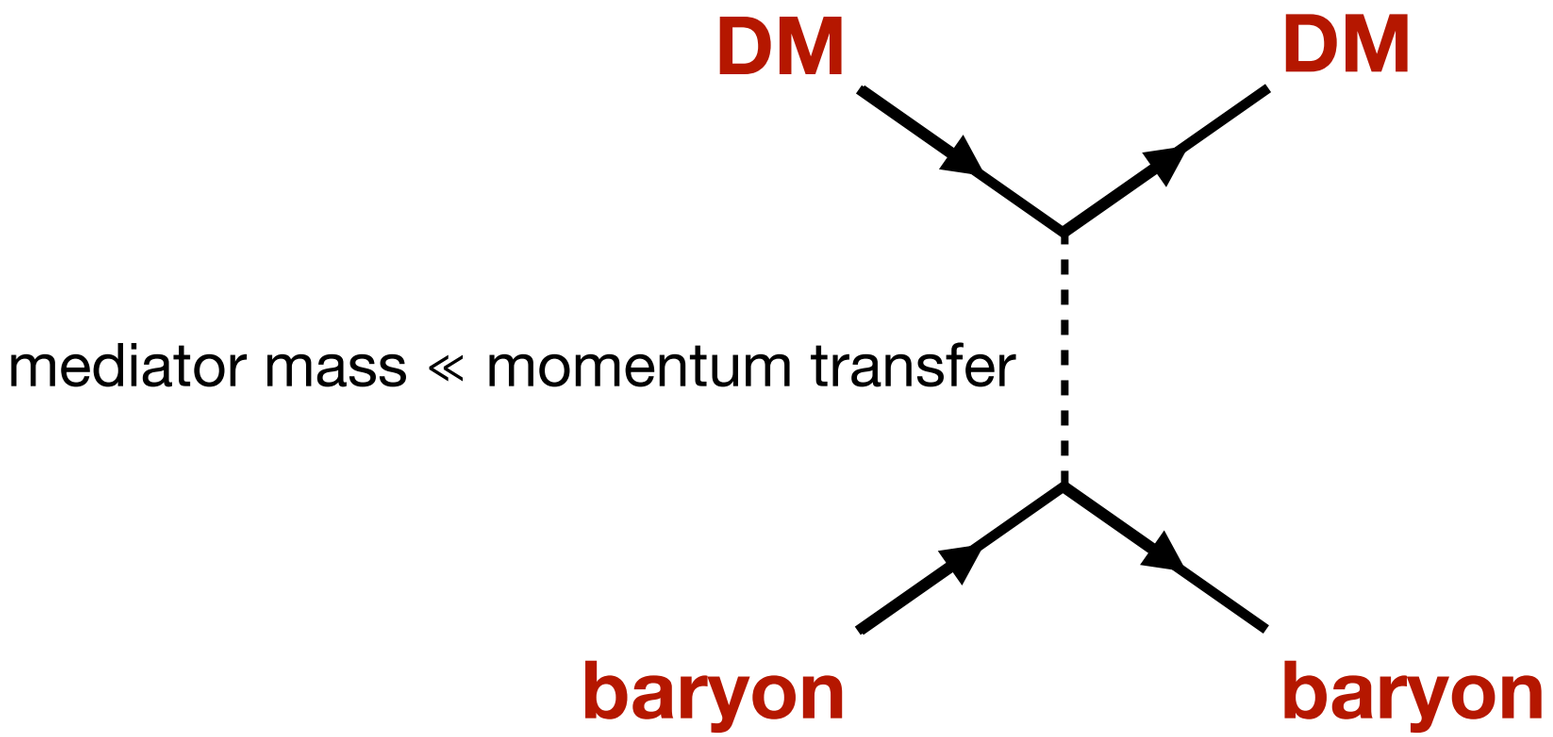

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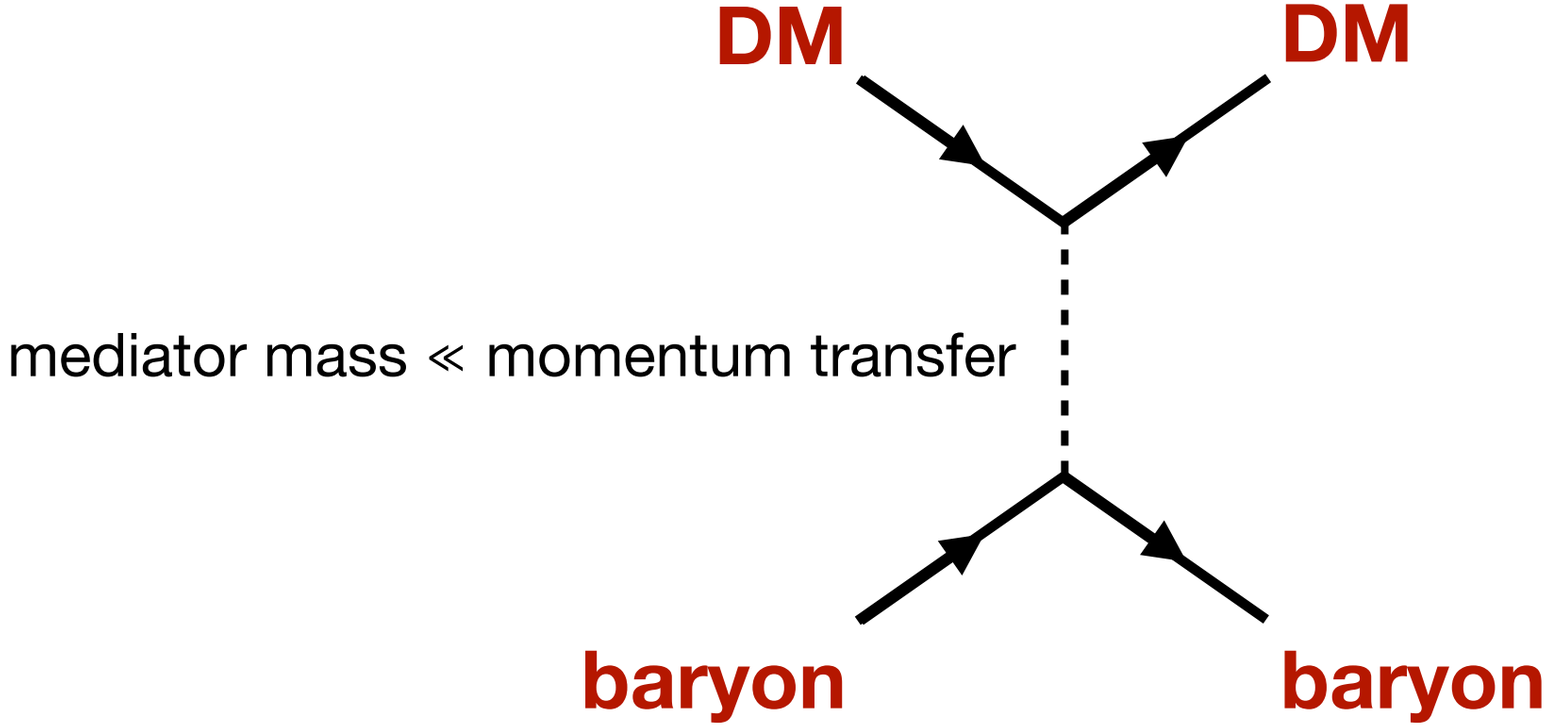
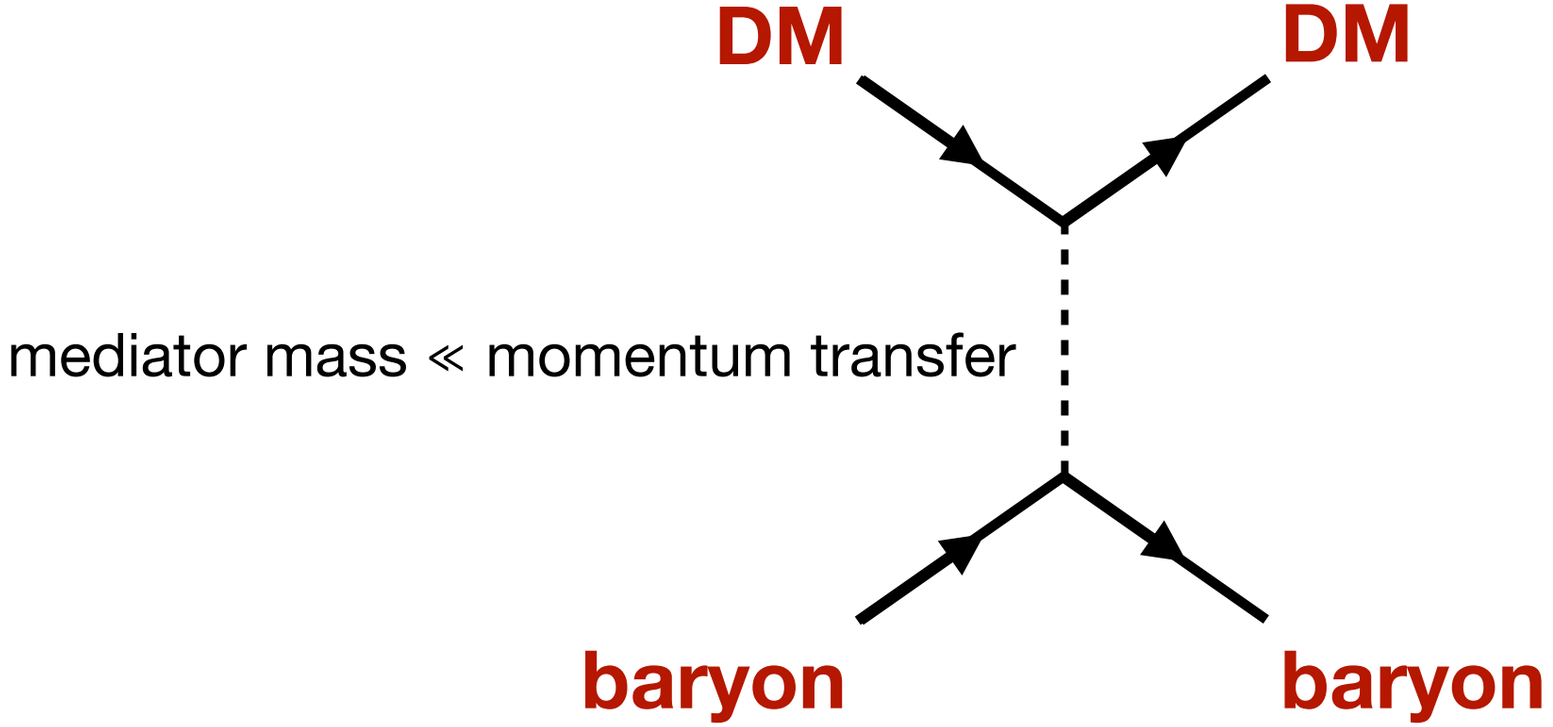


DM with electric/magnetic dipole moment

$$\sigma_{MT} \sim v^{-2}$$

Interactions via light mediators



DM with electric/magnetic dipole moment

$$\sigma_{MT} \sim v^{-2}$$

DM with Coulomb-like interaction

$$\sigma_{MT} \sim v^{-4}$$

Scattering via Light Mediators

$$\sigma_{MT}(v) = \sigma_0 v^n$$

- Expect small (large) cross section at early (late) times, but relevant quantity is rate of momentum transfer

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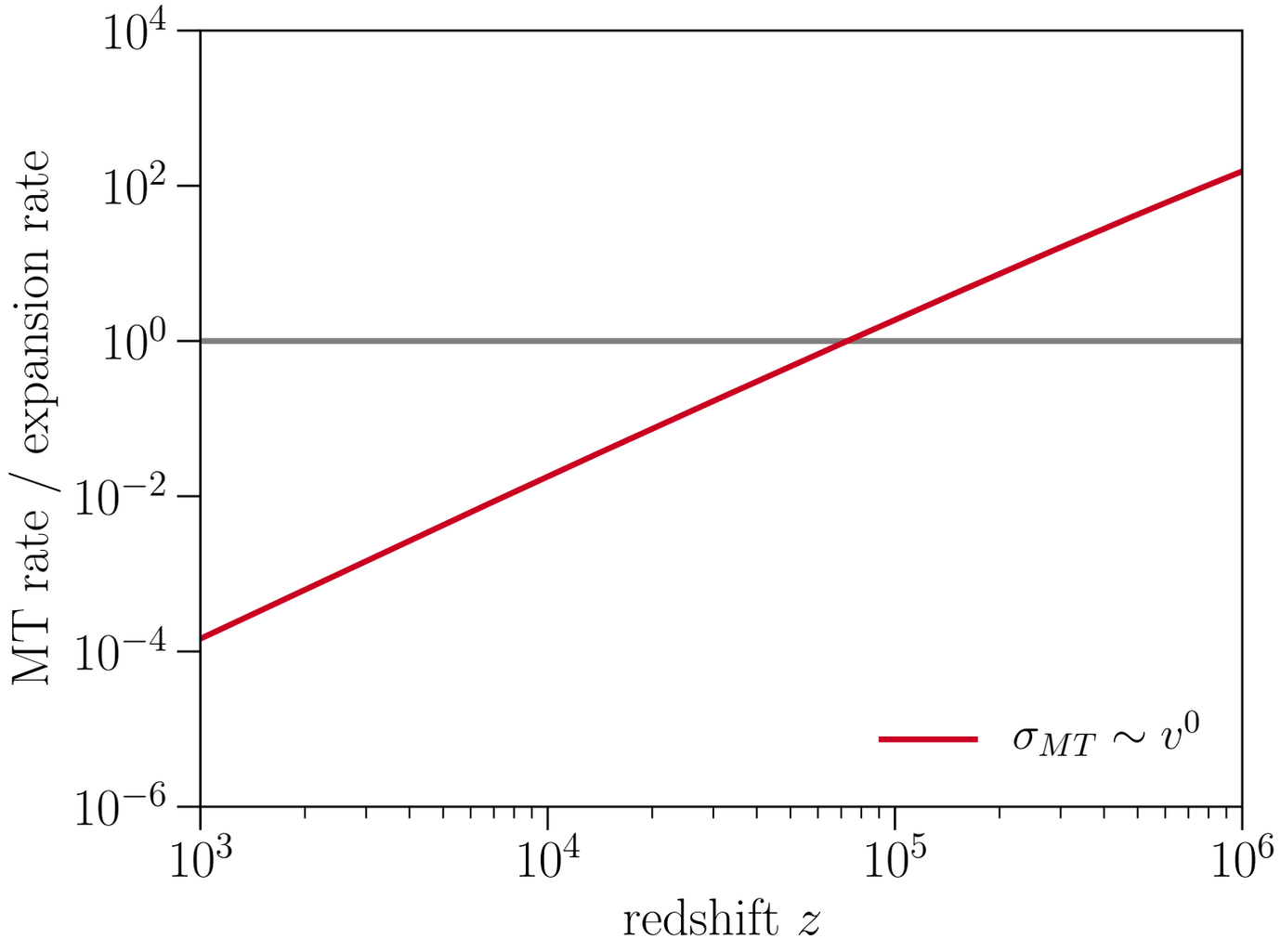

KB+ (1808.00001)

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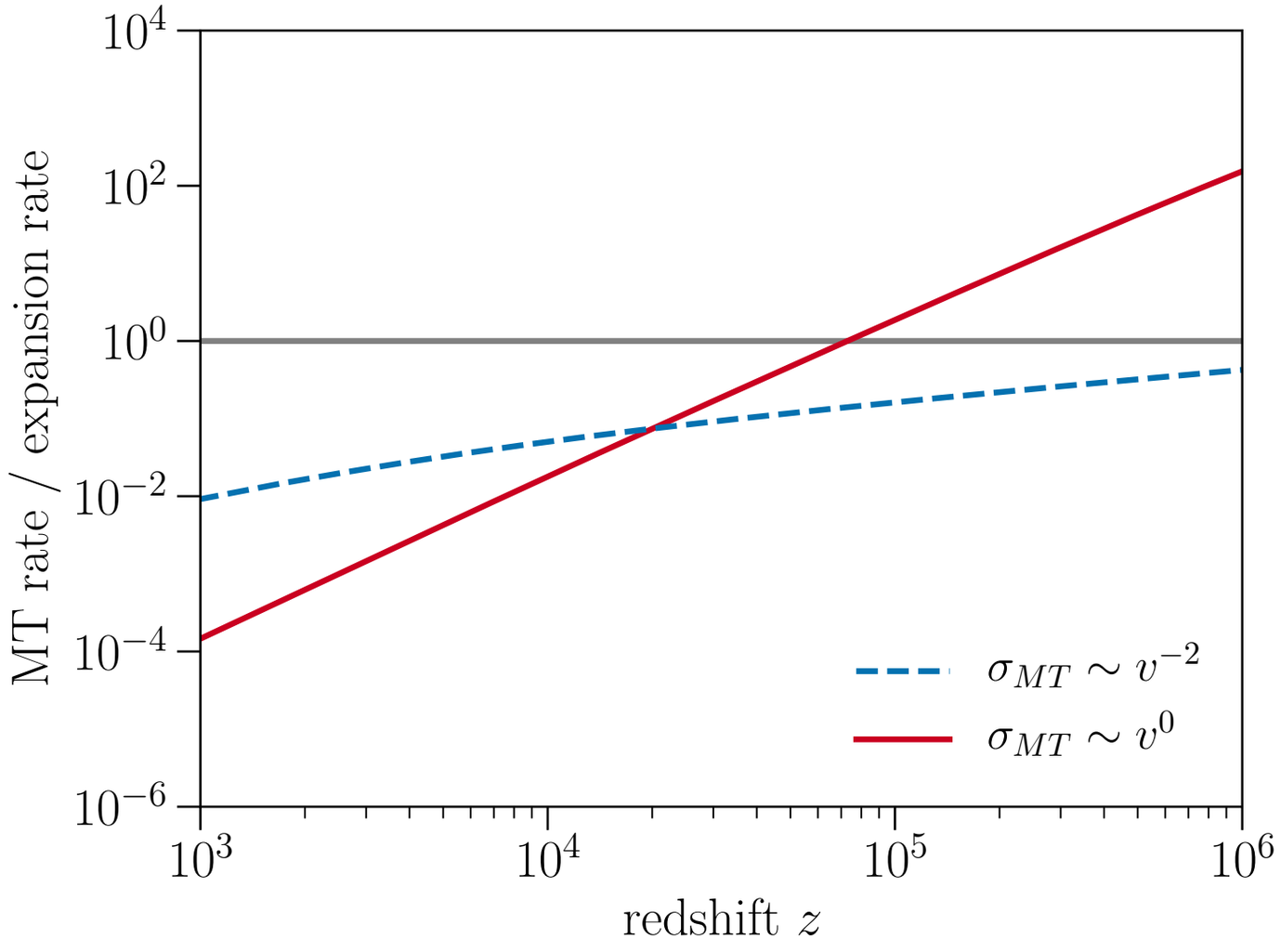

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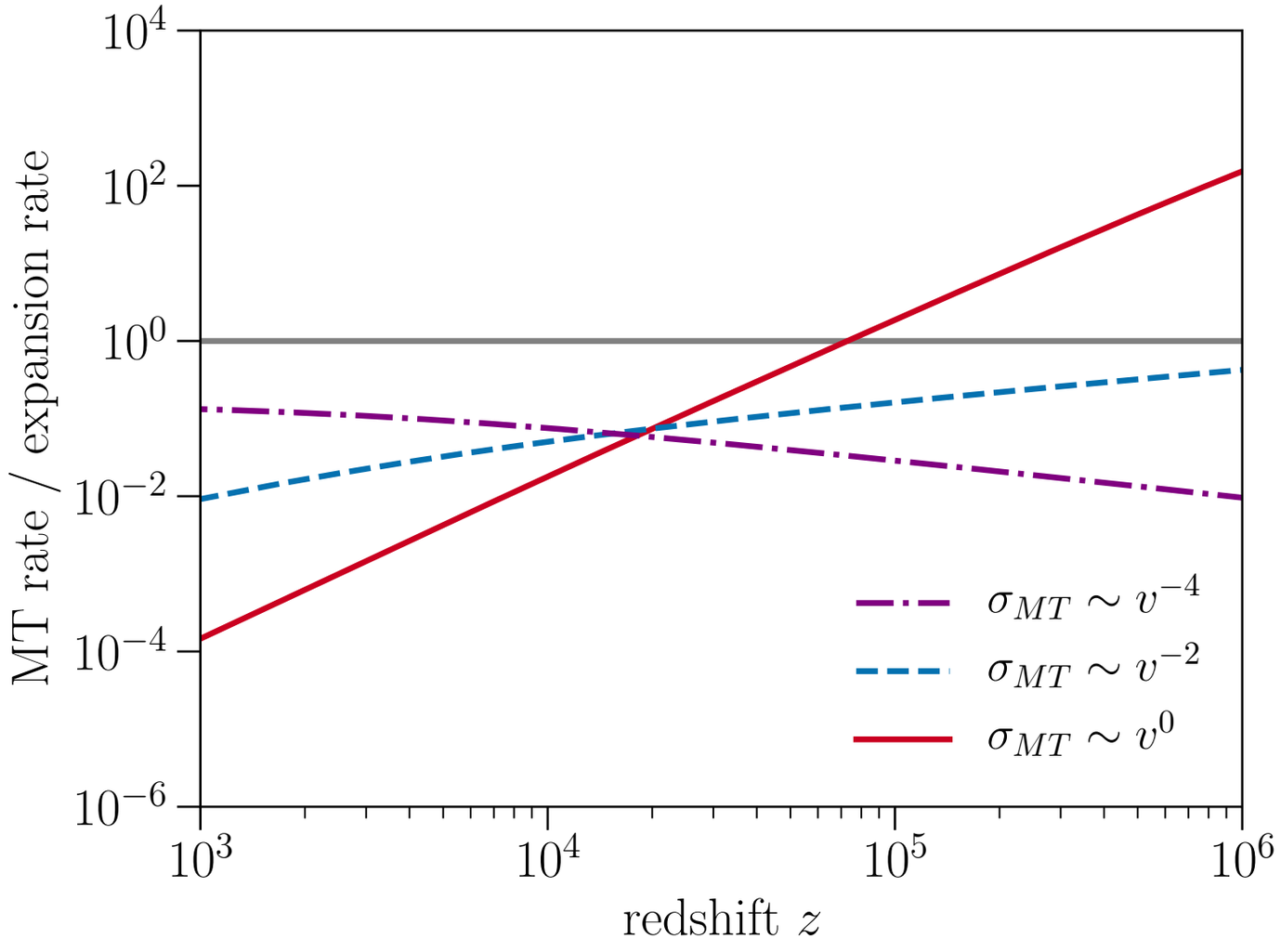

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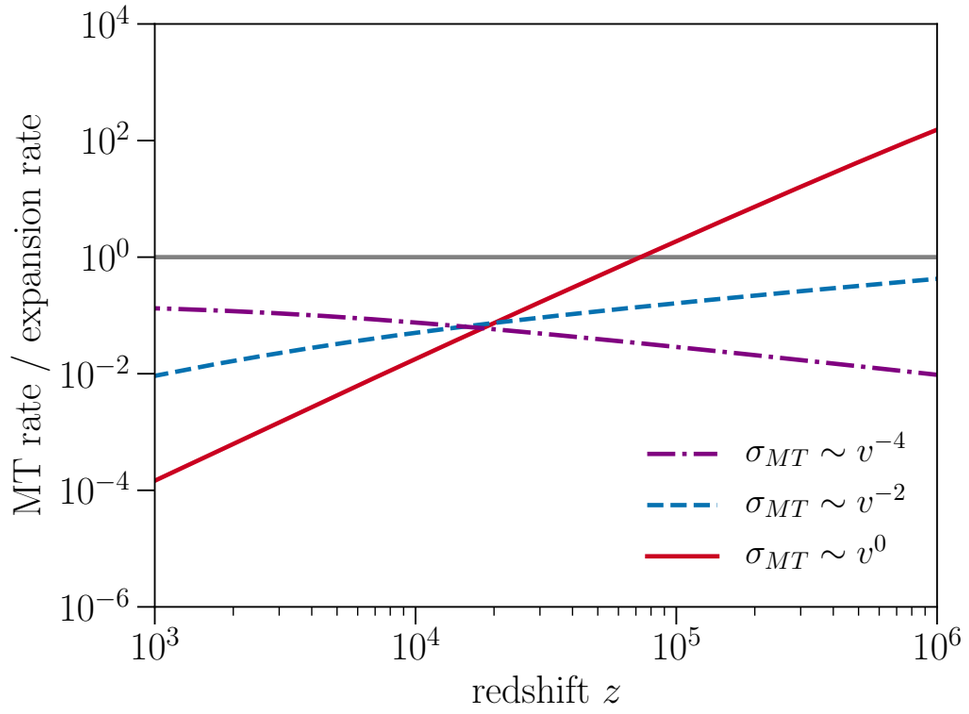
- For EFT models, could assume

$$|\vec{V}_{\rm DM} - \vec{V}_b|^2 \ll \bar{v}_{\rm th}^2$$



KB+ (1808.00001)

Scattering via Light Mediators

$$\sigma_{MT}(v) = \sigma_0 v^n$$

- Expect small (large) cross section at early (late) times, but relevant quantity is rate of momentum transfer

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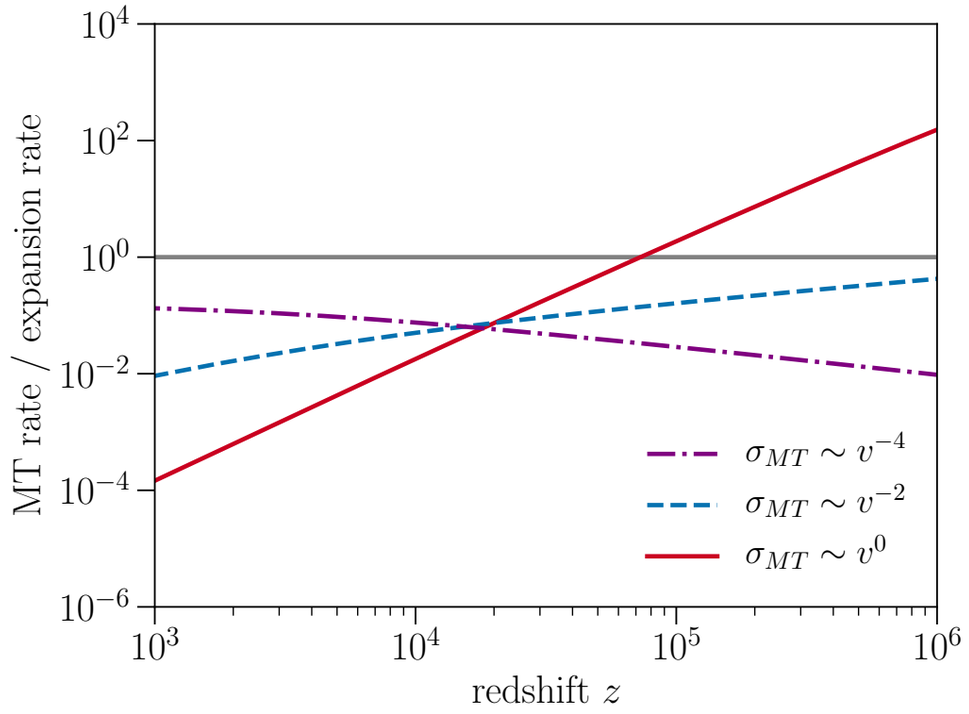
- Large bulk velocities lead to nonlinearities

  Dvorkin, Blum, Kamionkowski (2014)



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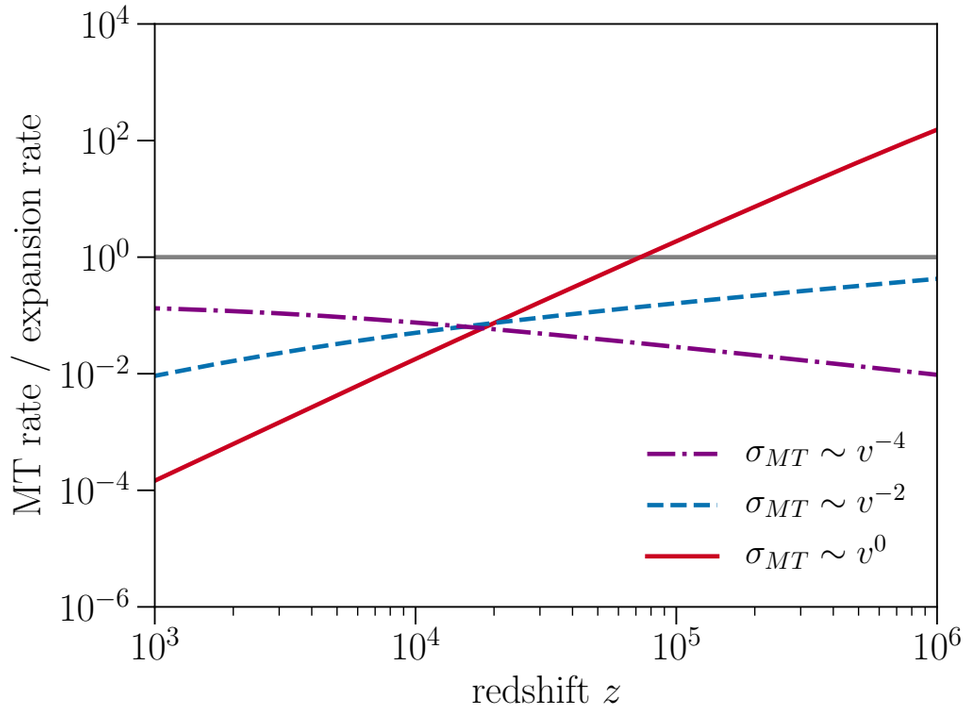
- Introduce new treatment of bulk velocities



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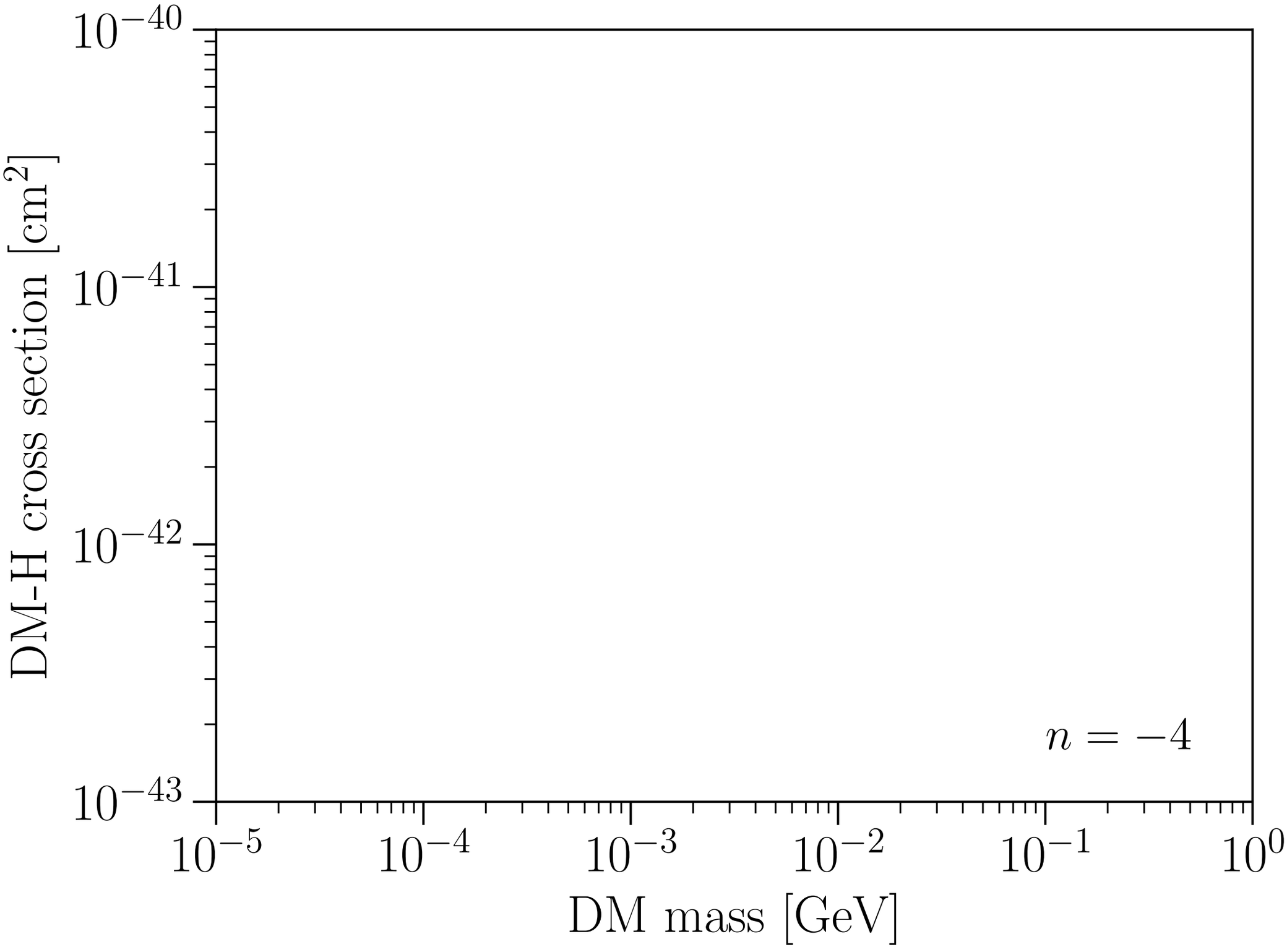

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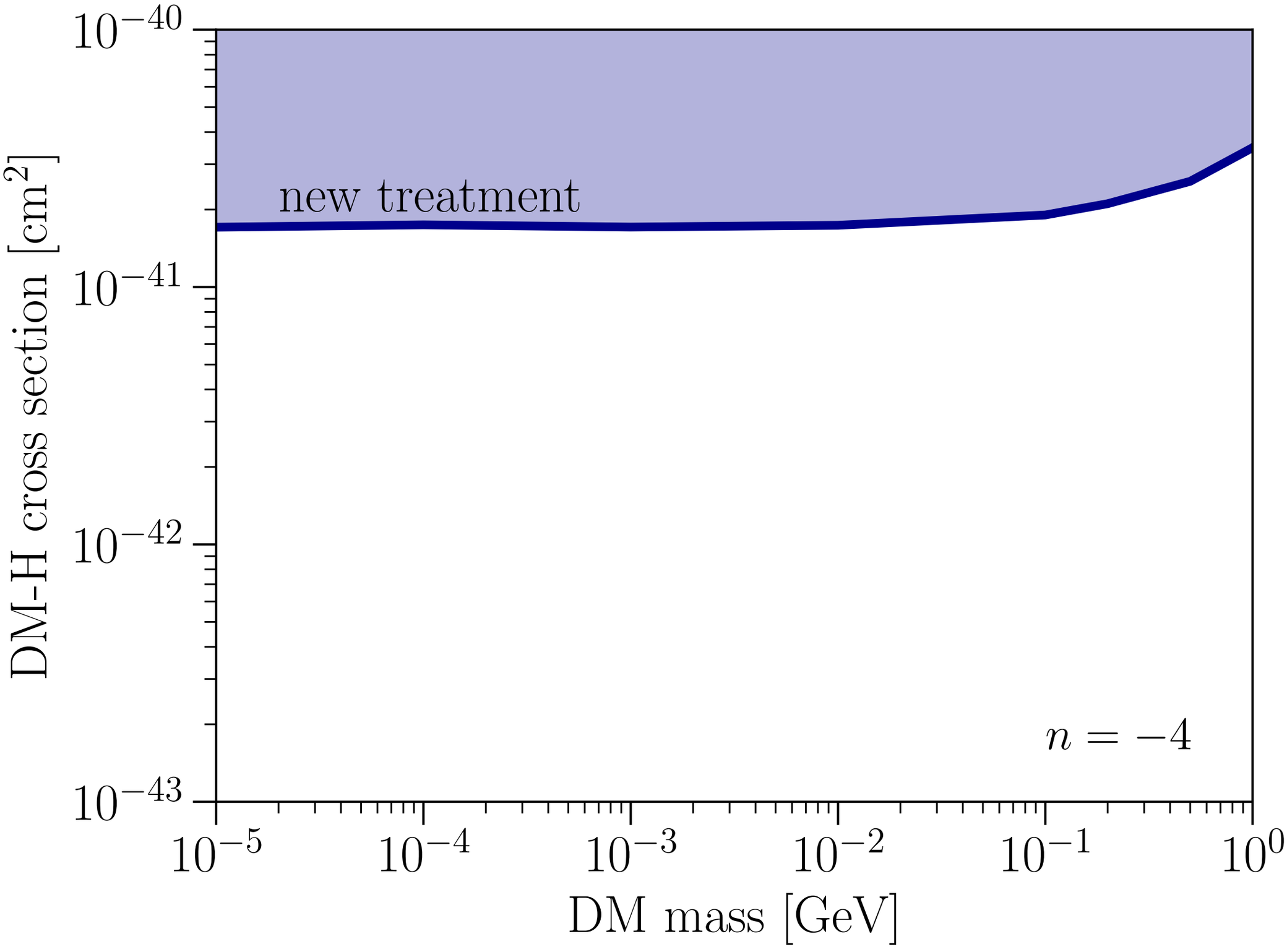

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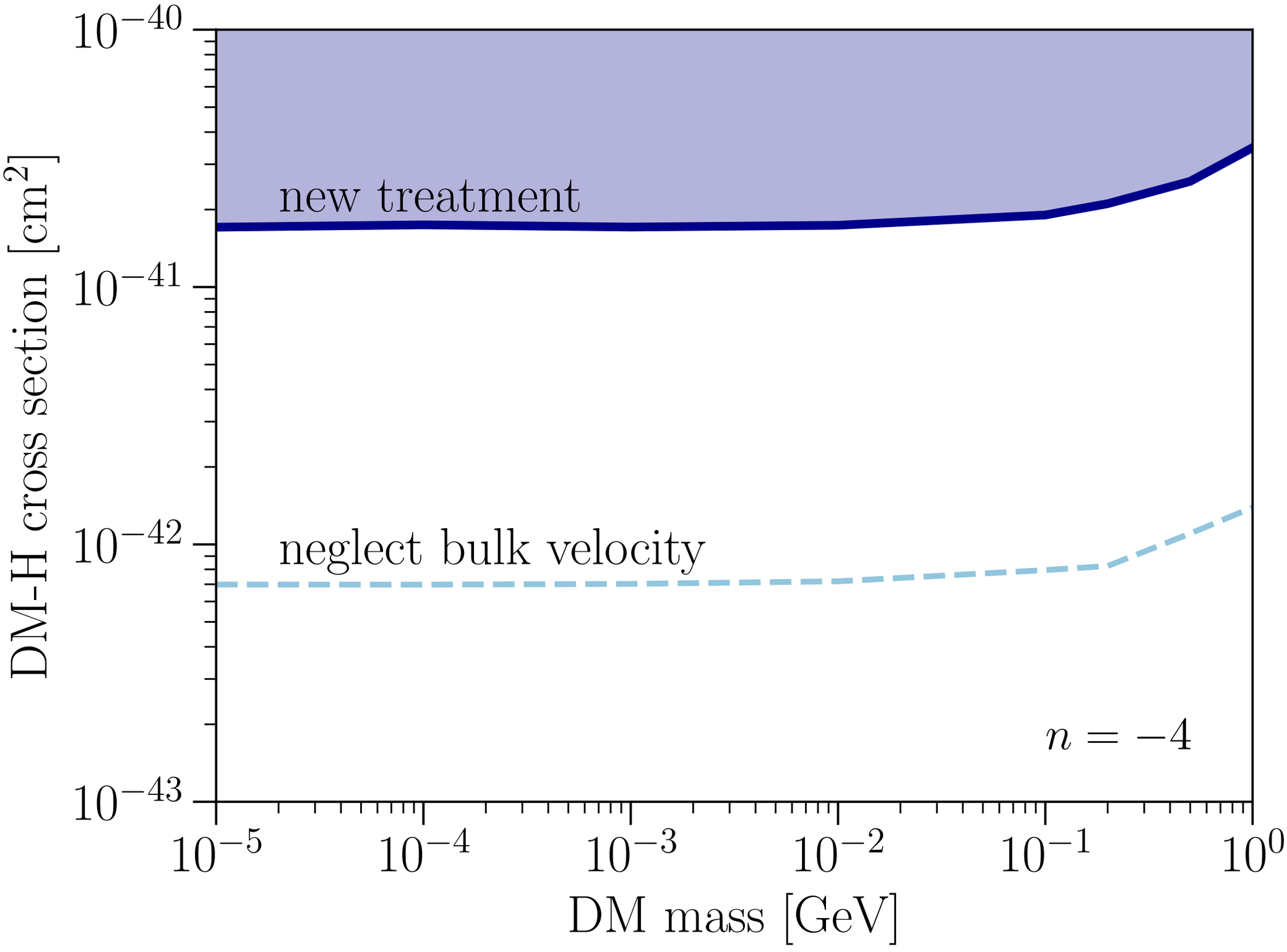

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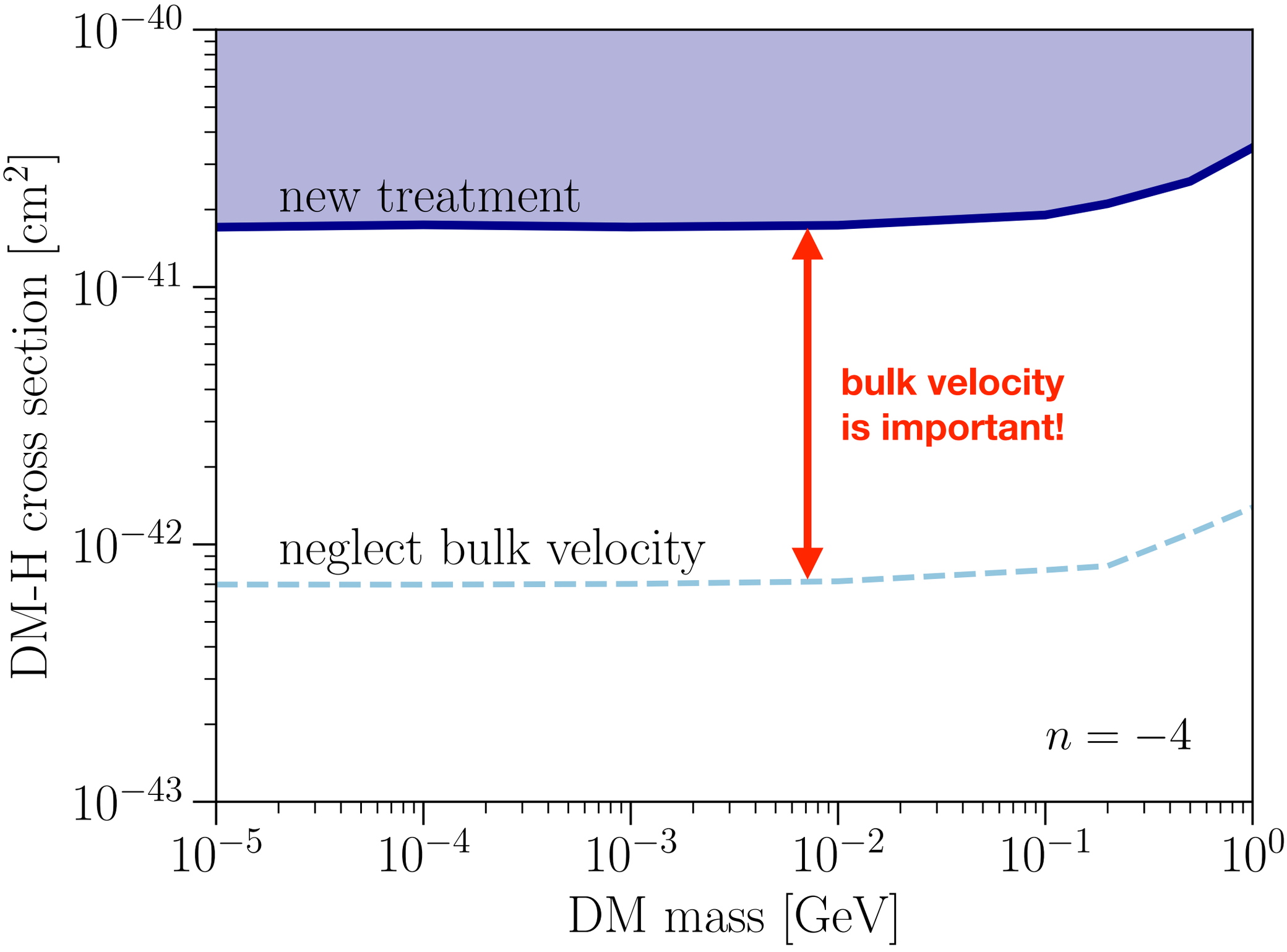

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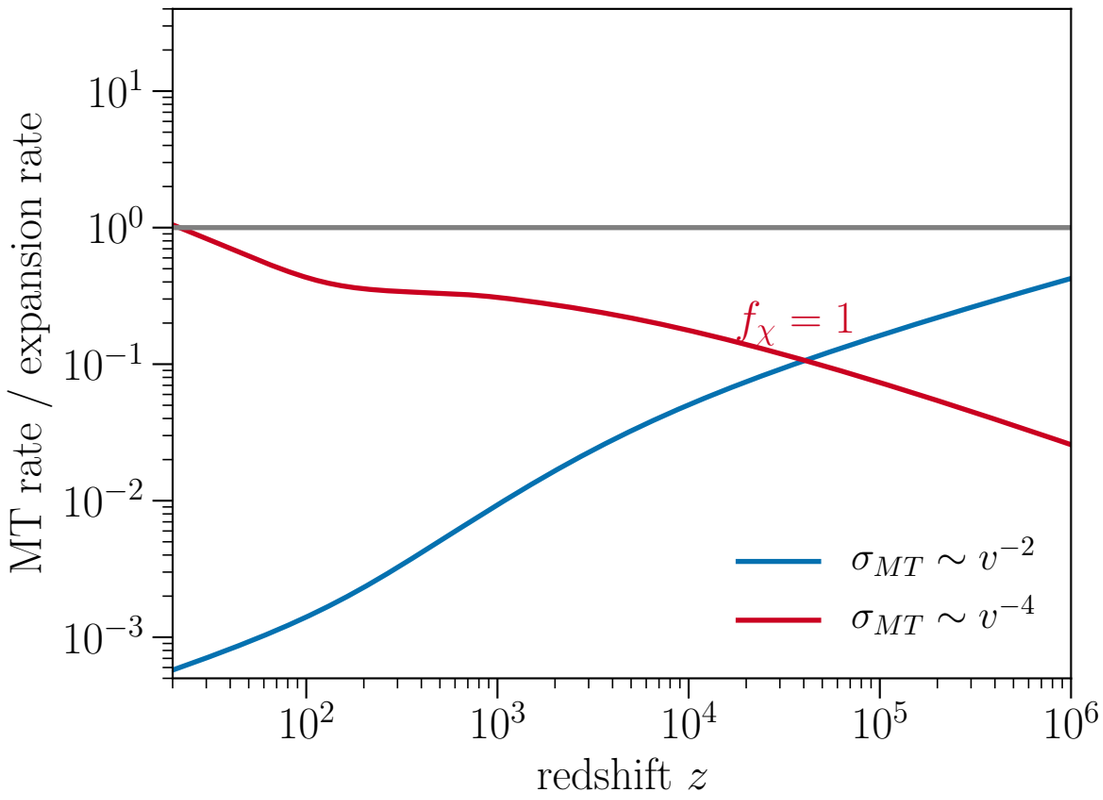
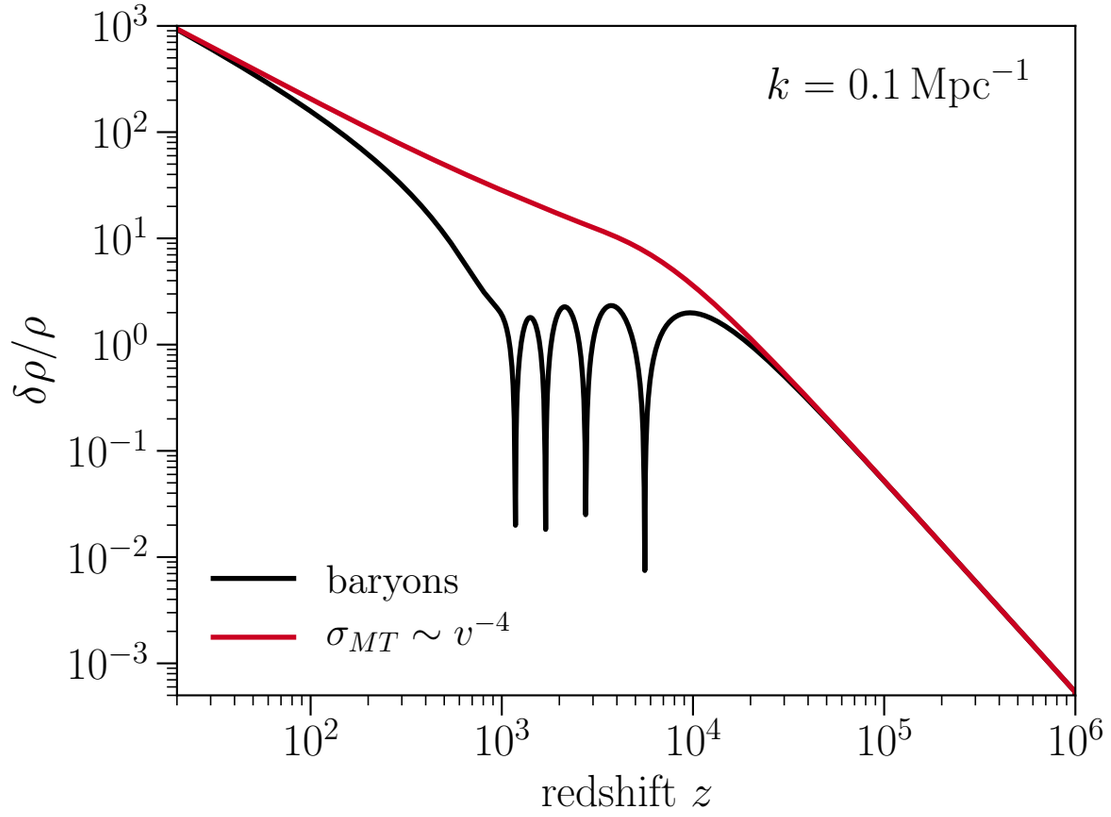
Fractional Case





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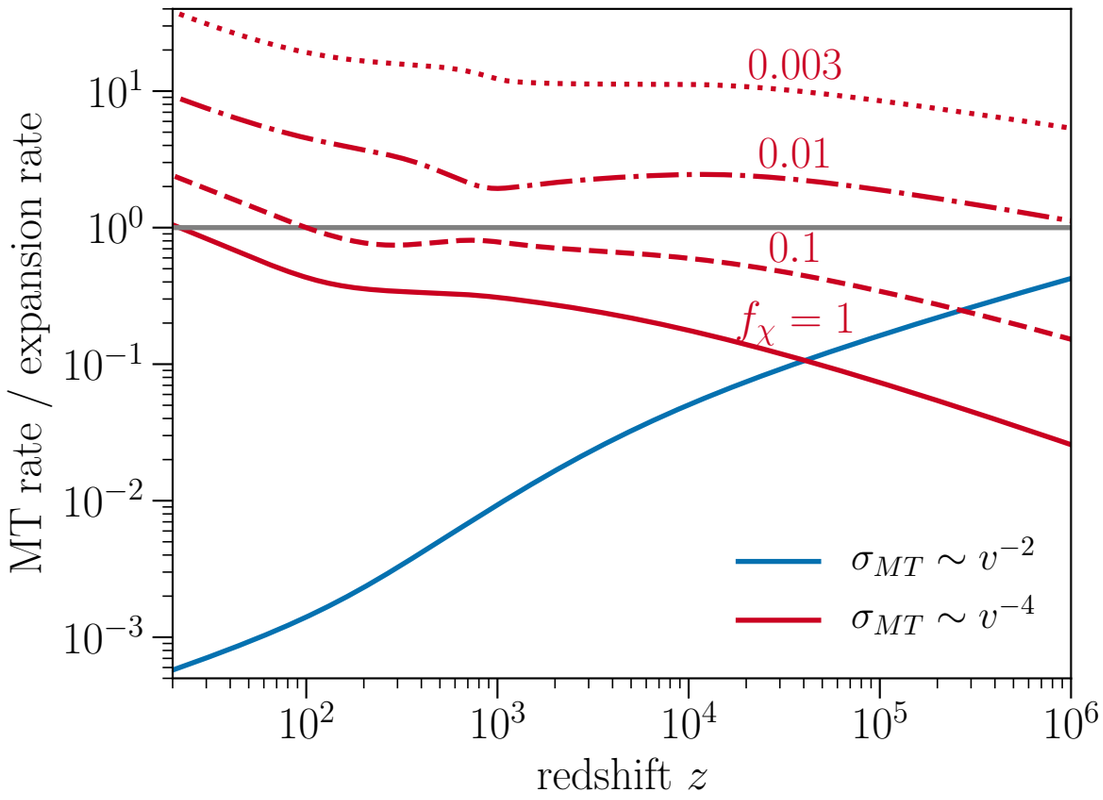

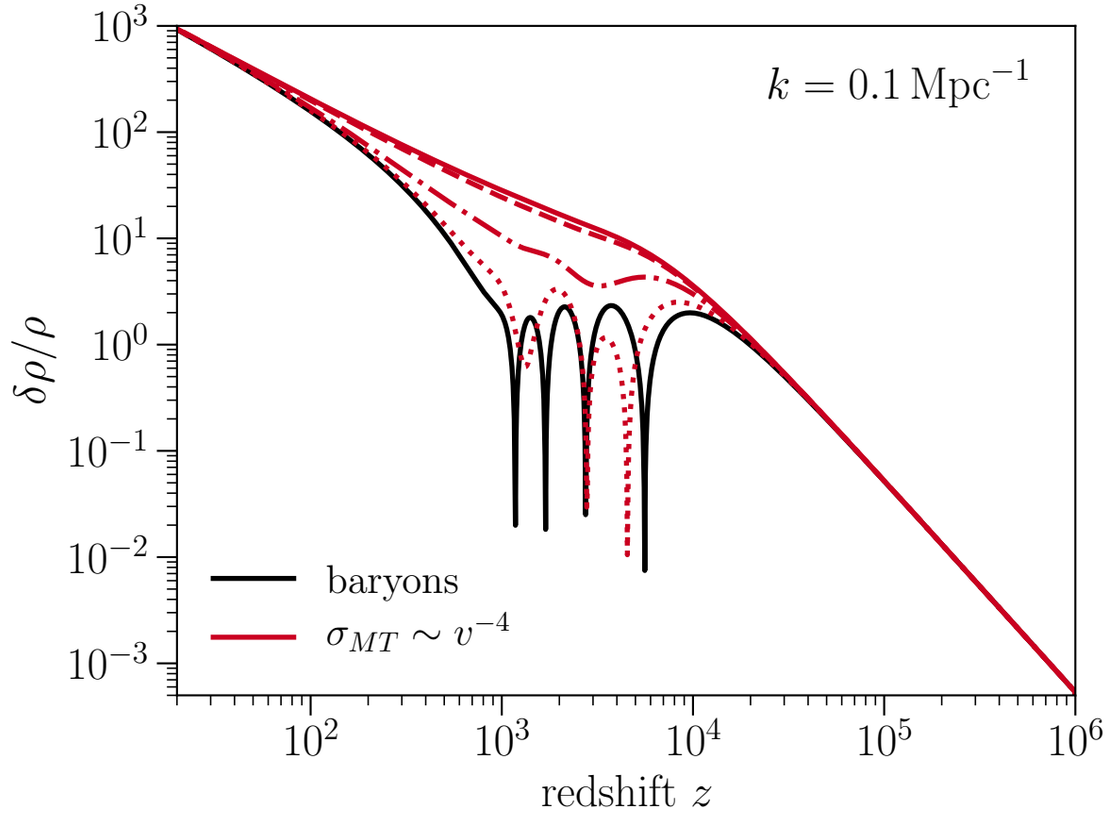

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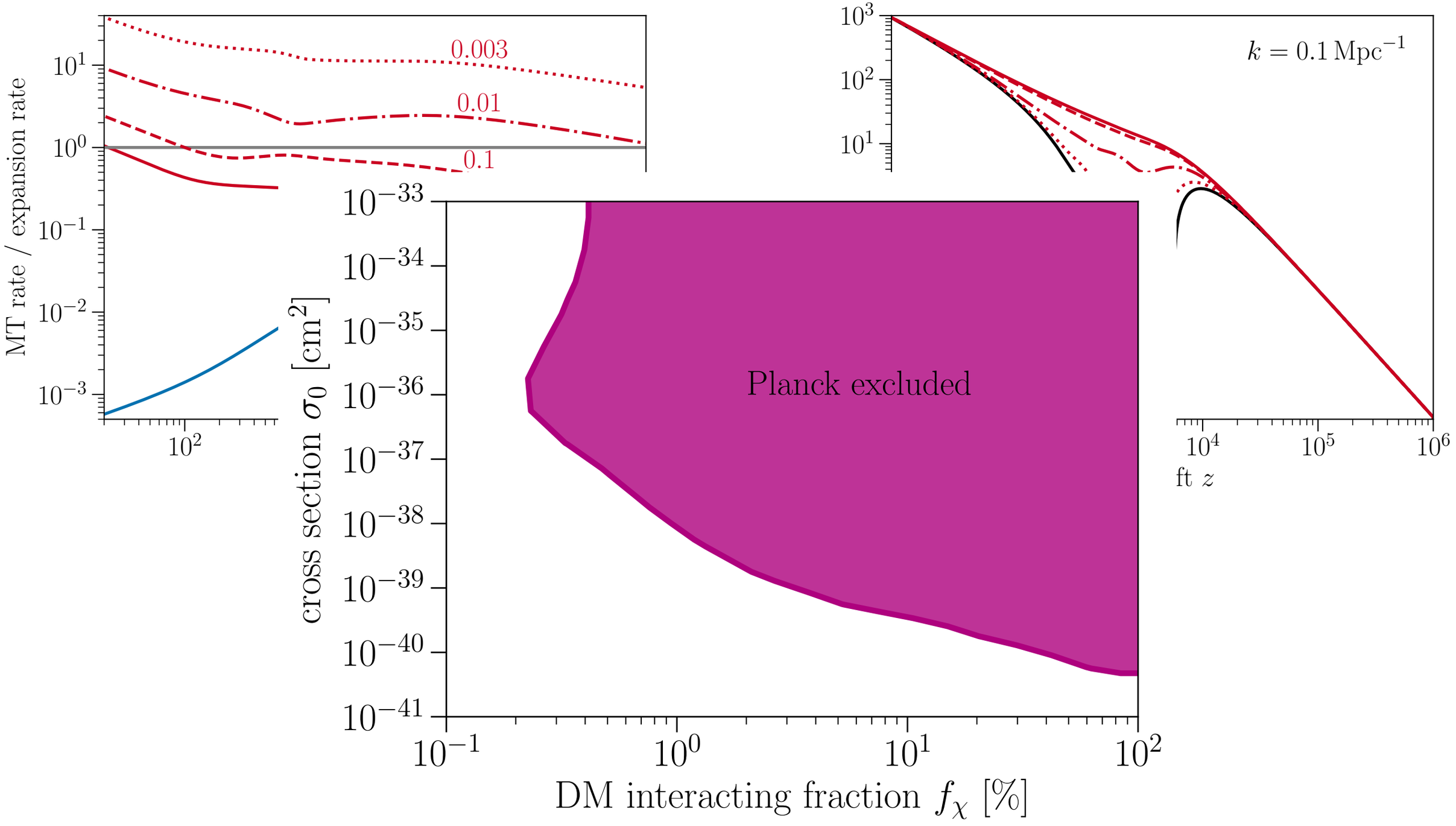

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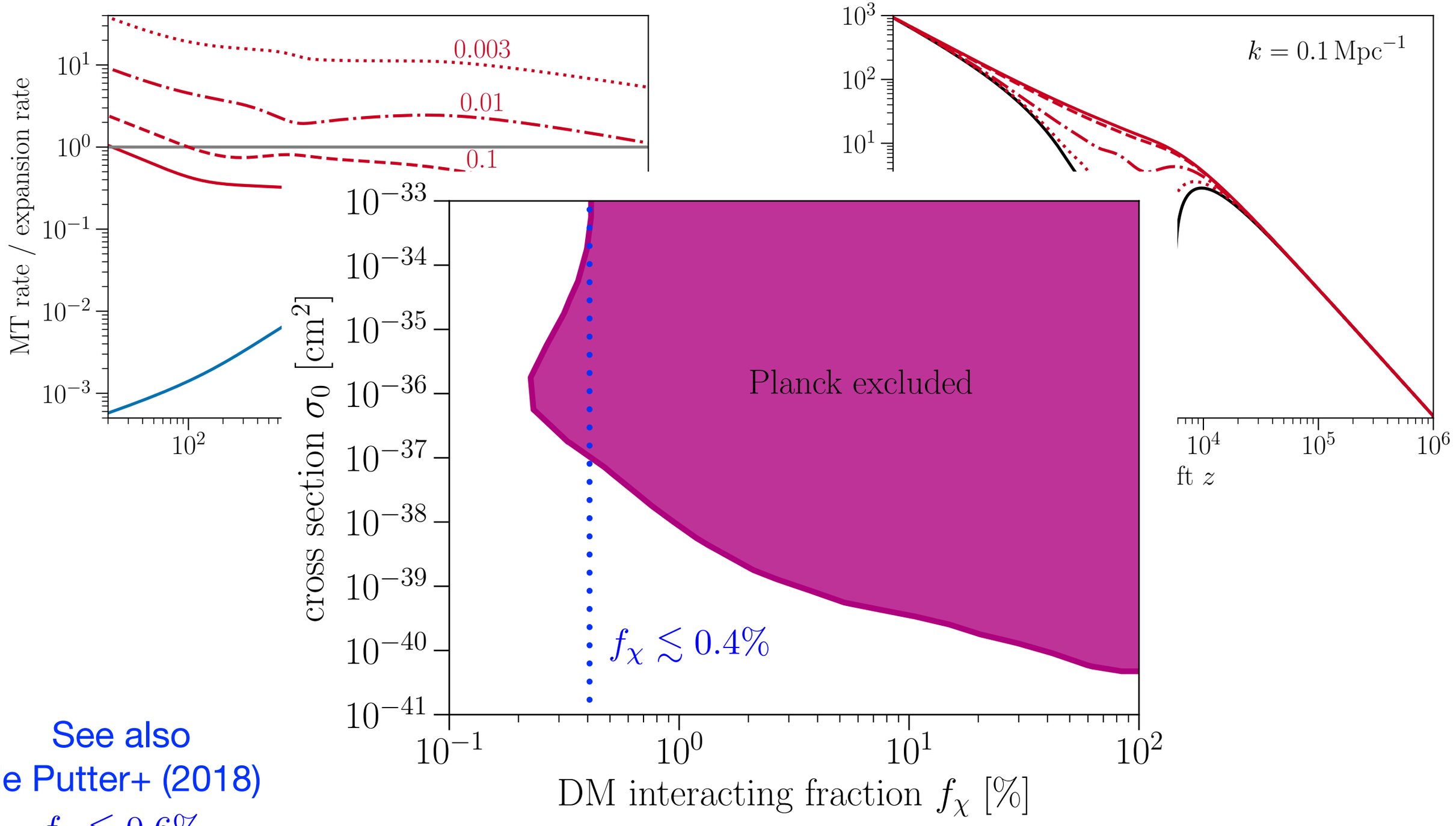

See also
de Putter+ (2018)
$f_\chi \lesssim 0.6\%$

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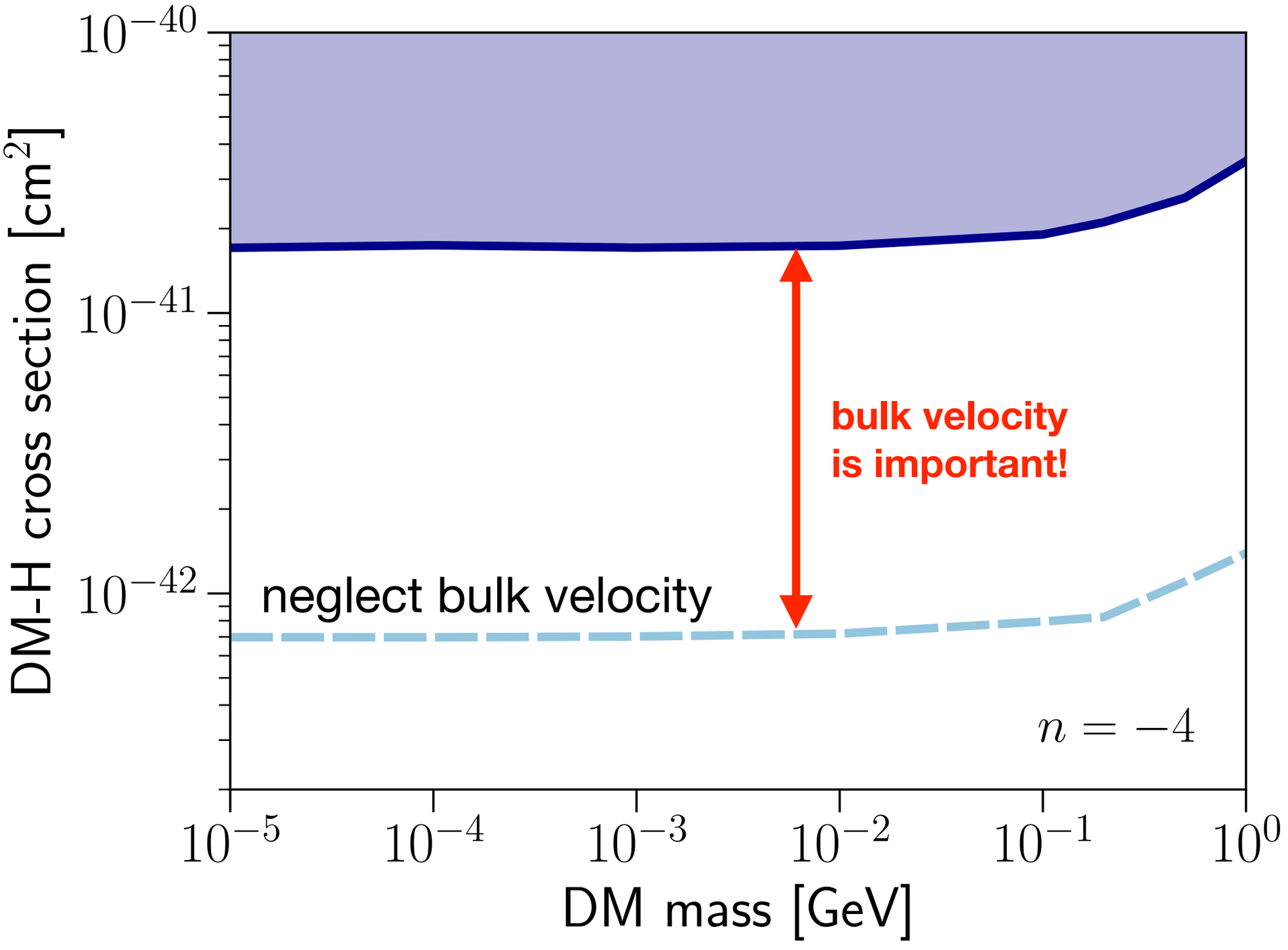
Implication for EDGES



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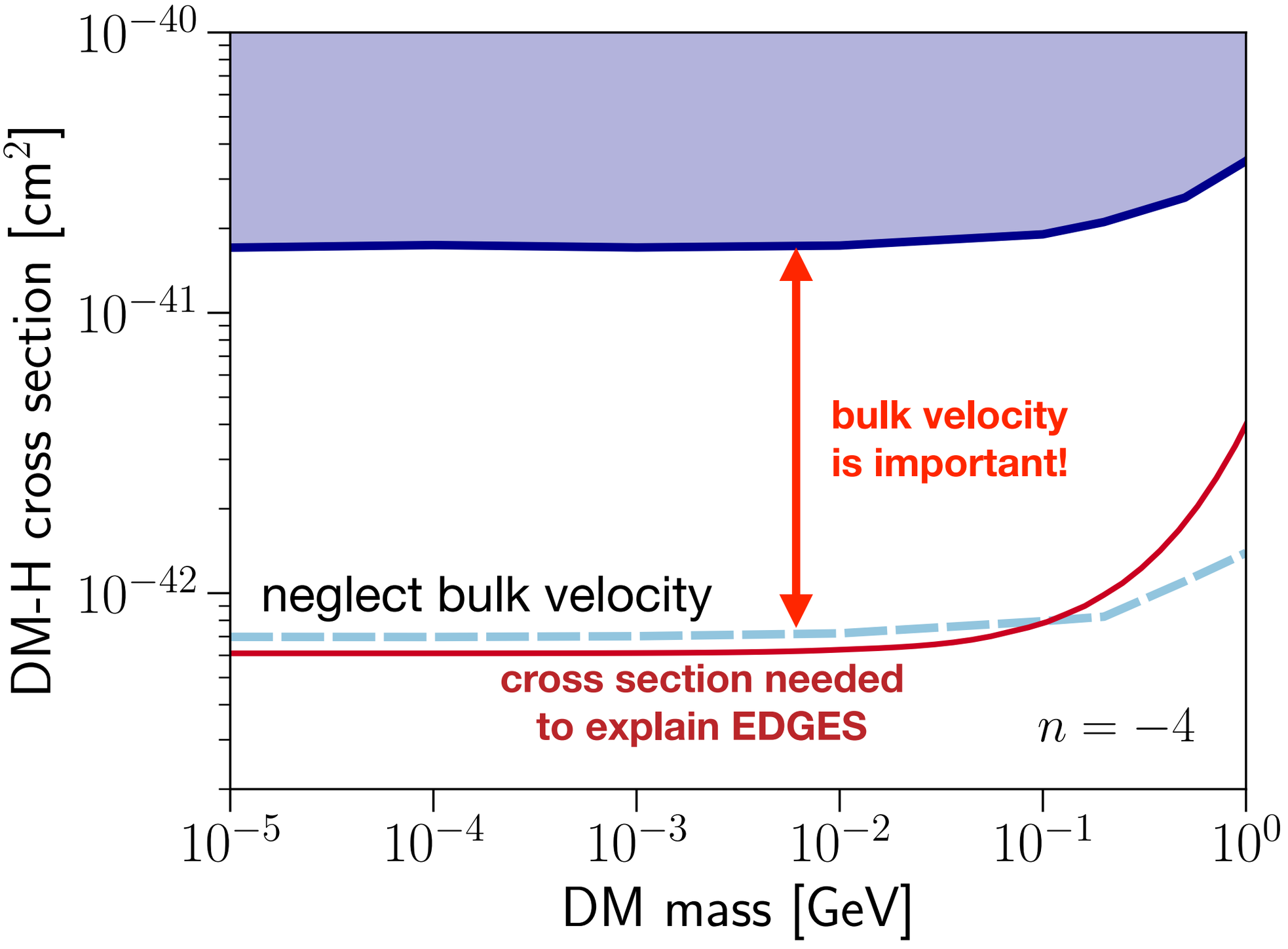
Implication for EDGES



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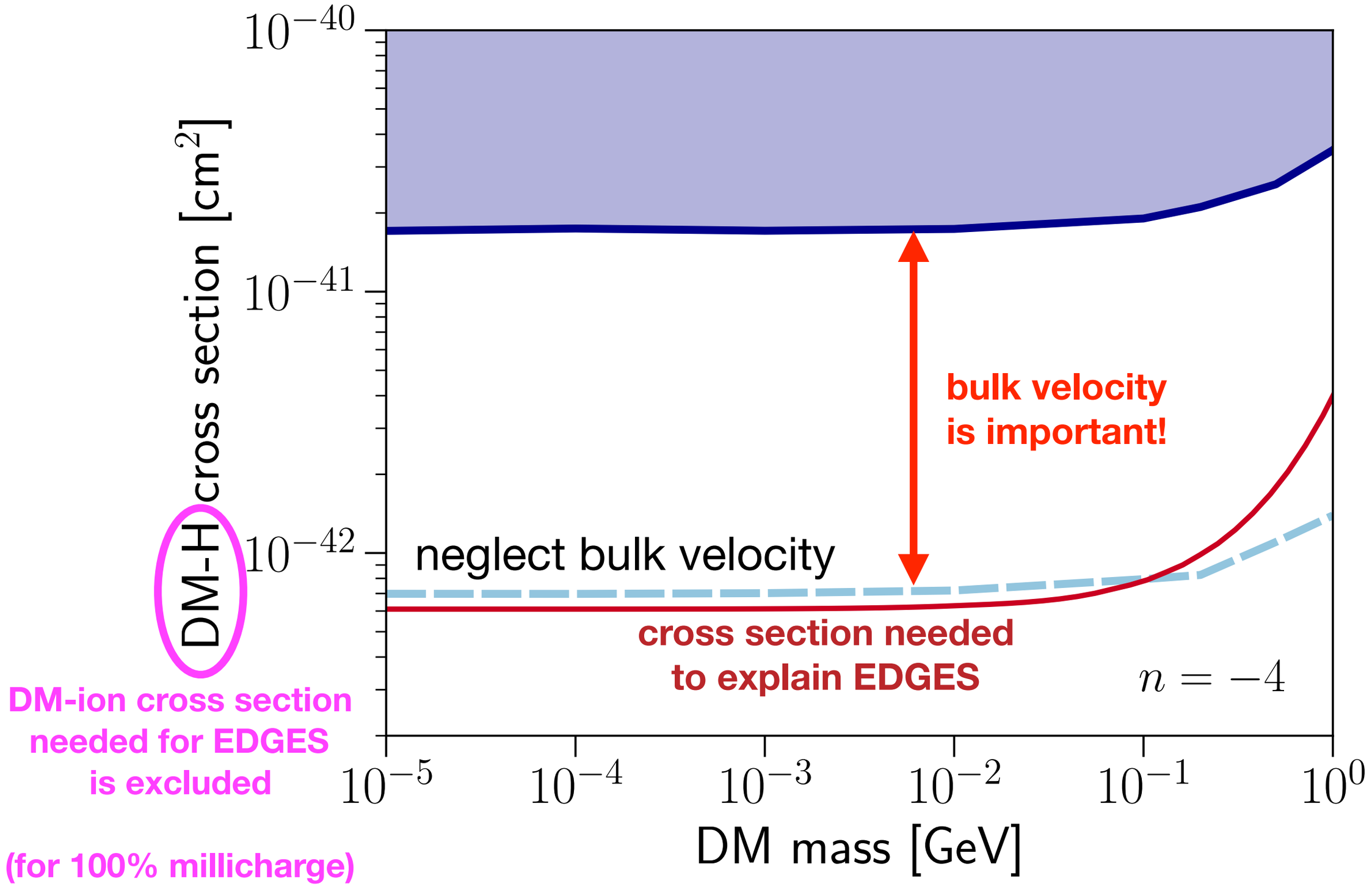
Implication for EDGES



DM-ion cross section needed for EDGES is excluded

(for 100% millicharge)

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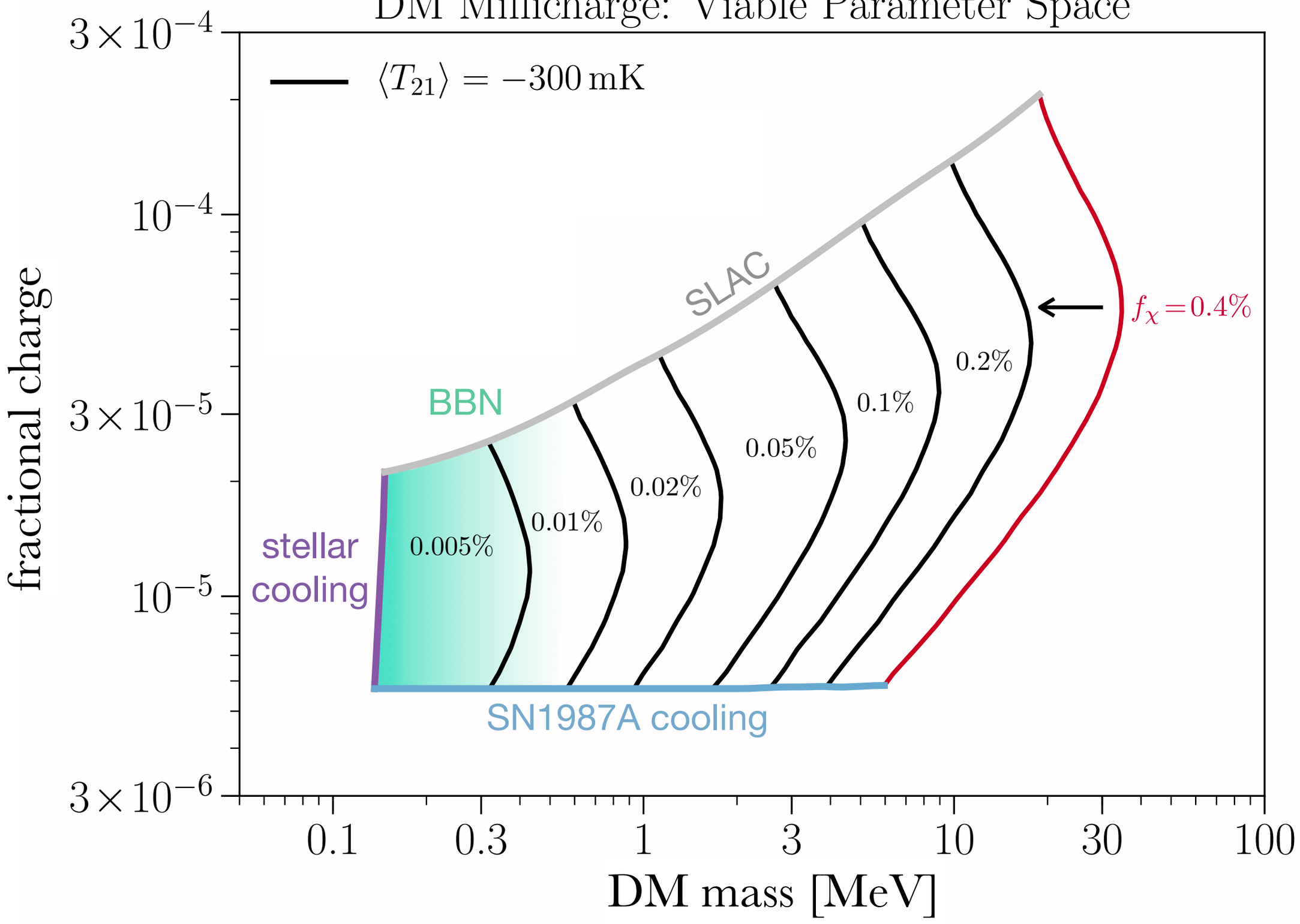
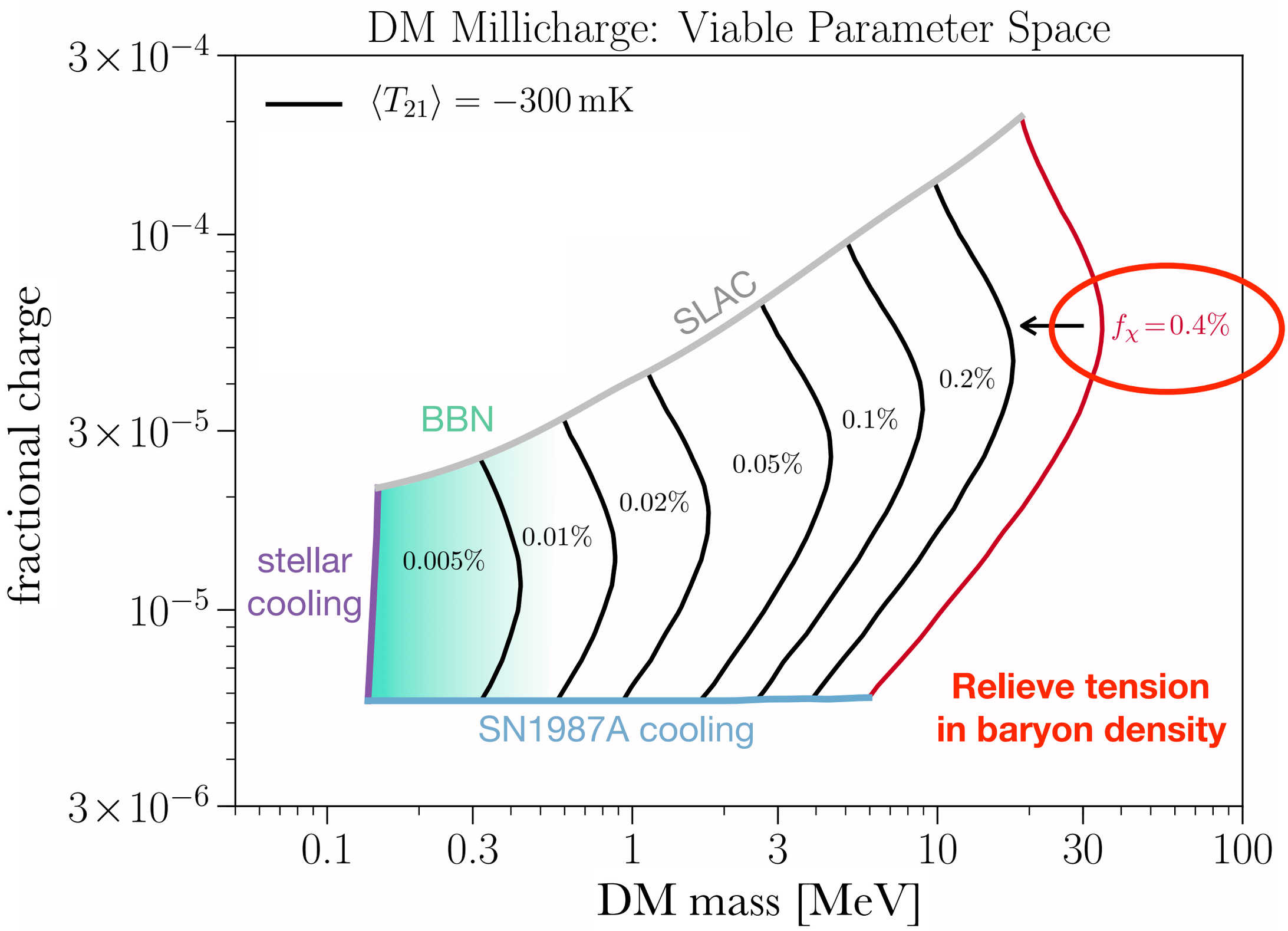


SN1987A: Chang, Essig, and McDermott (2018)
SLAC: Prinz et al. (1998)
Stellar: Vogel and Redondo (2014)

Kovetz, Poulin, Gluscevic, **KB**+ (1807.11482)



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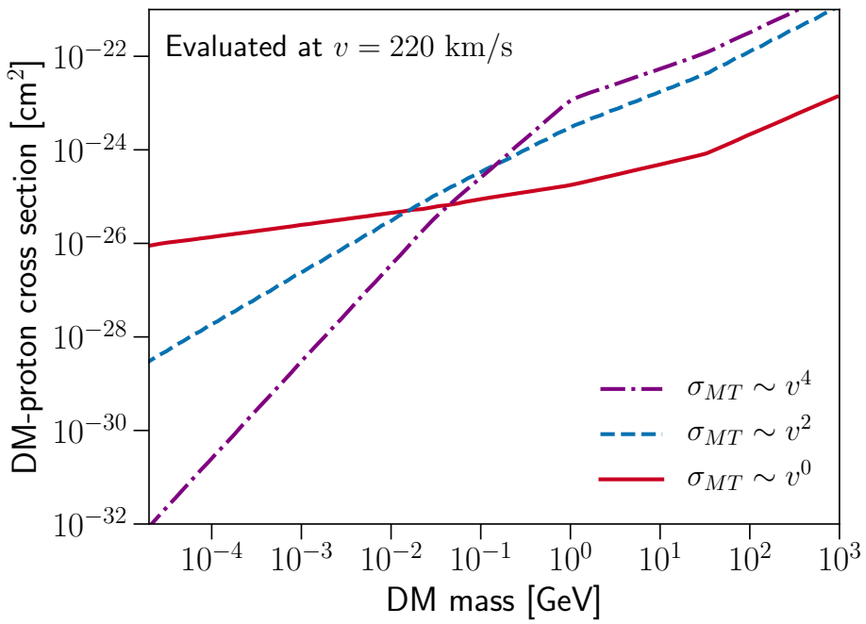
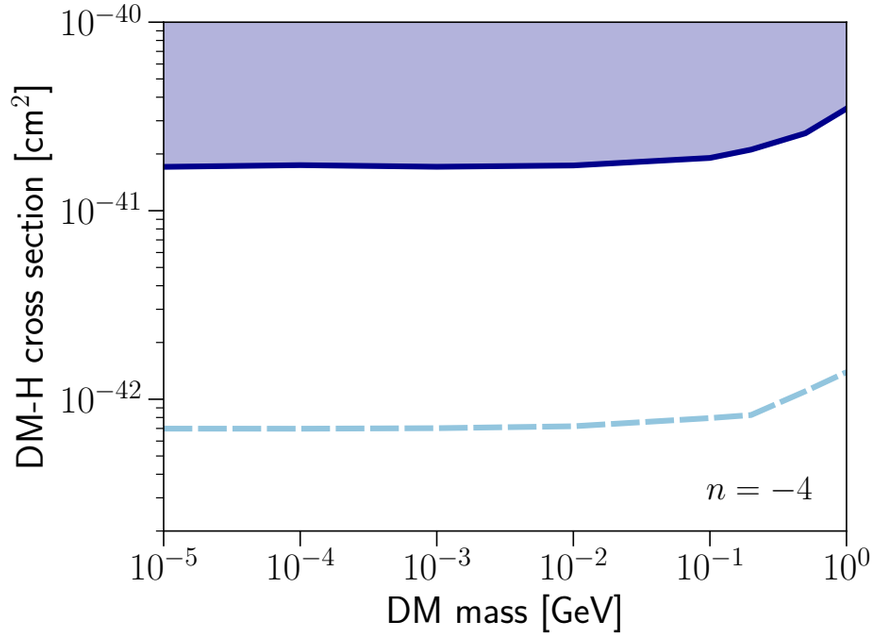
Conclusions

- Cosmological observables provide a rich foundation to search for particle dark matter interactions

- Highly complementary to direct and indirect detection searches





- CMB constrains parameter space needed to explain millicharge interpretation of EDGES signal ($f_\chi \lesssim 0.4\%$)