Progress on Old and New Themes in Cosmology
Palais des Papes, Avignon, 2–5 May 2023

DARK MATTER-BARYON INTERACTIONS IN THE MILKY WAY

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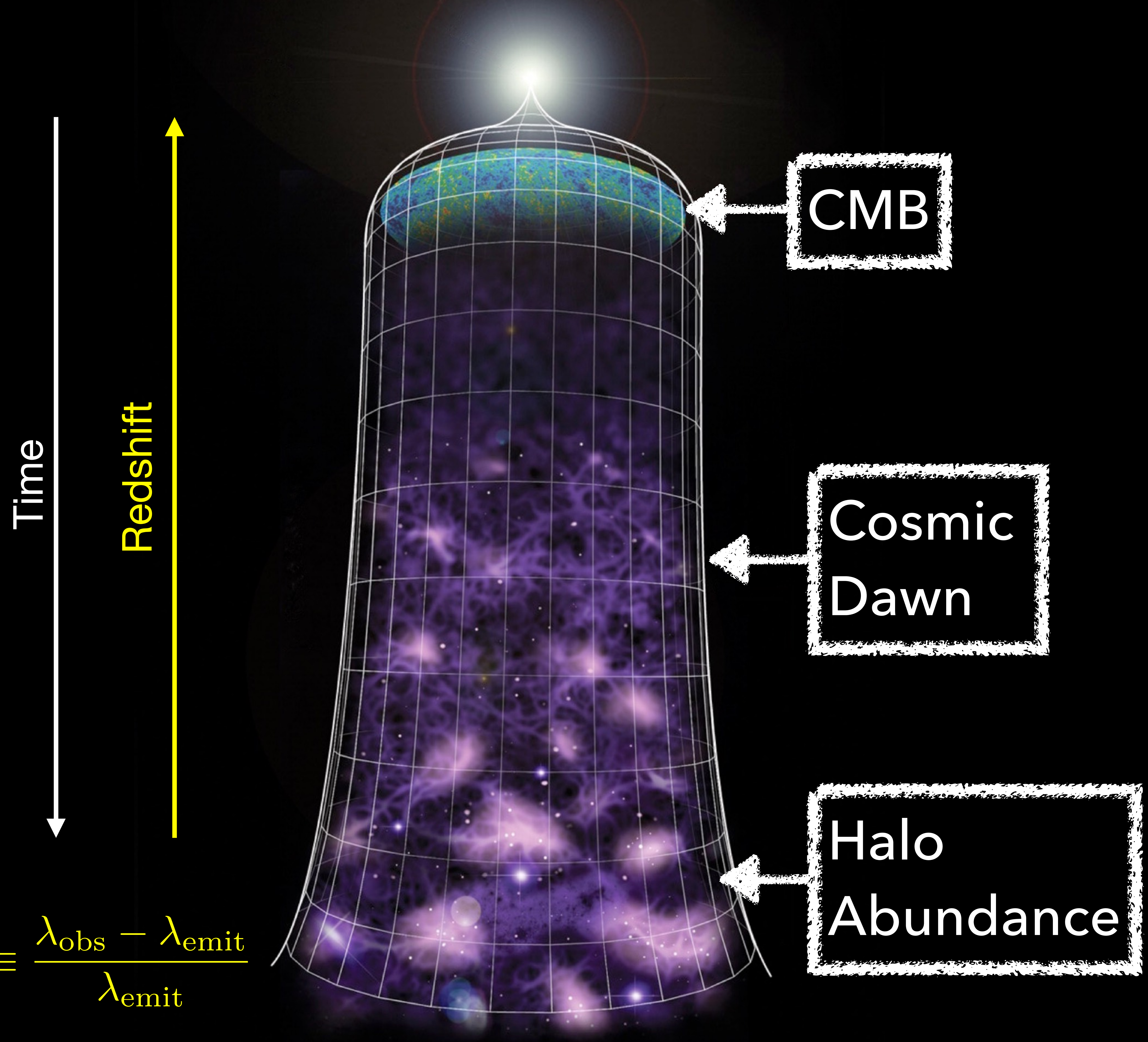
Cosmic History



$$z \equiv \frac{\lambda_{\rm obs} - \lambda_{\rm emit}}{\lambda_{\rm emit}}$$

DM–baryon scattering probes

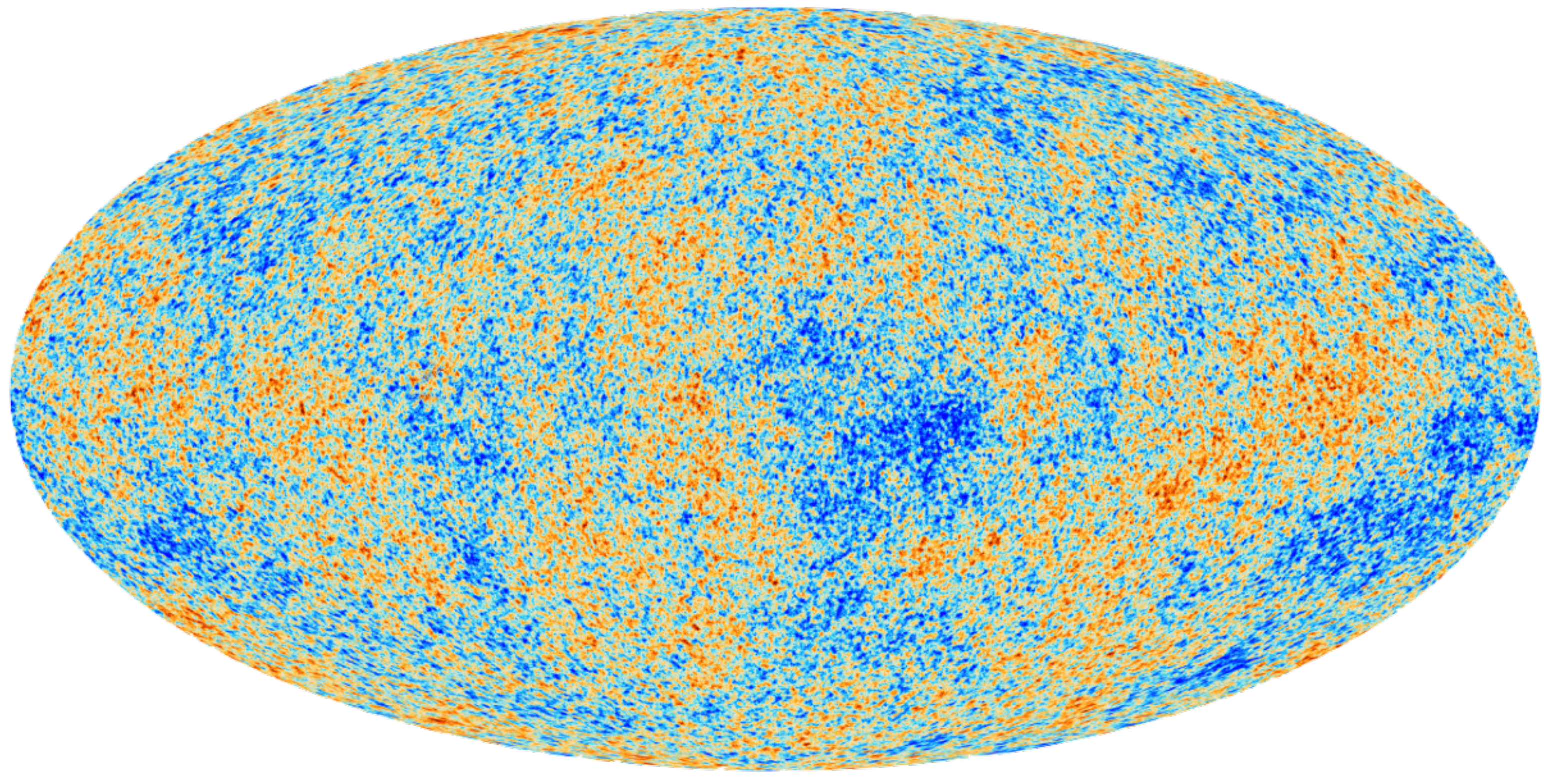
(1) CMB

(2) Milky Way satellite abundance

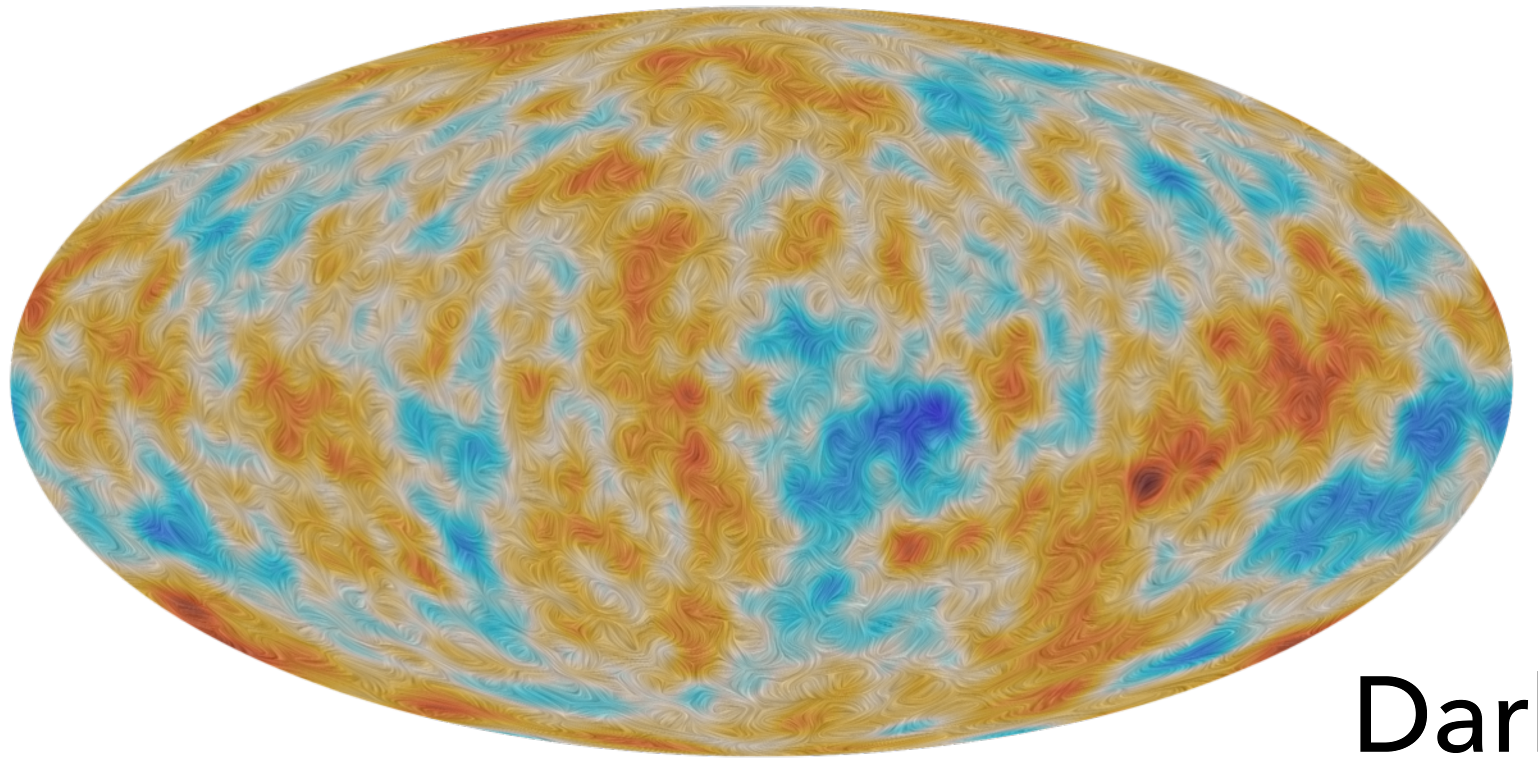
(3) 21cm signal from cosmic dawn

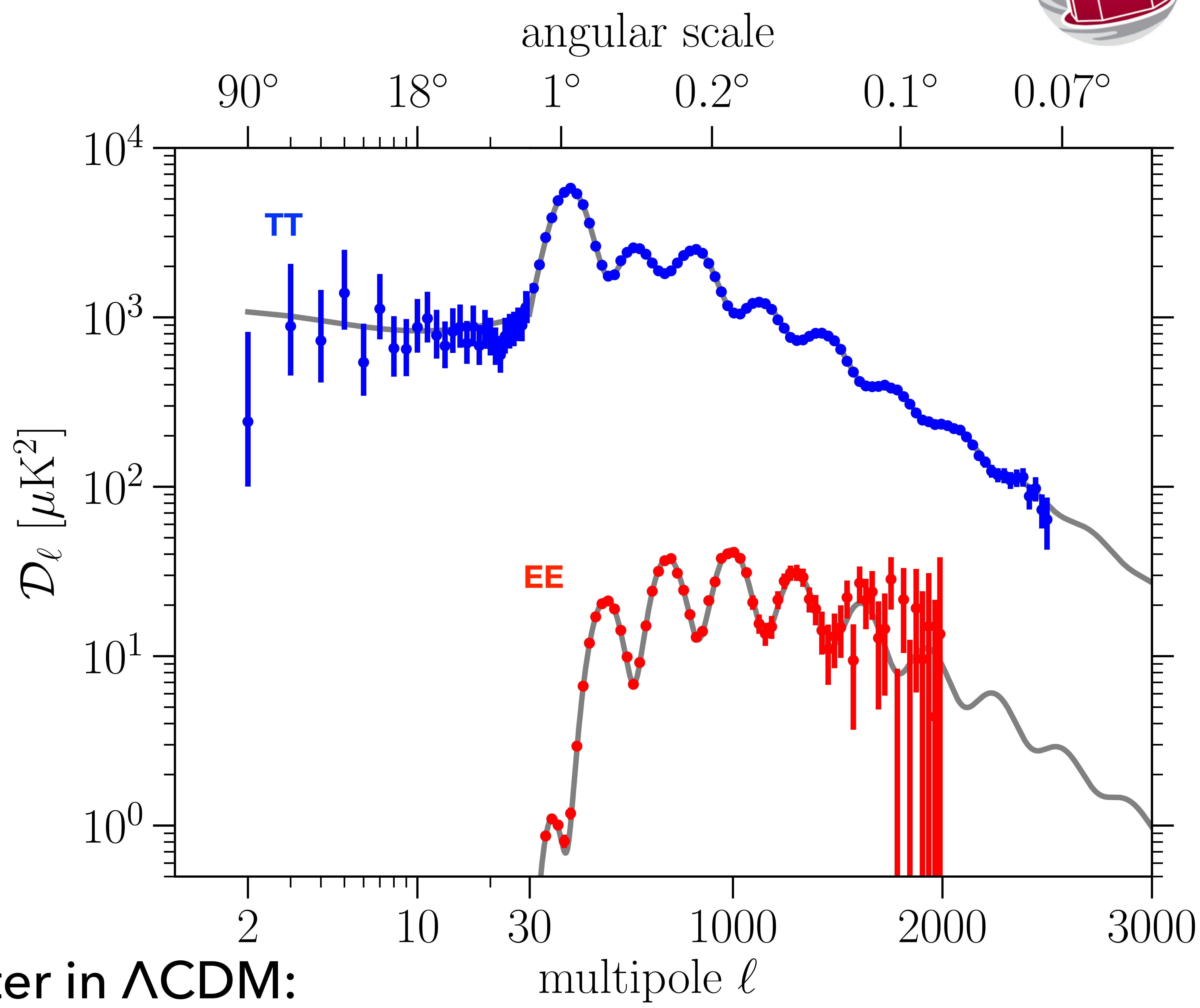
Cosmic Microwave Background

Temperature



Polarization



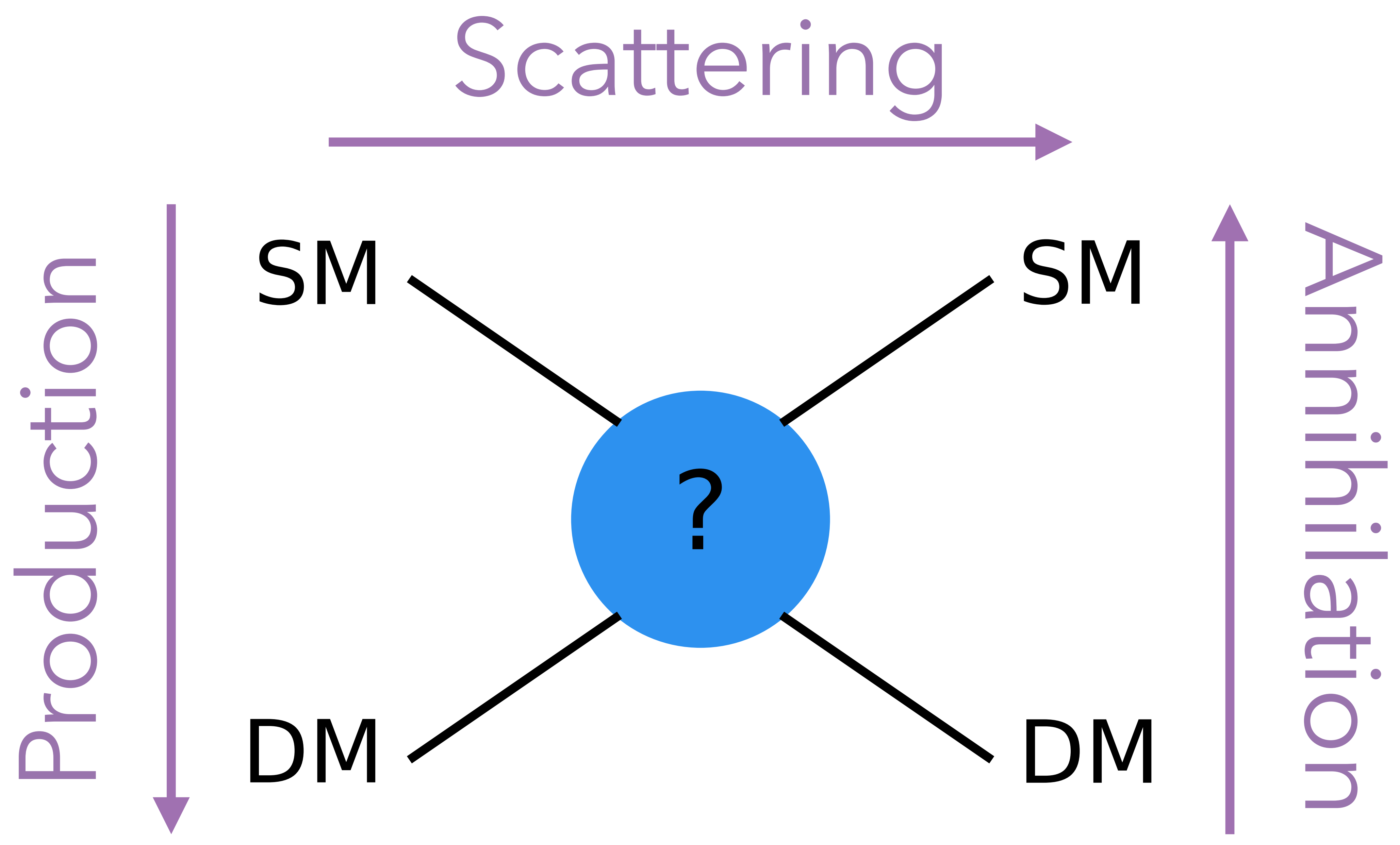


Dark matter in ΛCDM:

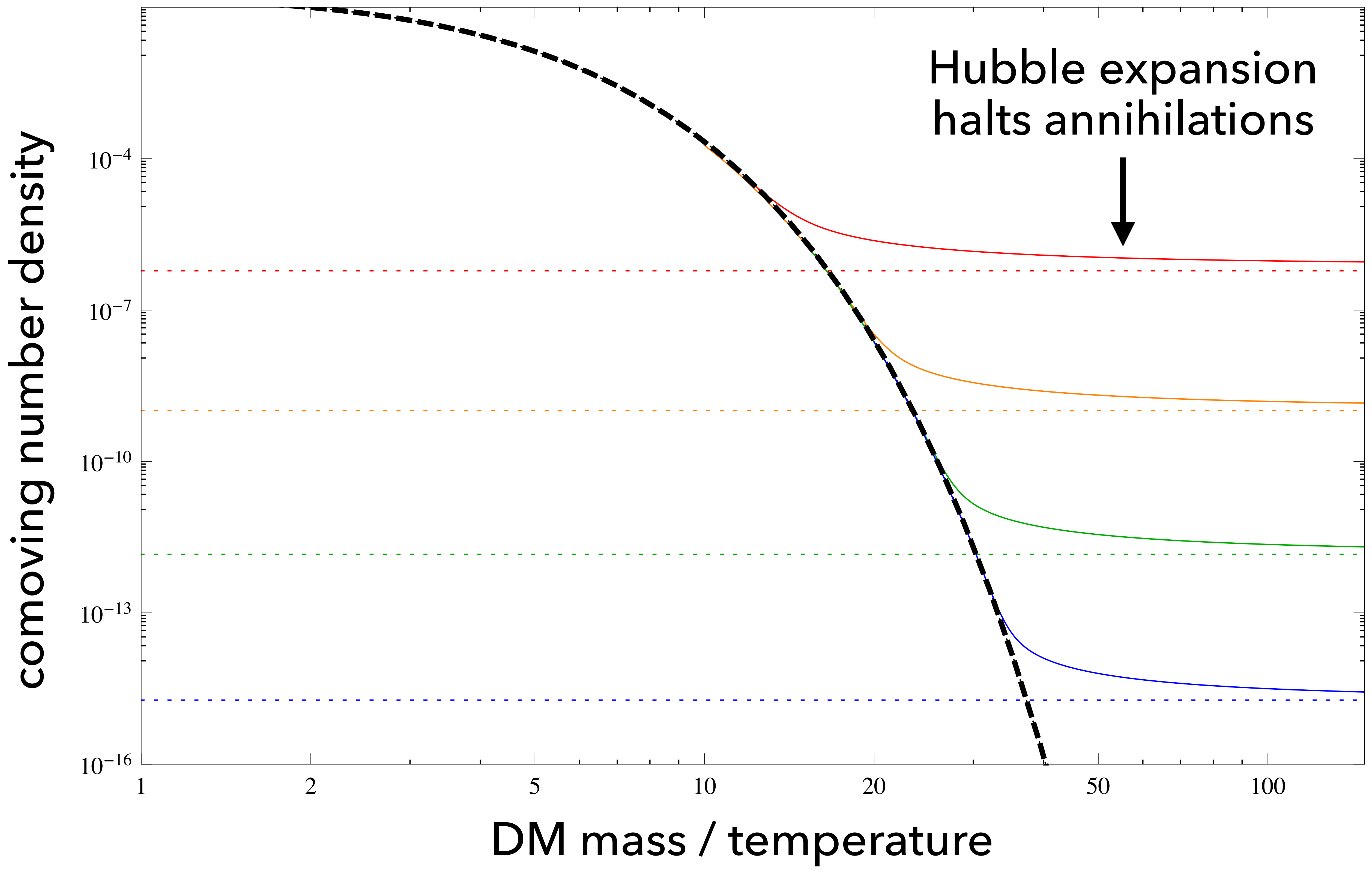
- cold, collisionless
- ~6x more abundant than baryons

ESA and Planck Collaboration

Weakly Interacting Massive Particles (WIMPs)



assume $\langle \sigma v \rangle \sim \frac{\pi \alpha^2}{m^2}$



match observed abundance for weak-scale particles (WIMP miracle)

Dark Matter Scattering

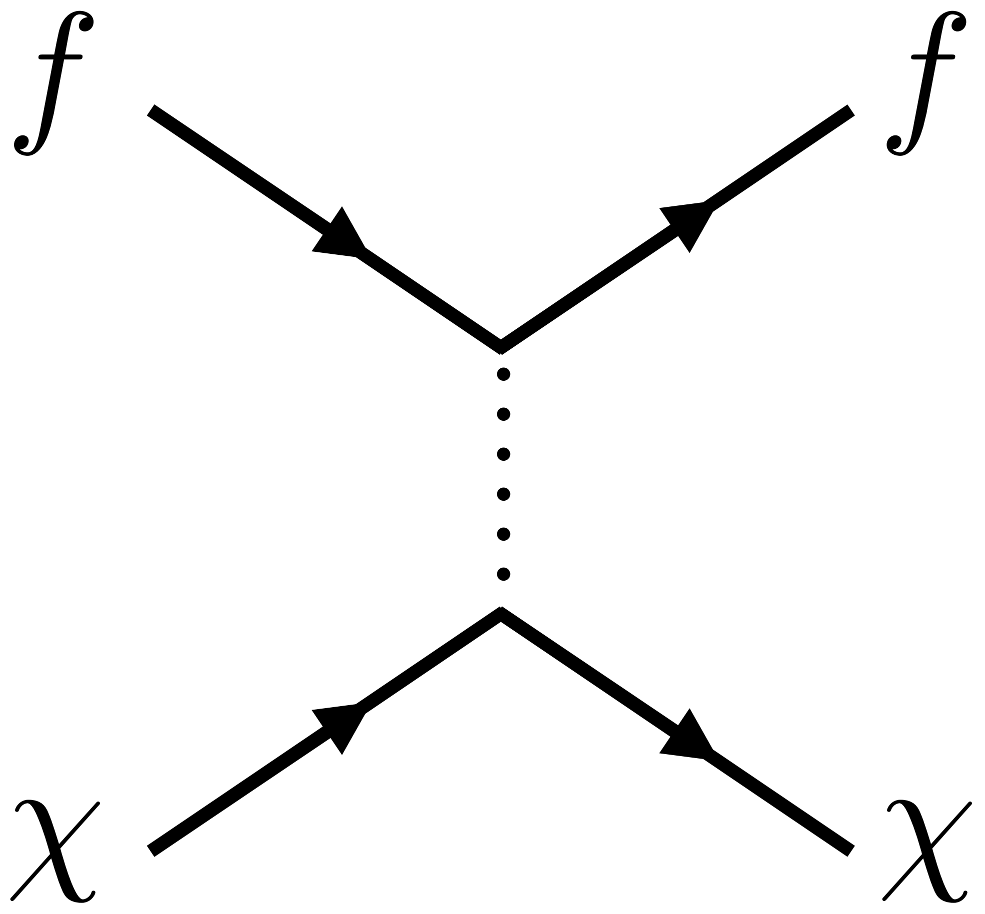
$$\sigma_{MT}(v) = \int (1-\cos\theta)\frac{d\sigma}{d\Omega}\, d\Omega = \sigma_0 v^n$$

Heavy mediator

- $n = 0 \quad \mathscr{L} \sim \bar{\chi}\chi\bar{f}f$
- $n = 2 \quad \mathscr{L} \sim i\bar{\chi}\chi\bar{f}\gamma^5 f,\ i\bar{\chi}\gamma^5\chi\bar{f}f$
- $n = 4 \quad \mathscr{L} \sim \bar{\chi}\gamma^5\chi\bar{f}\gamma^5 f$

Light mediator

- $n = -2$ (electric dipole)
- $n = -4$ (Coulomb)



f in early Universe:

e^-, p, He

Modify Boltzmann Equations

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

$$\dot{\delta}_b = -\theta_b - \frac{\dot{h}}{2}, \ \dot{\delta}_\chi = -\theta_\chi - \frac{\dot{h}}{2}$$

$$\dot{\theta}_b = -\frac{\dot{a}}{a}\theta_b + c_b^2 k^2 \delta_b + R_\gamma(\theta_\gamma - \theta_b) + \frac{\rho_\chi}{\rho_b} R_\chi(\theta_\chi - \theta_b)$$

$$\dot{\theta}_\chi = -\frac{\dot{a}}{a}\theta_\chi + c_\chi^2 k^2 \delta_\chi + R_\chi(\theta_b - \theta_\chi)$$

$$\dot{T}_b + 2\frac{\dot{a}}{a}T_b = 2\frac{\mu_b}{m_e}R_\gamma(T_\gamma - T_b) + 2\frac{\mu_b}{m_\chi}R'_\chi(T_\chi - T_b)$$

$$\dot{T}_\chi + 2\frac{\dot{a}}{a}T_\chi = 2R'_\chi(T_b - T_\chi)$$

- Momentum-transfer rate

$$R_{\chi,f} \sim a n_f \left(\frac{\sigma_0}{m_\chi + m_f}\right)\left(\frac{T_b}{m_f} + \frac{T_\chi}{m_\chi}\right)^{(n+1)/2}$$

- Heat-transfer rate

$$R'_{\chi,f} = \frac{m_\chi}{m_\chi + m_f} R_{\chi,f}$$

- Nonlinearities arise if relative bulk velocity > thermal velocity; relevant for $n = -2, -4$

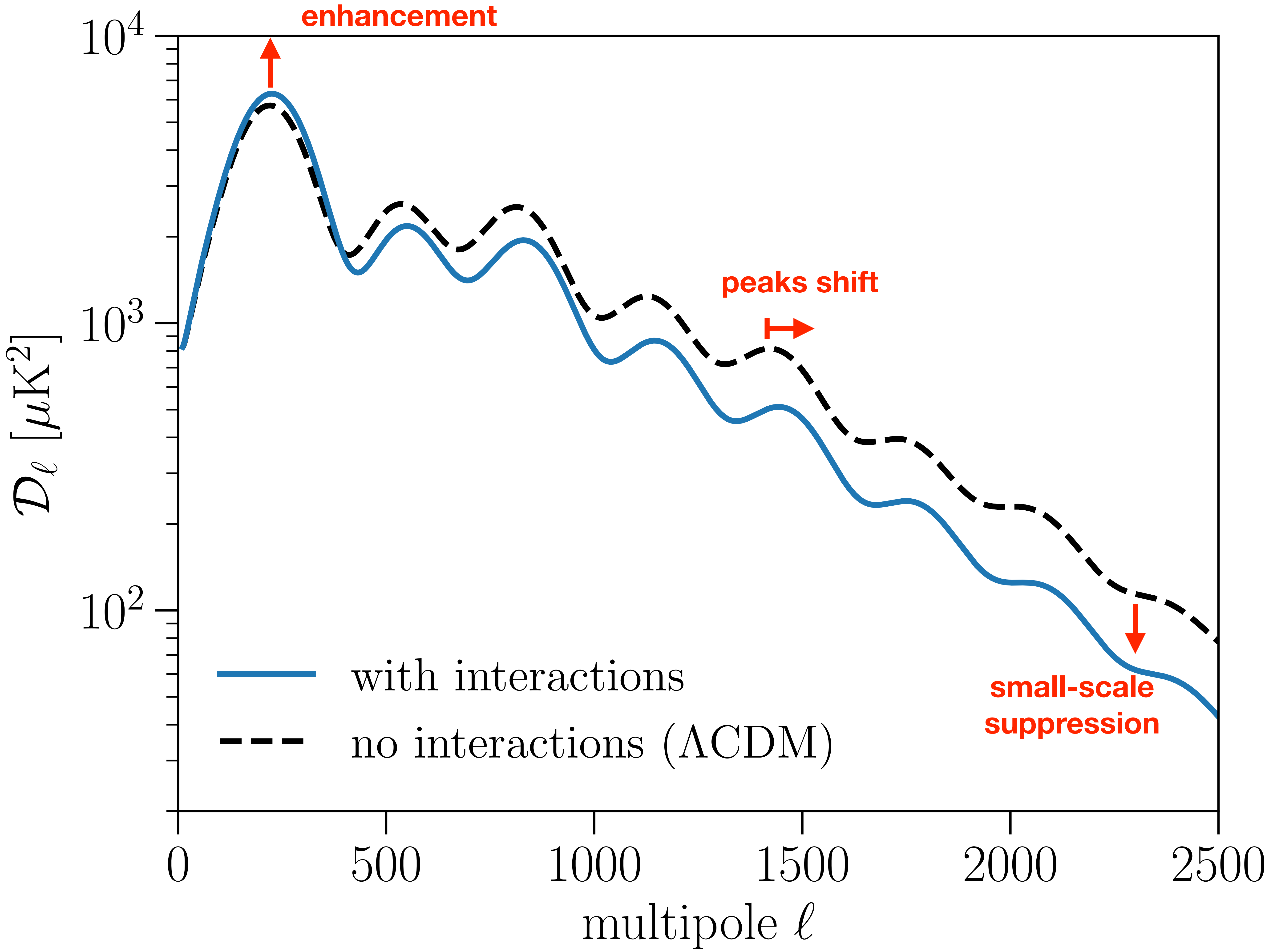
Dvorkin+ (PRD 2014), KB+ (PRD 2018)

Chen+ (2002); Sigurdson+ (2004); Dvorkin+ (2014); Gluscevic and KB (2018); KB and Gluscevic (2018); Xu+ (2018); Slatyer+ (2018); KB+ (2018)

Modified CLASS: https://github.com/kboddy/class_public/tree/dmeff

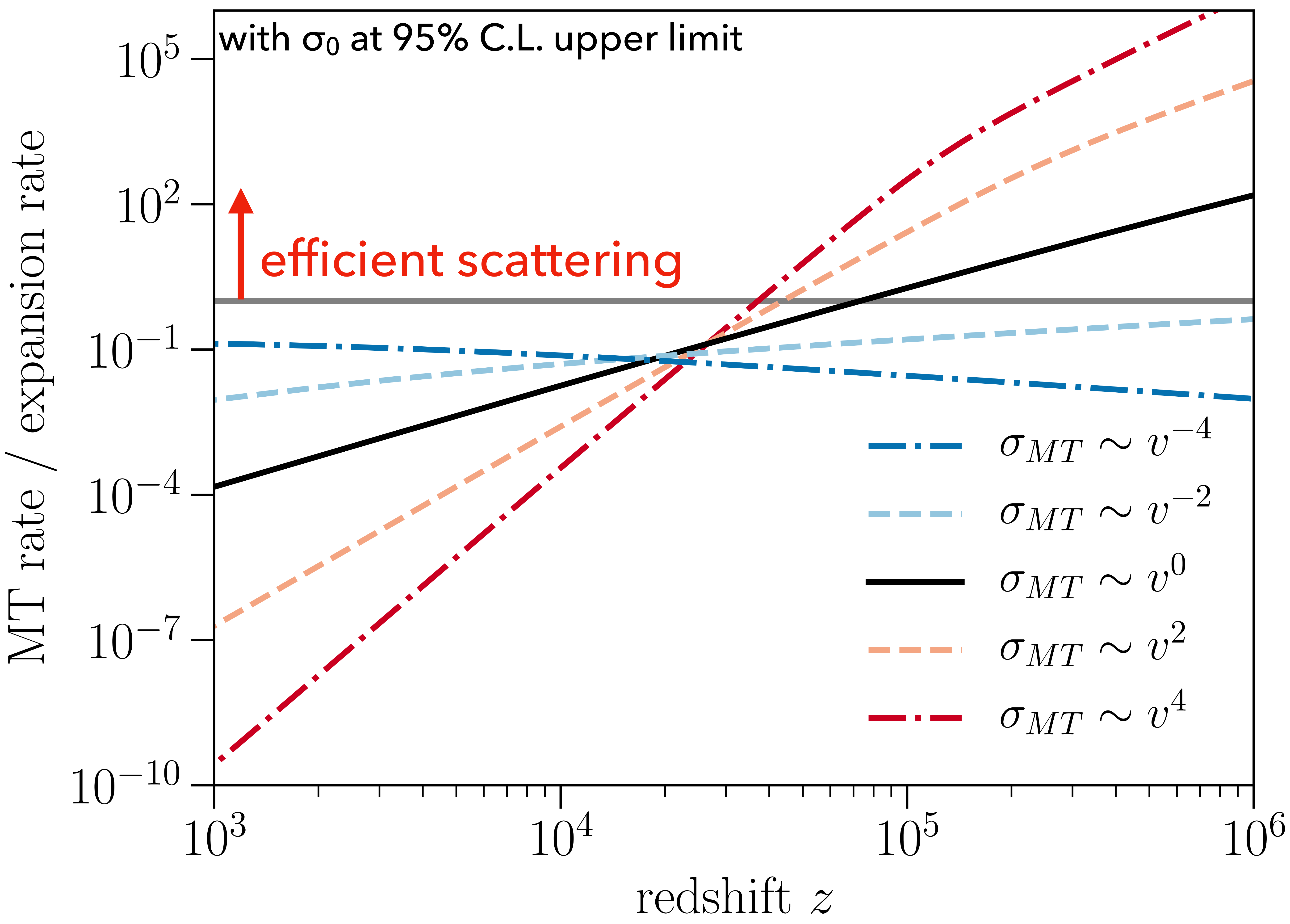
Effects of Dark Matter Scattering

for $n = 0$



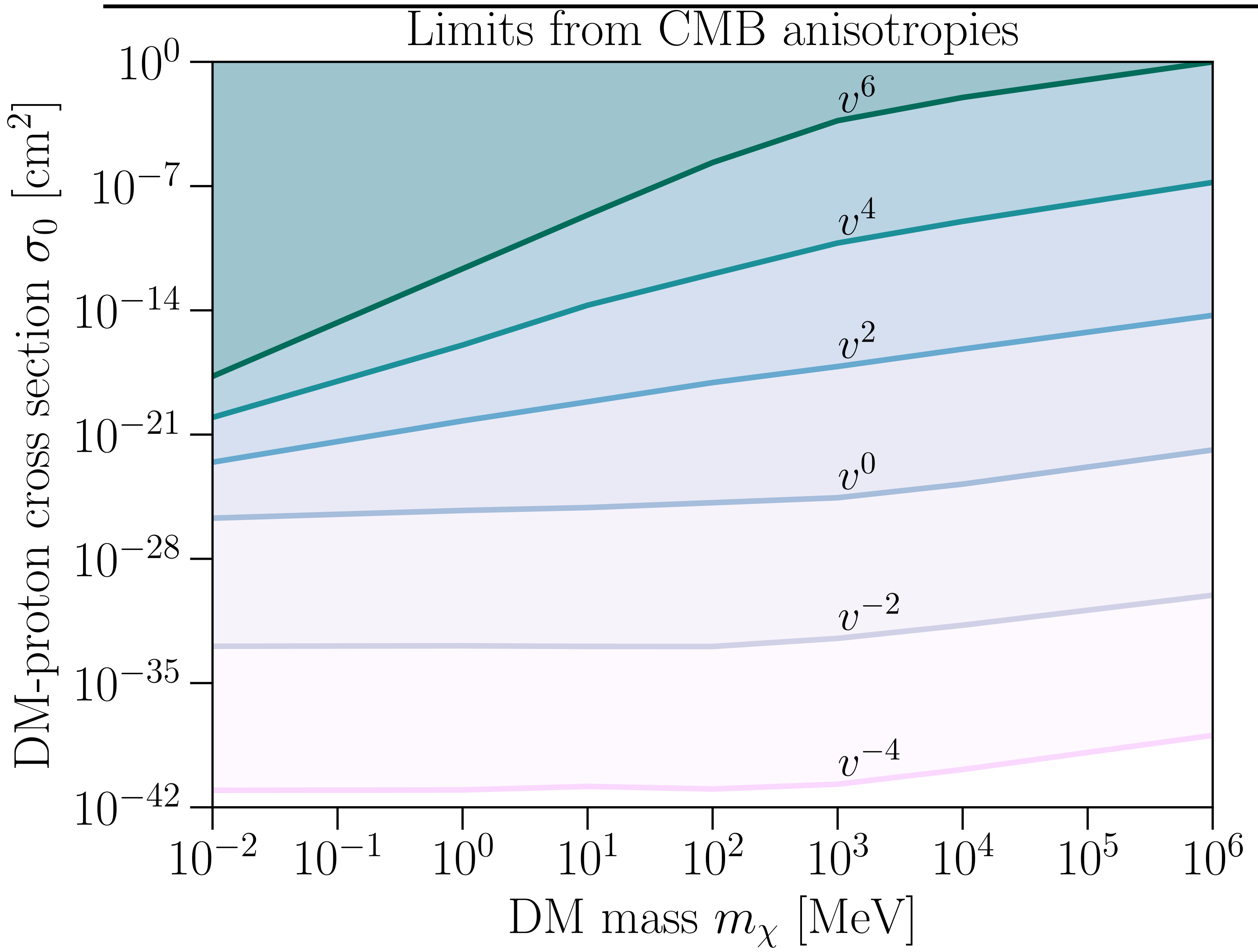
Momentum Transfer

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



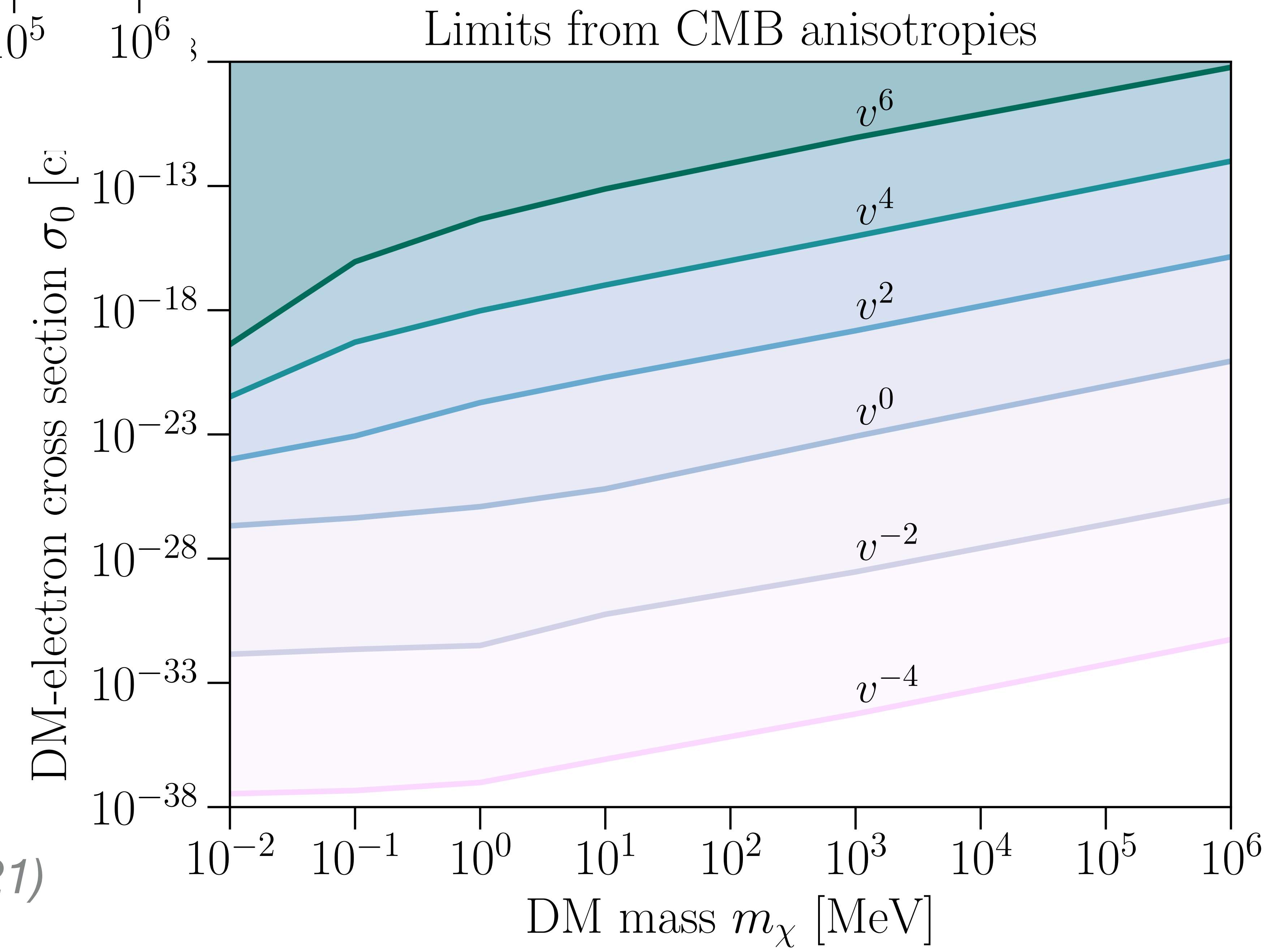
for n≥0: KB, Gluscevic (PRD 2018); Gluscevic, KB (PRL 2018)
for n<0: KB, Gluscevic, Poulin, Kovetz, Kamionkowski, Barkana (PRD 2018)

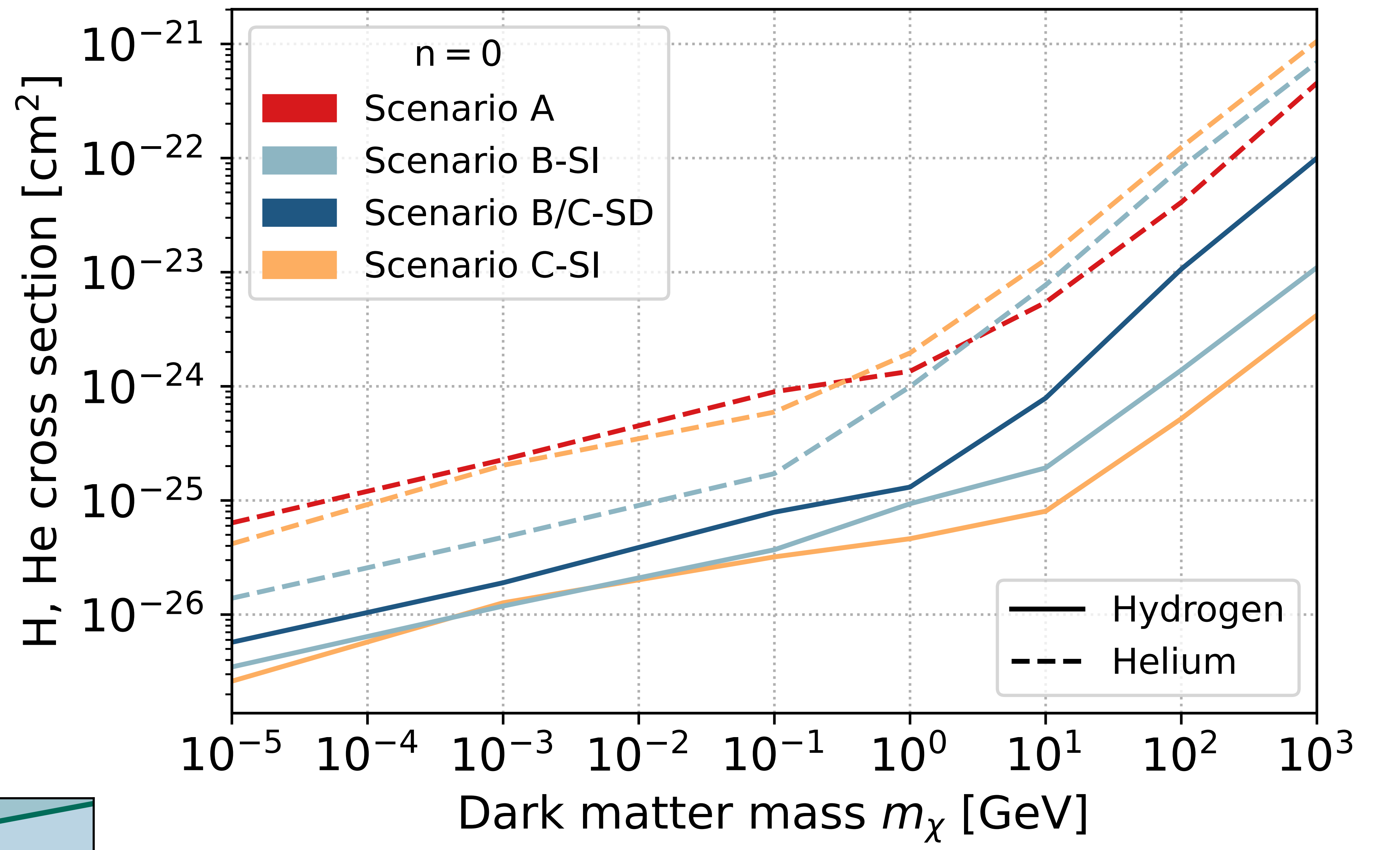
CMB Constraints from *Planck* 2018



Scattering
with Protons

Scattering
with Electrons



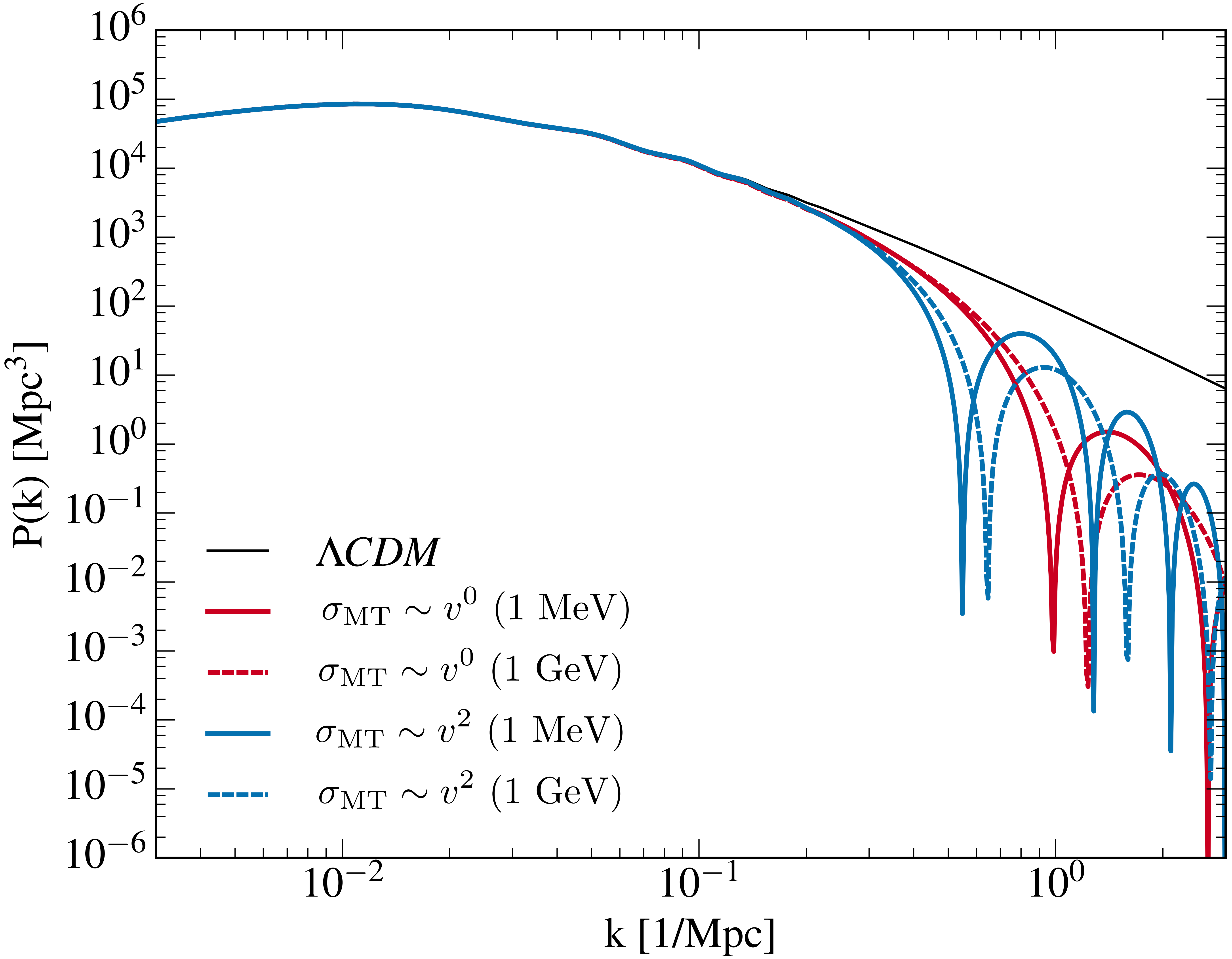


Scattering
with Helium

Nguyen, Sarnaaik, KB, Nadler, Gluscevic (PRD 2021)
see also Buen-Abad+ (2021)

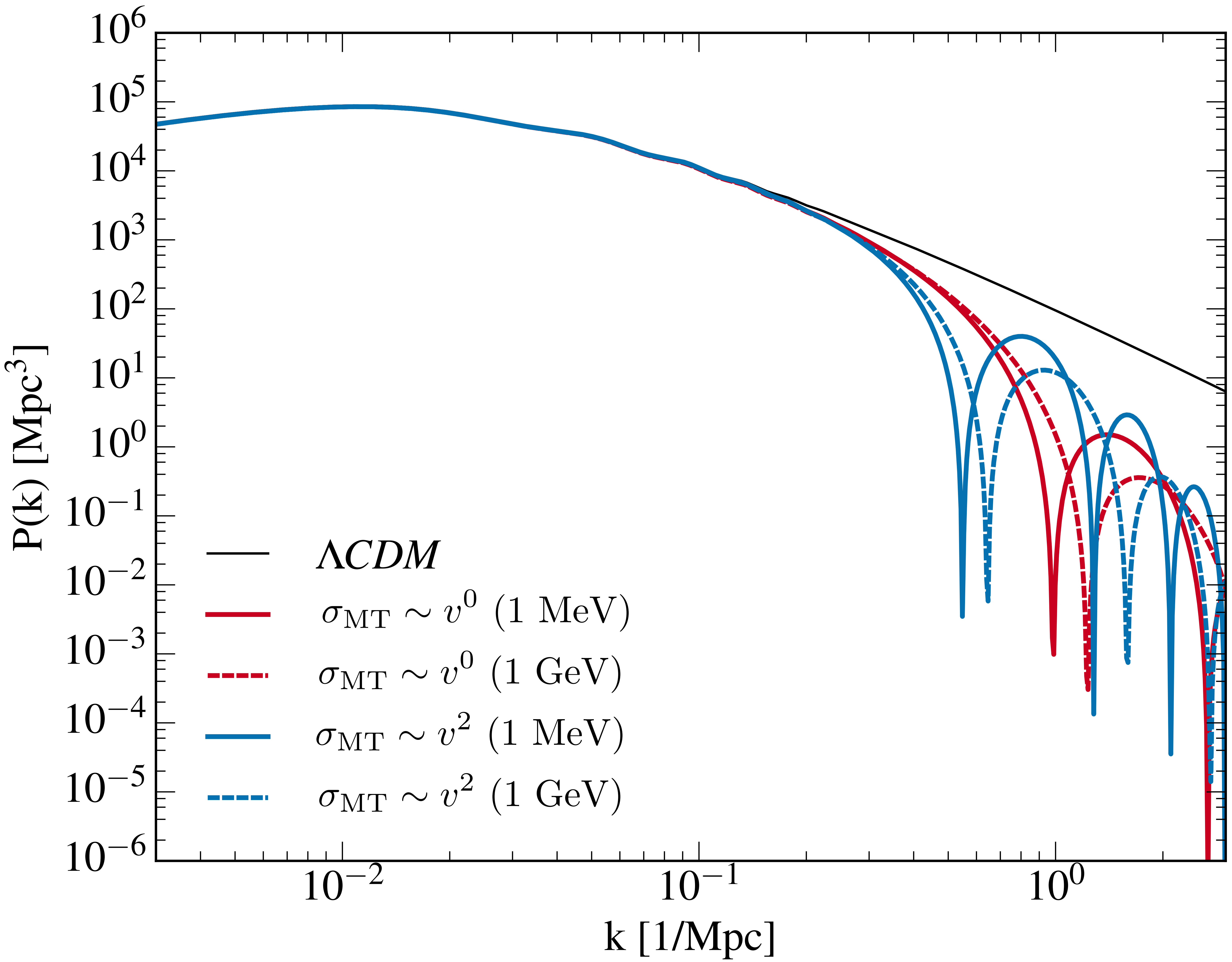
KB, Krnjaic, Moltner (PRD 2022)

Matter Power Spectrum

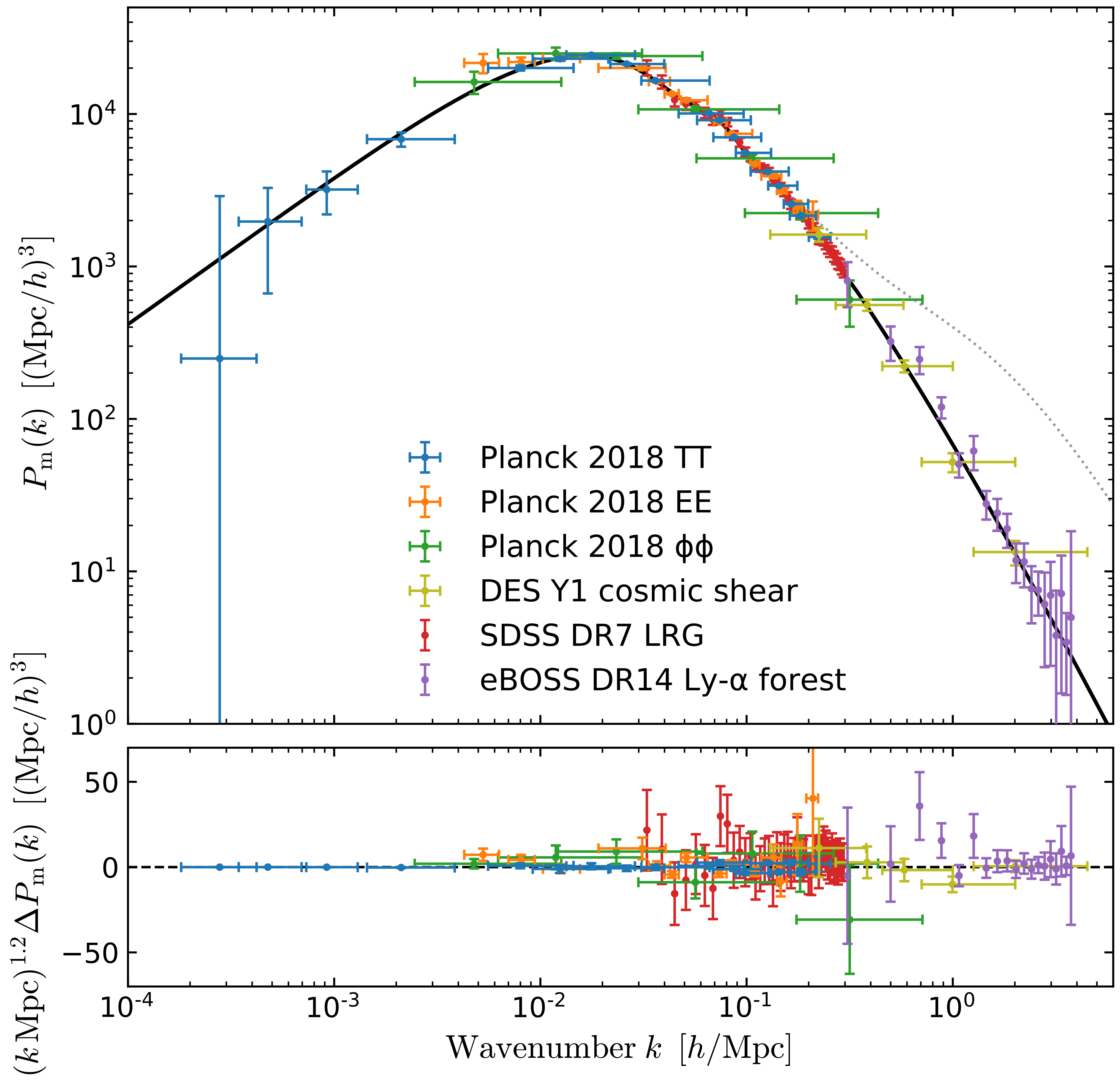


KB and Gluscevic (PRD 2018)

Matter Power Spectrum

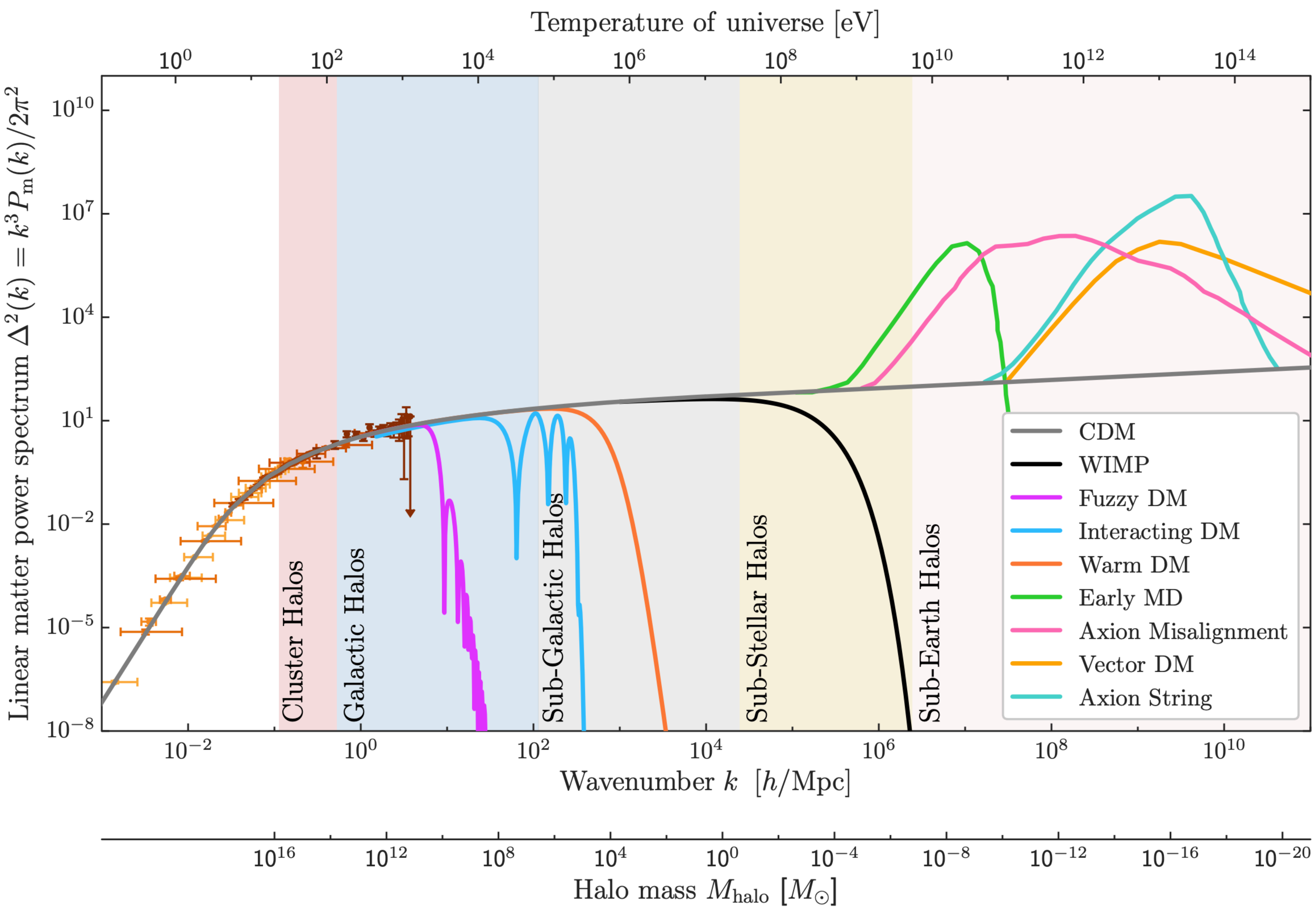


KB and Gluscevic (PRD 2018)



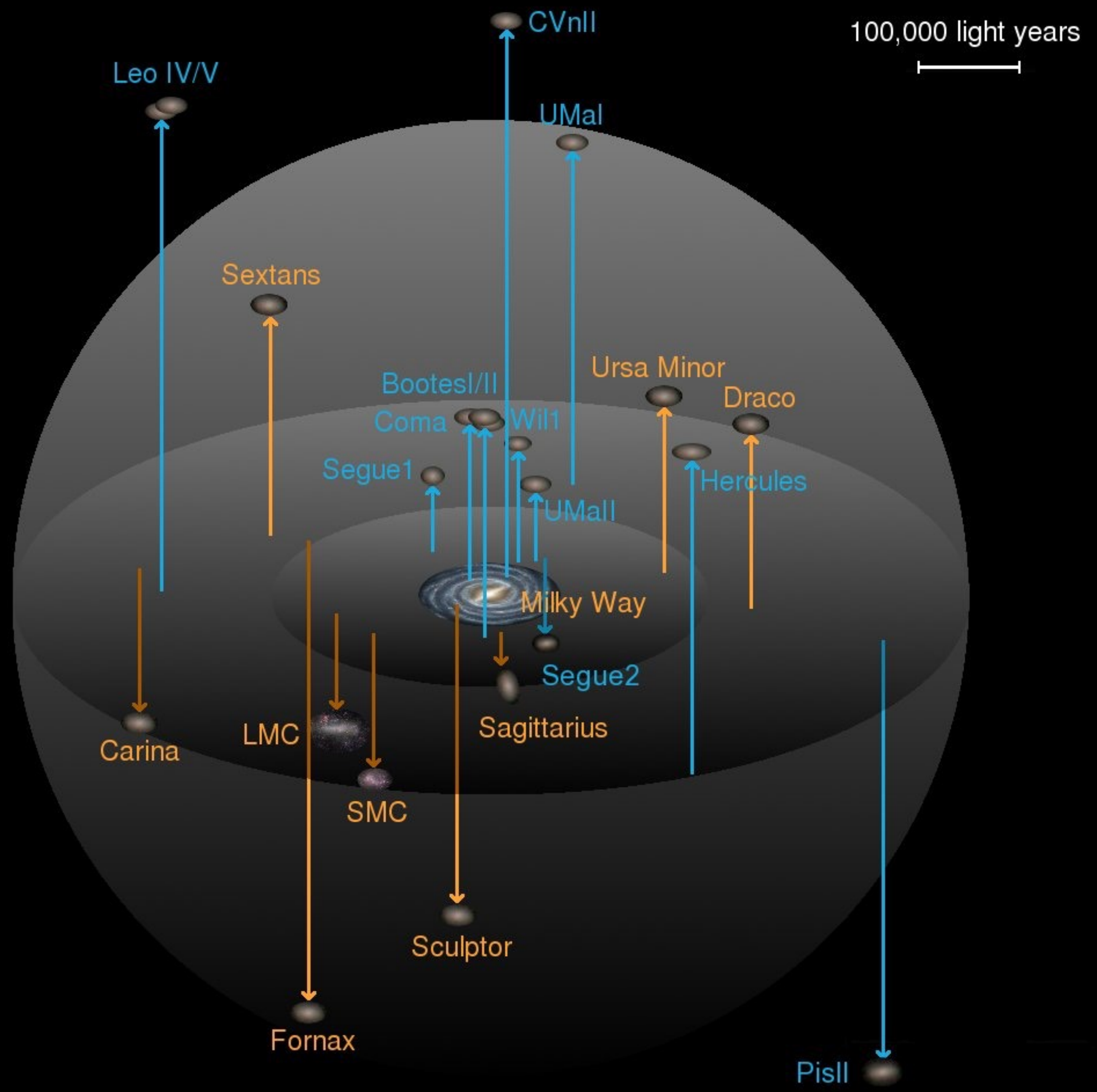
Chabanier+ (MNRAS 2019)

Small-Scale Modifications

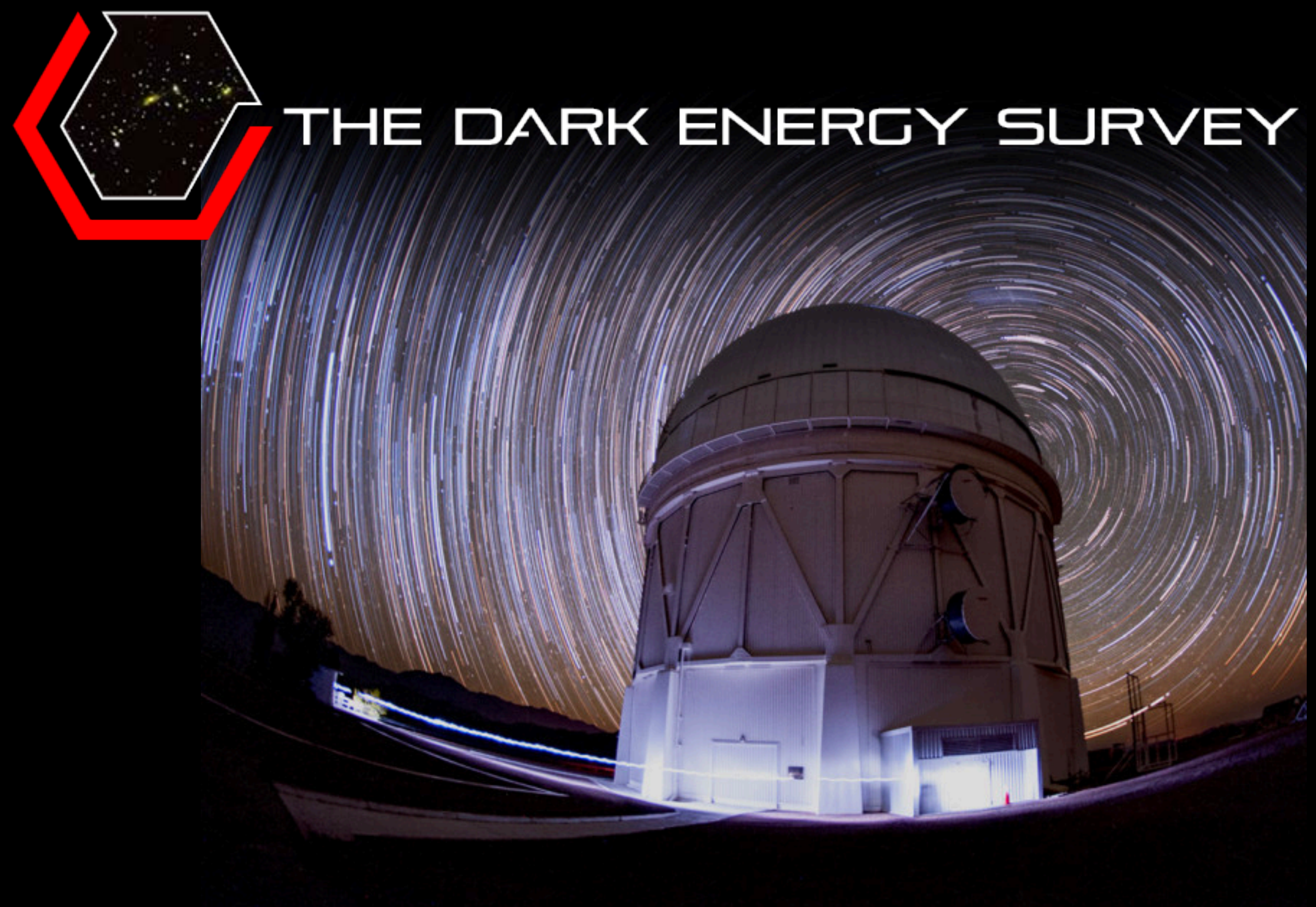


Snowmass 2021 Cosmic Frontier: Dark Matter Physics from Halo Measurements
Bechtol, Birrer, Cyr-Racine, Schutz+ (2203.07354)

Milky Way Satellites

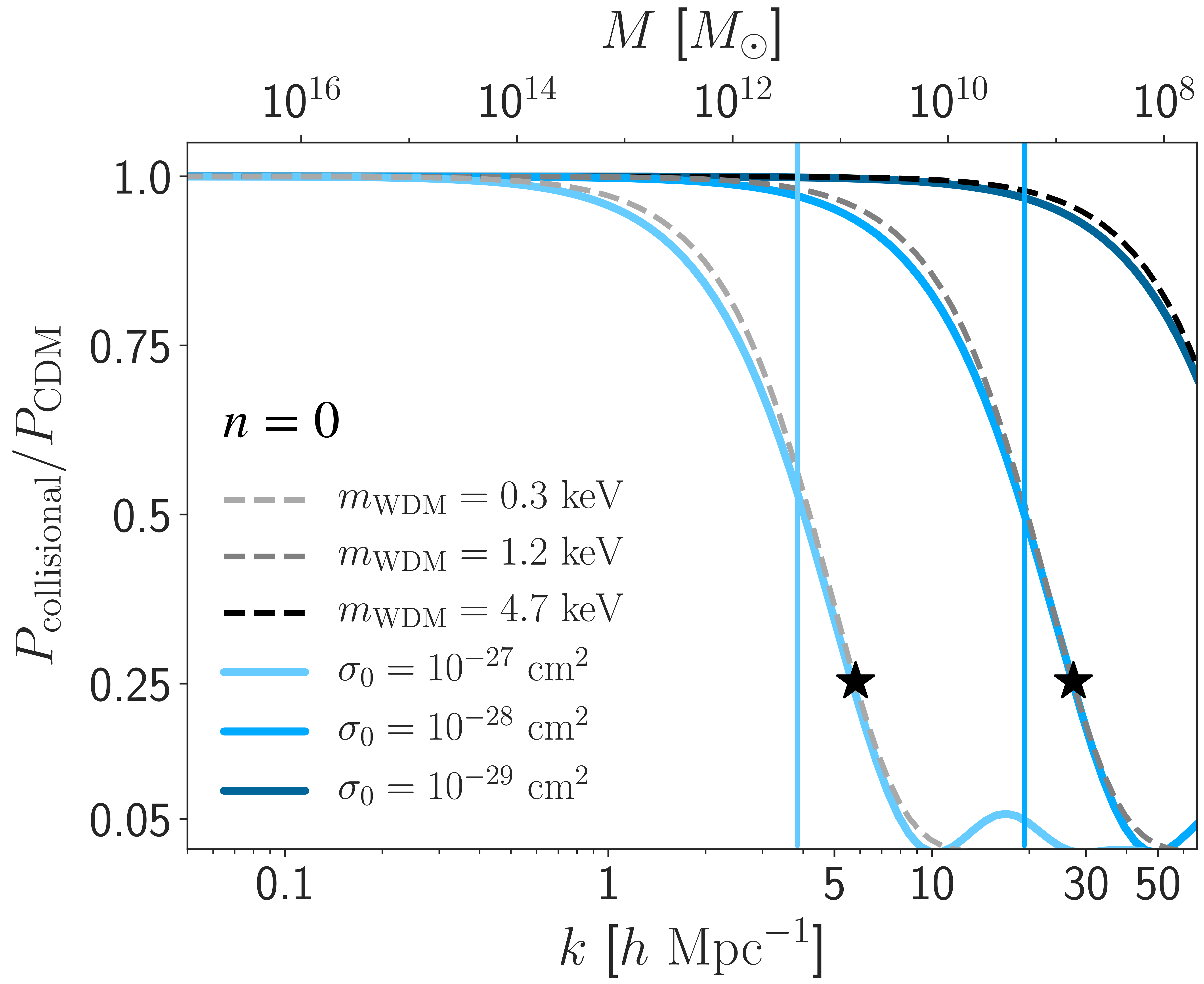


DES and Pan-STARRS1 identified dwarfs



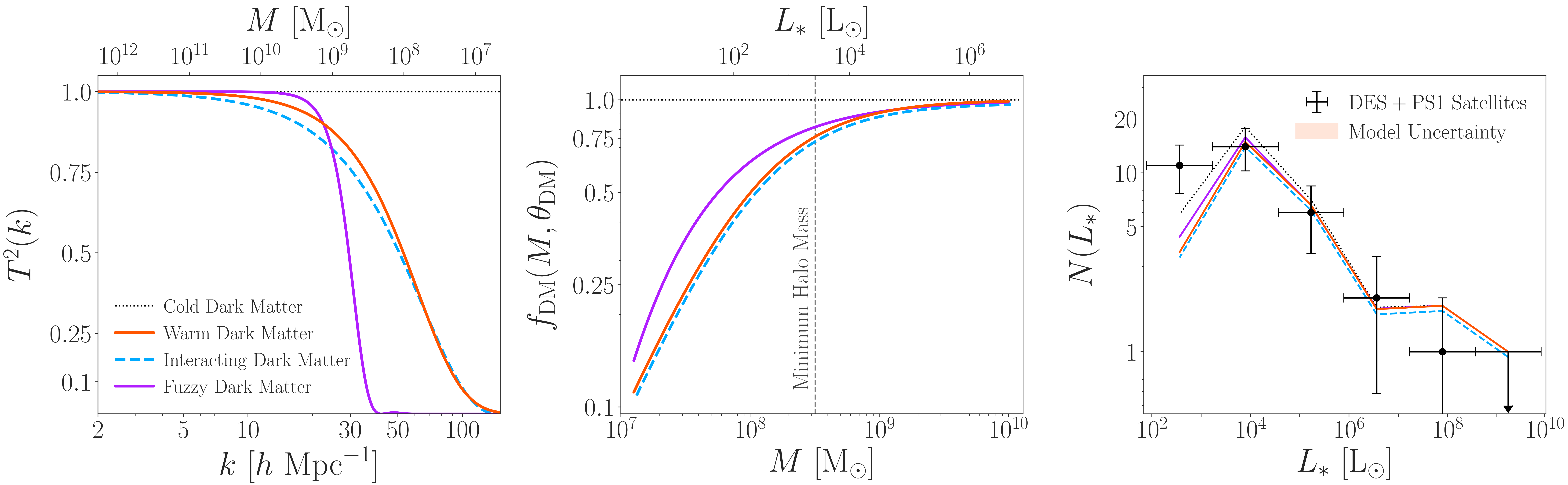
Classic dwarfs
SDSS-identified dwarfs

Suppression of (Linear) Matter Power Spectrum



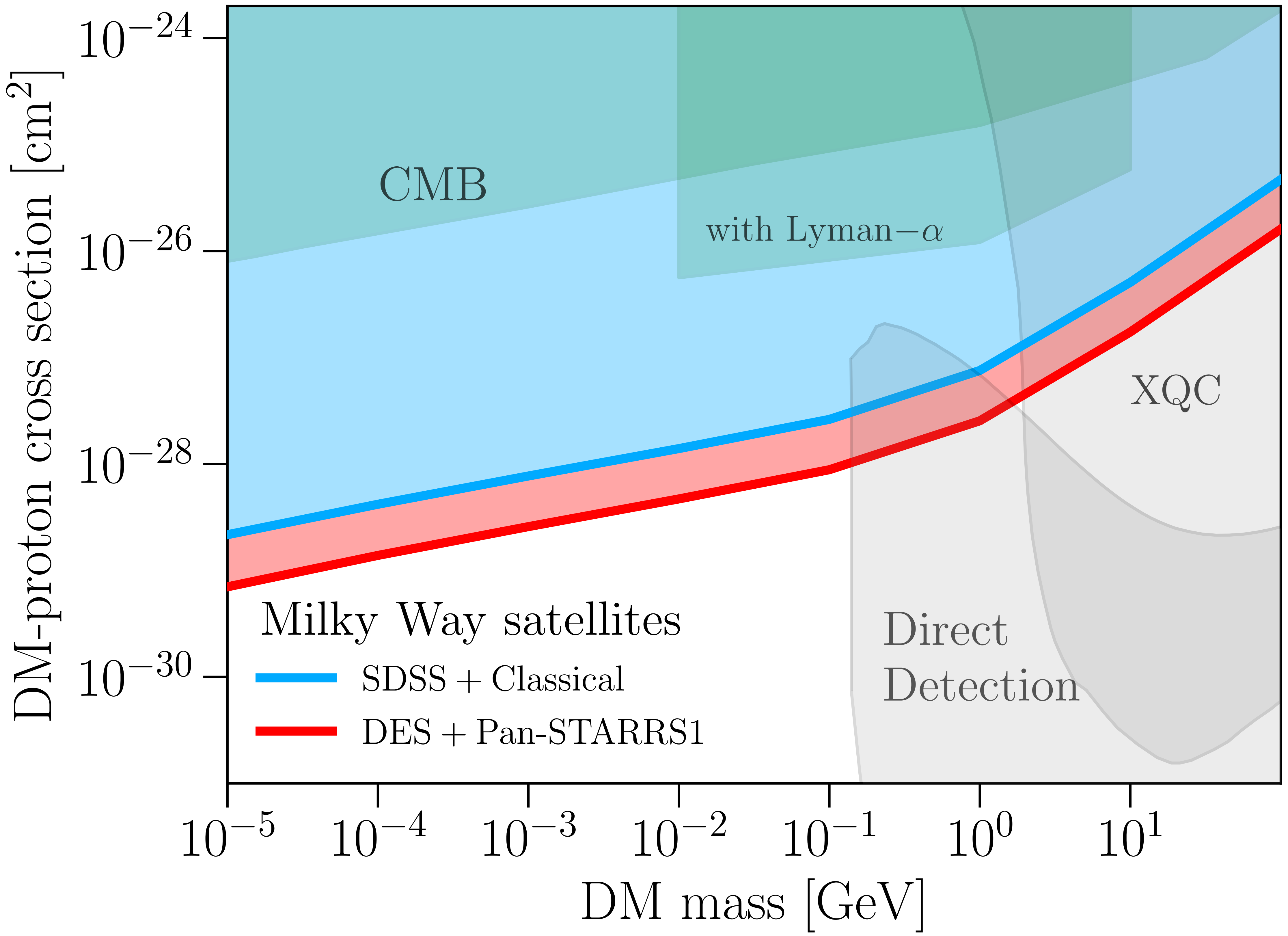
Nadler, Gluscevic, KB, Wechsler (ApJL 2019)

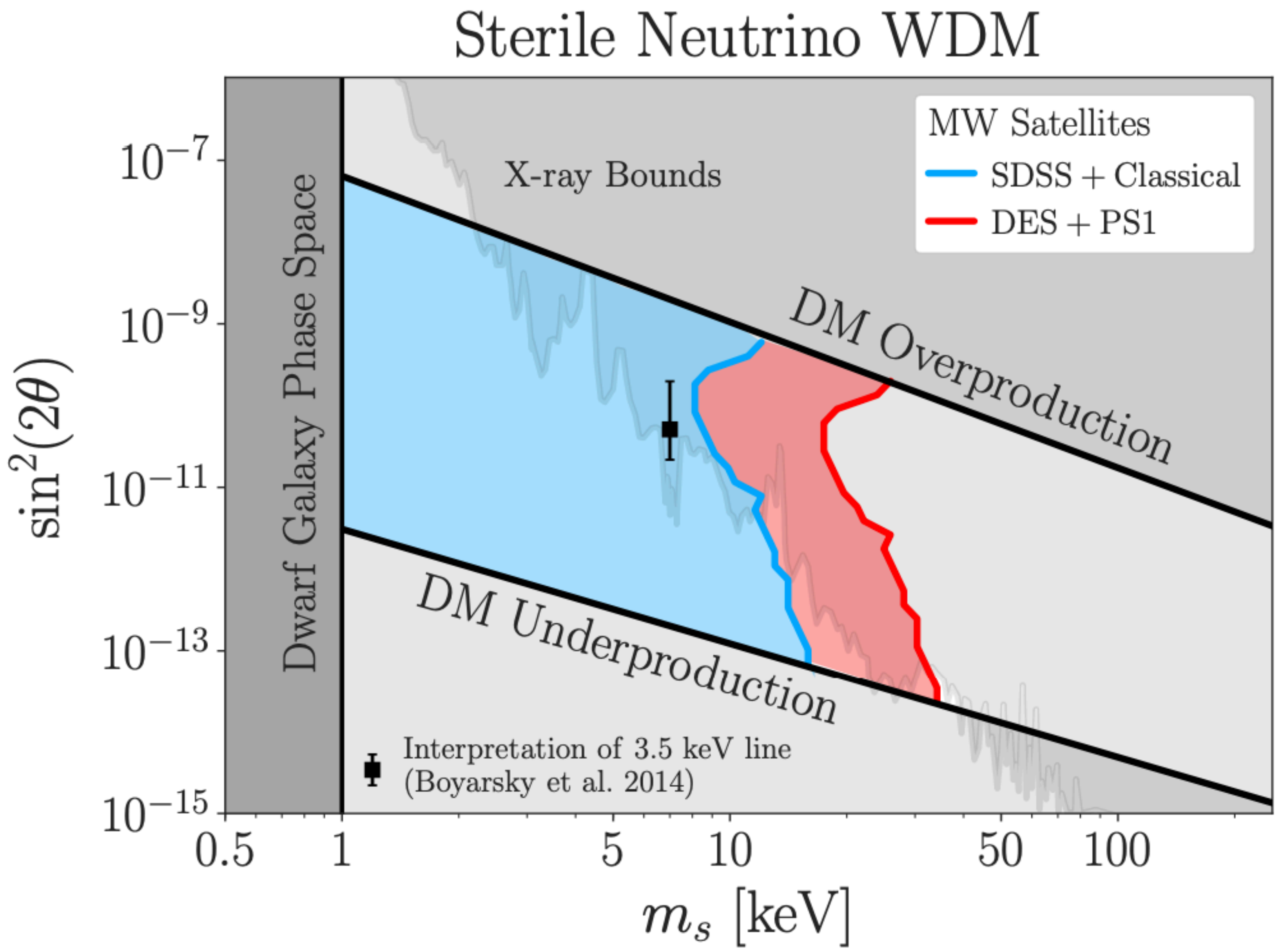
Suppression for Various Models

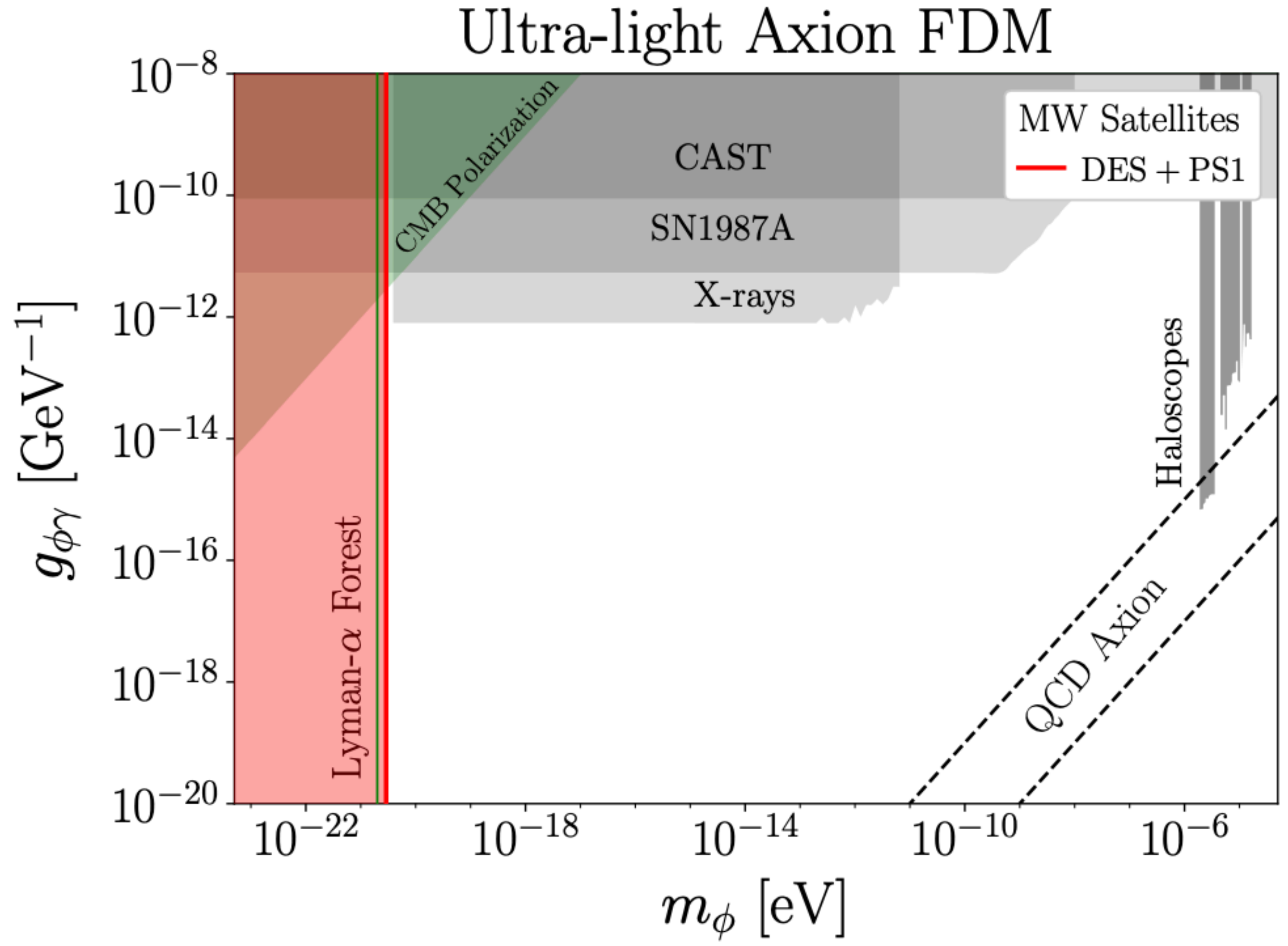


DES Collaboration, Nadler (PRL 2021)

Constraints from MW Satellites

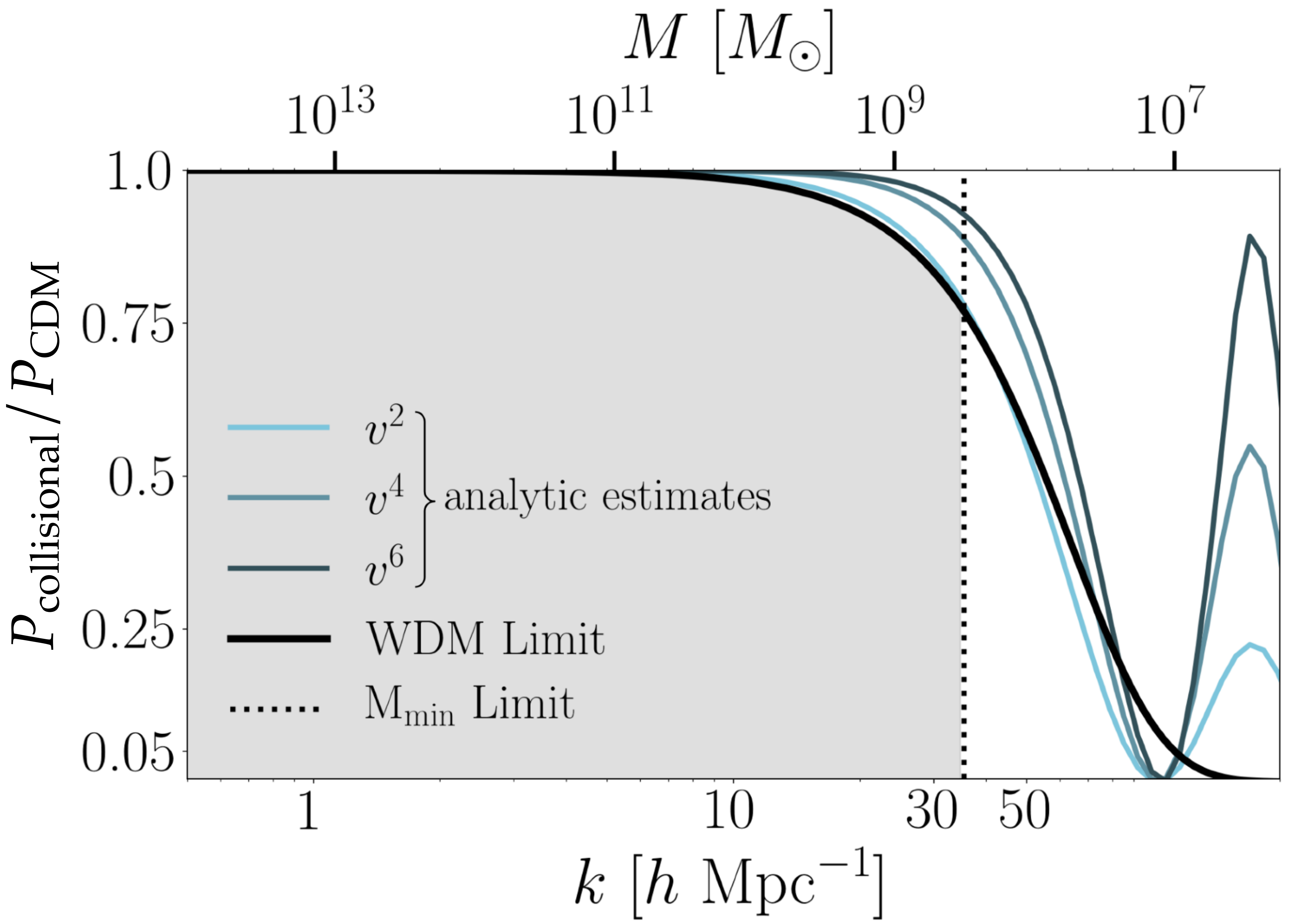


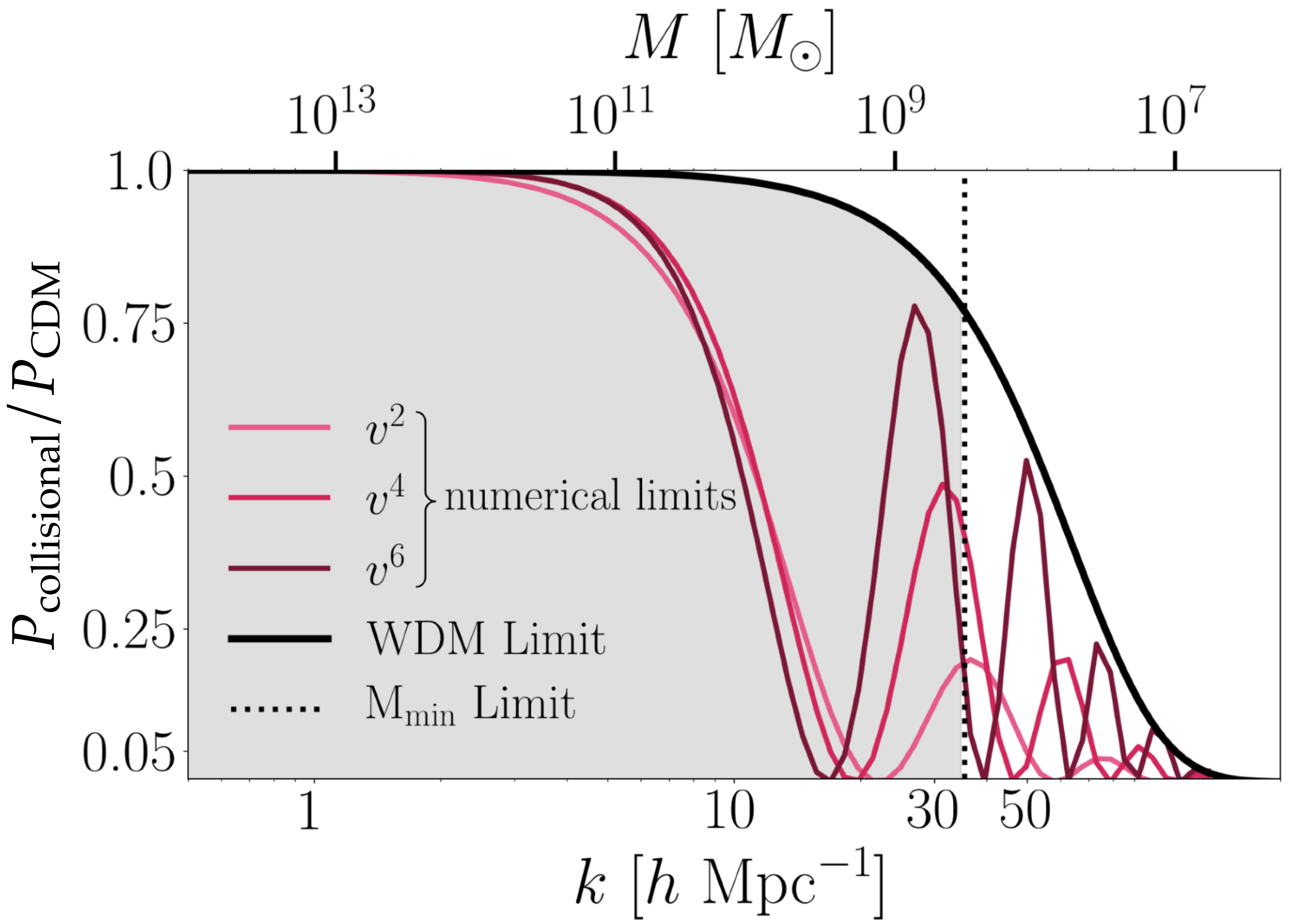




DES Collaboration (PRL 2021)

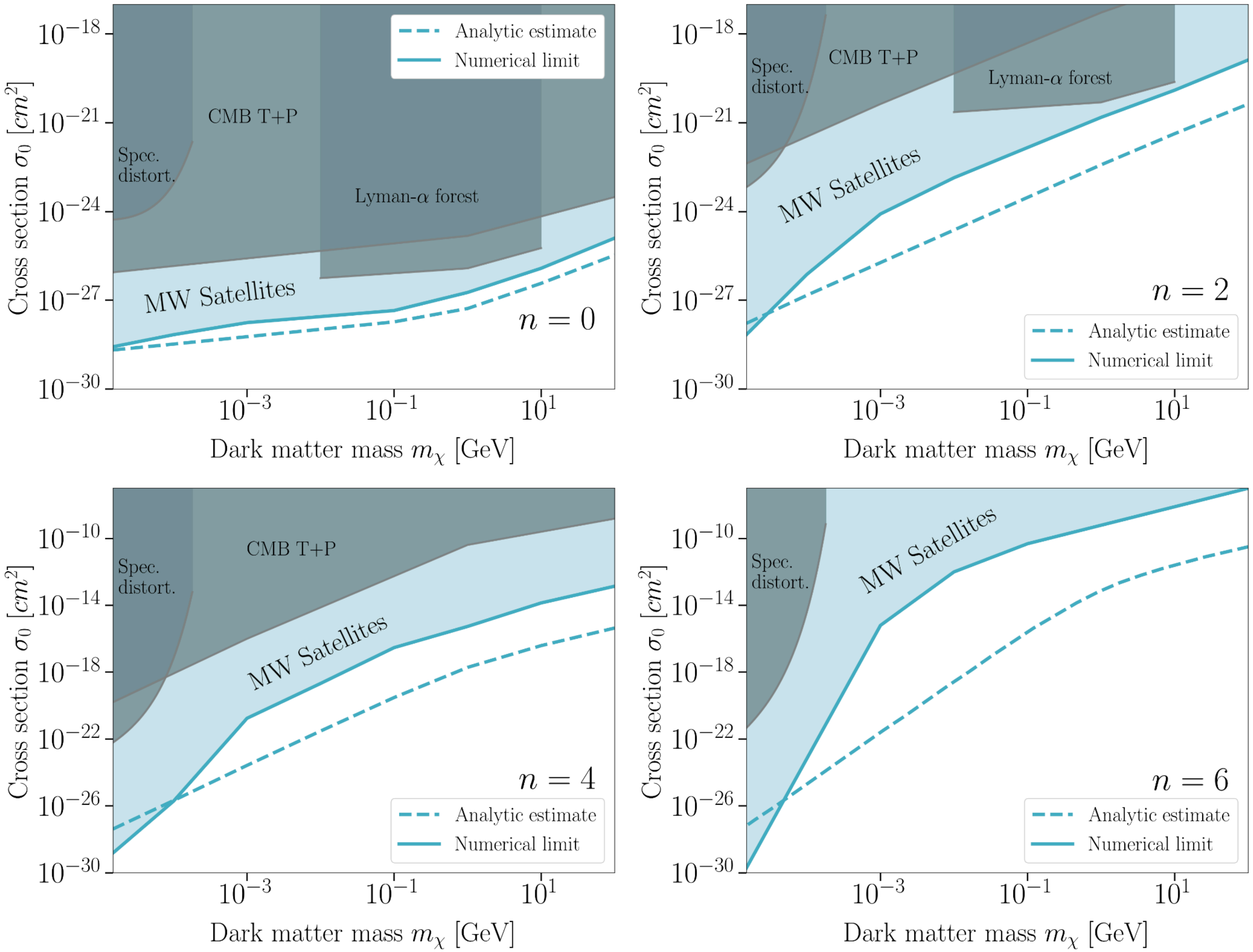
Velocity-Dependent Models

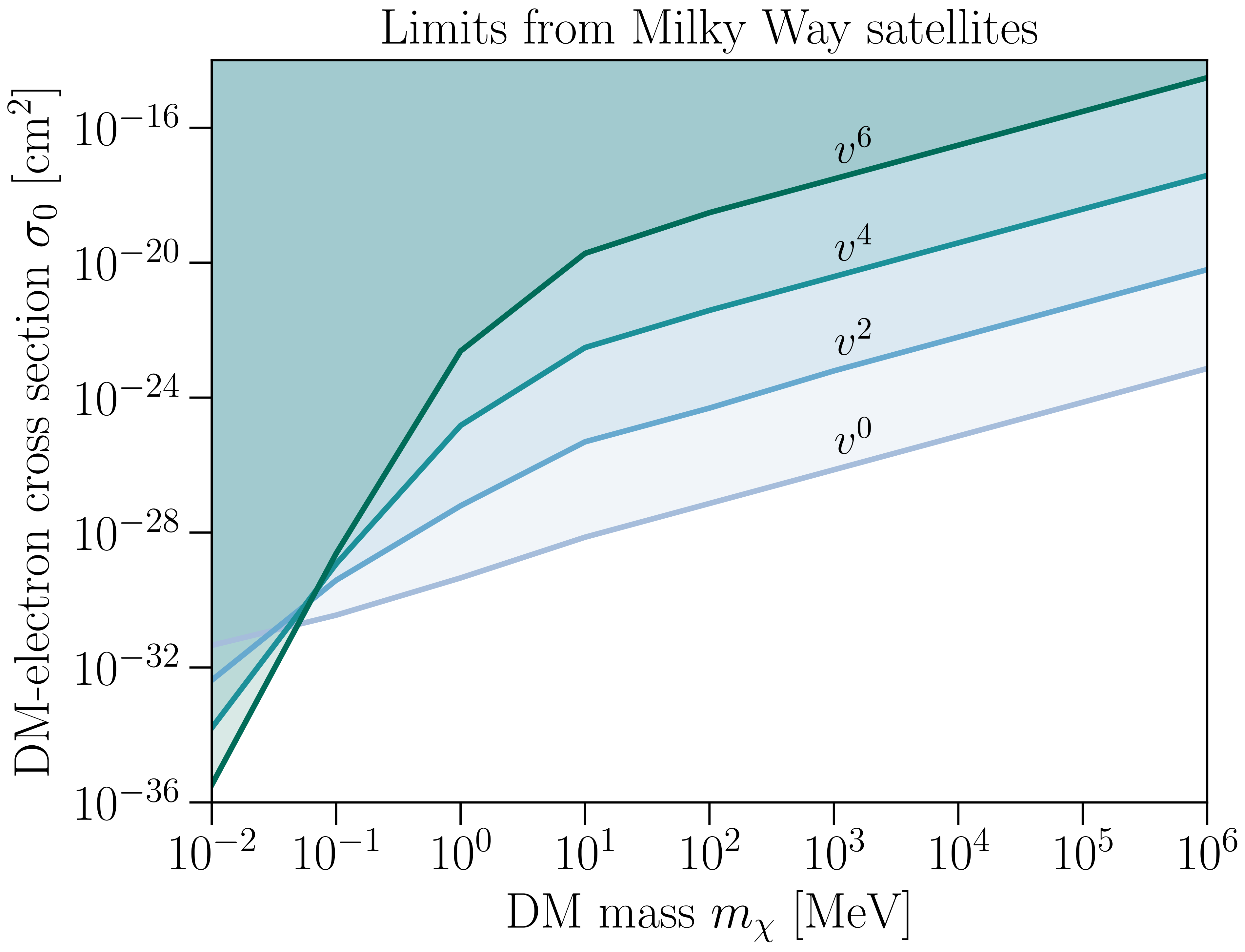




Maamari, Gluscevic, KB, Nadler, Wechsler (ApJL 2021)

Scattering Constraints with MW Satellites





Maamari, Gluscevic, KB, Nadler, Wechsler (ApJL 2021)

Nguyen, Sarnaaik, KB, Nadler, Gluscevic (PRD 2021)

21cm Cosmology

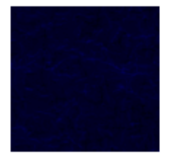
Time dependence of different temperatures:

At $z > 200$: $T_{\rm CMB} \sim T_{\rm gas} \sim T_{\rm spin}$ (Compton scattering off remaining electrons)

At $z < 200$: $T_{\rm CMB} \sim (1+z)$; $T_{\rm gas} \sim (1+z)^2$ (Gas decouples from CMB, cools adiabatically)

$30 < z < 200$: First, $T_{\rm spin} \sim T_{\rm gas}$ (Collisions in the IGM). After $z \sim 80$: $T_{\rm spin} \to T_{\rm CMB}$

Absorption: $T_{\rm spin} < T_{\rm CMB}$ (dark ages)



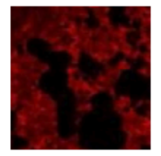
At $z \lesssim 30$: First stars form!

Stars emit Lyα photons: $T_{\rm spin} \to T_{\rm gas}$

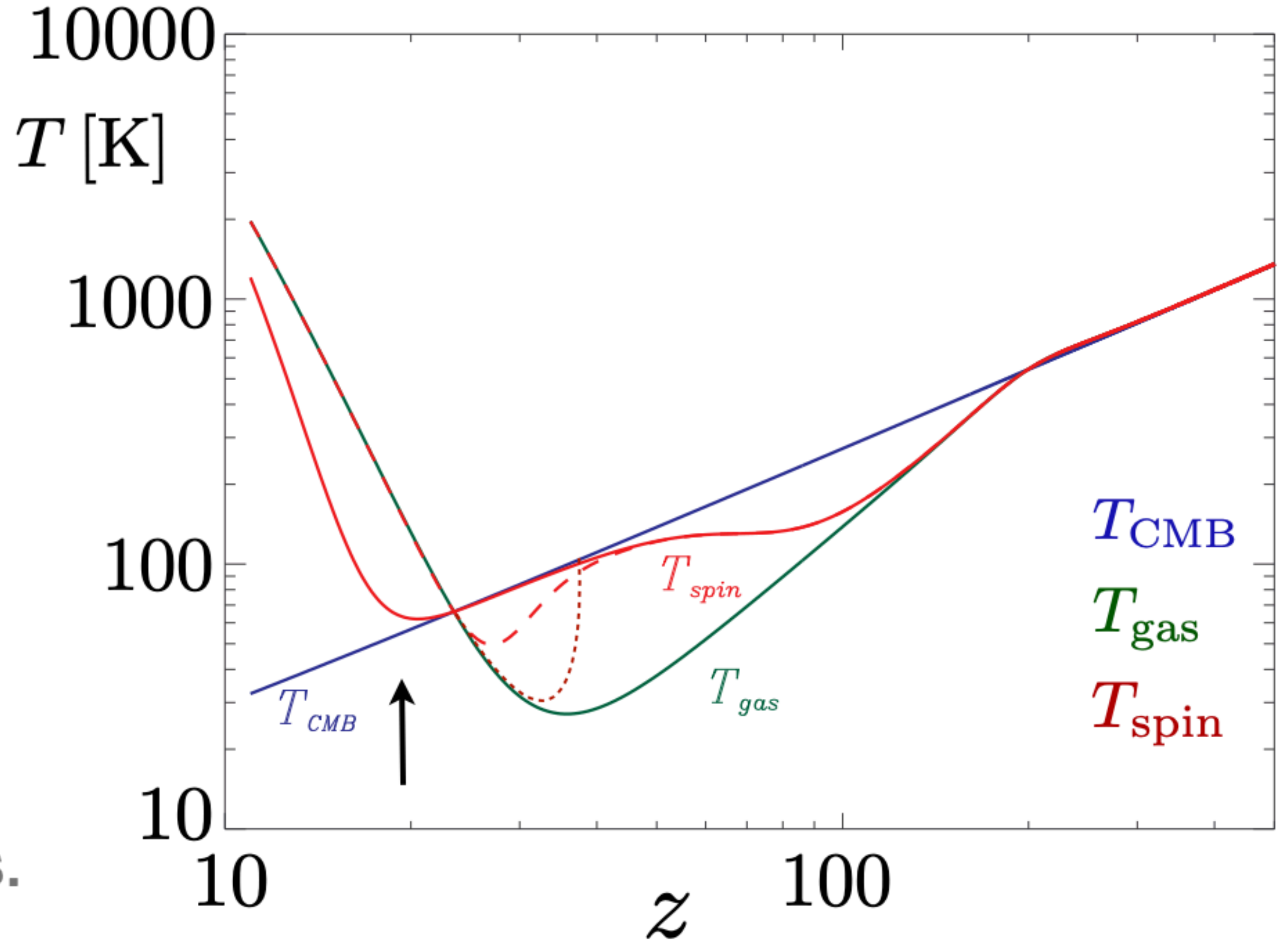
Absorption: $T_{\rm spin} < T_{\rm CMB}$ (cosmic dawn)

By $z \sim 13$: remnants heat gas above CMB.

Emission: $T_{\rm spin} > T_{\rm CMB}$ (reionization)

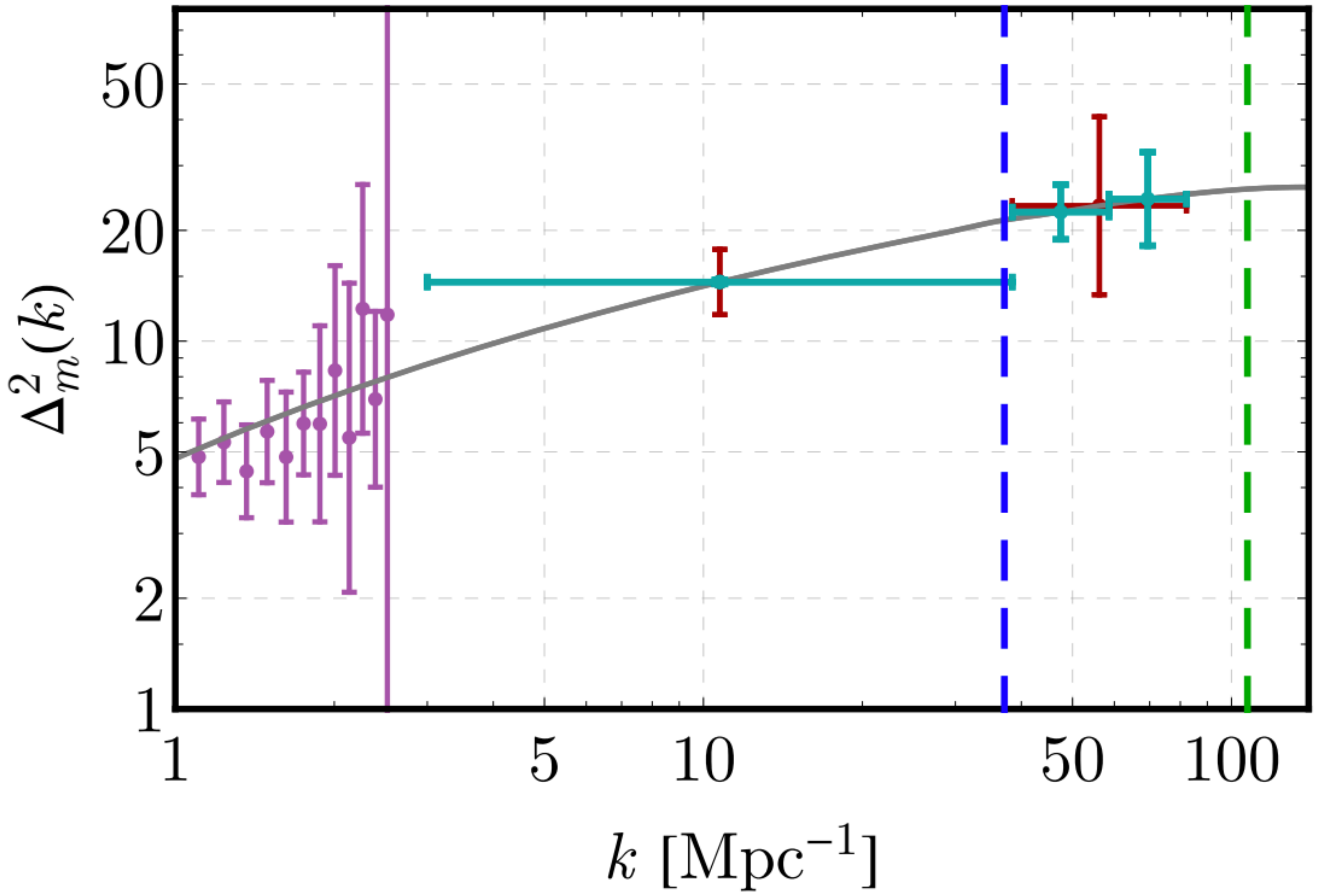


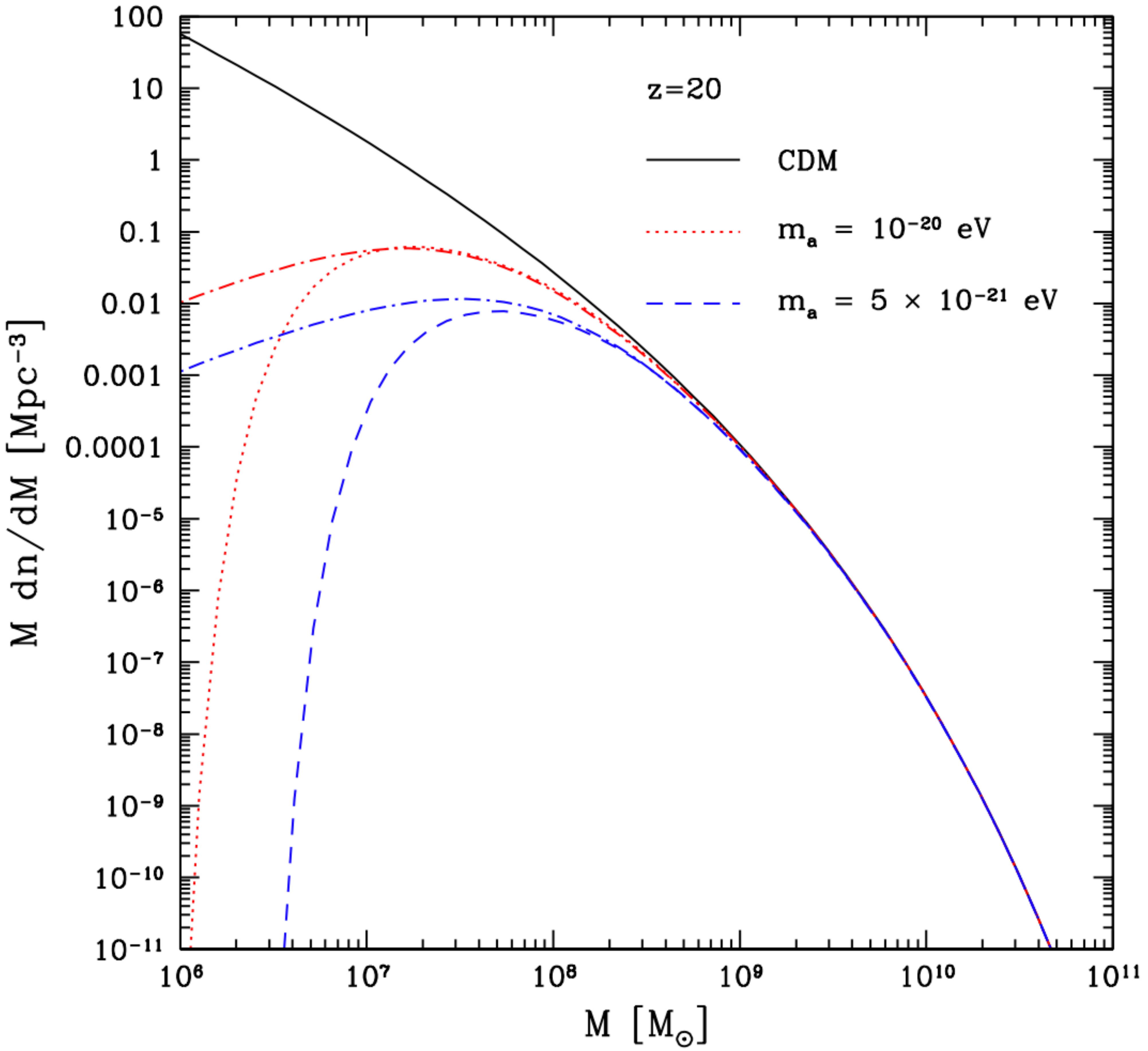
The 21cm signal cuts off when reionization ends.



Overview slide from E. Kovetz

Probing Small Scale Structure with 21cm



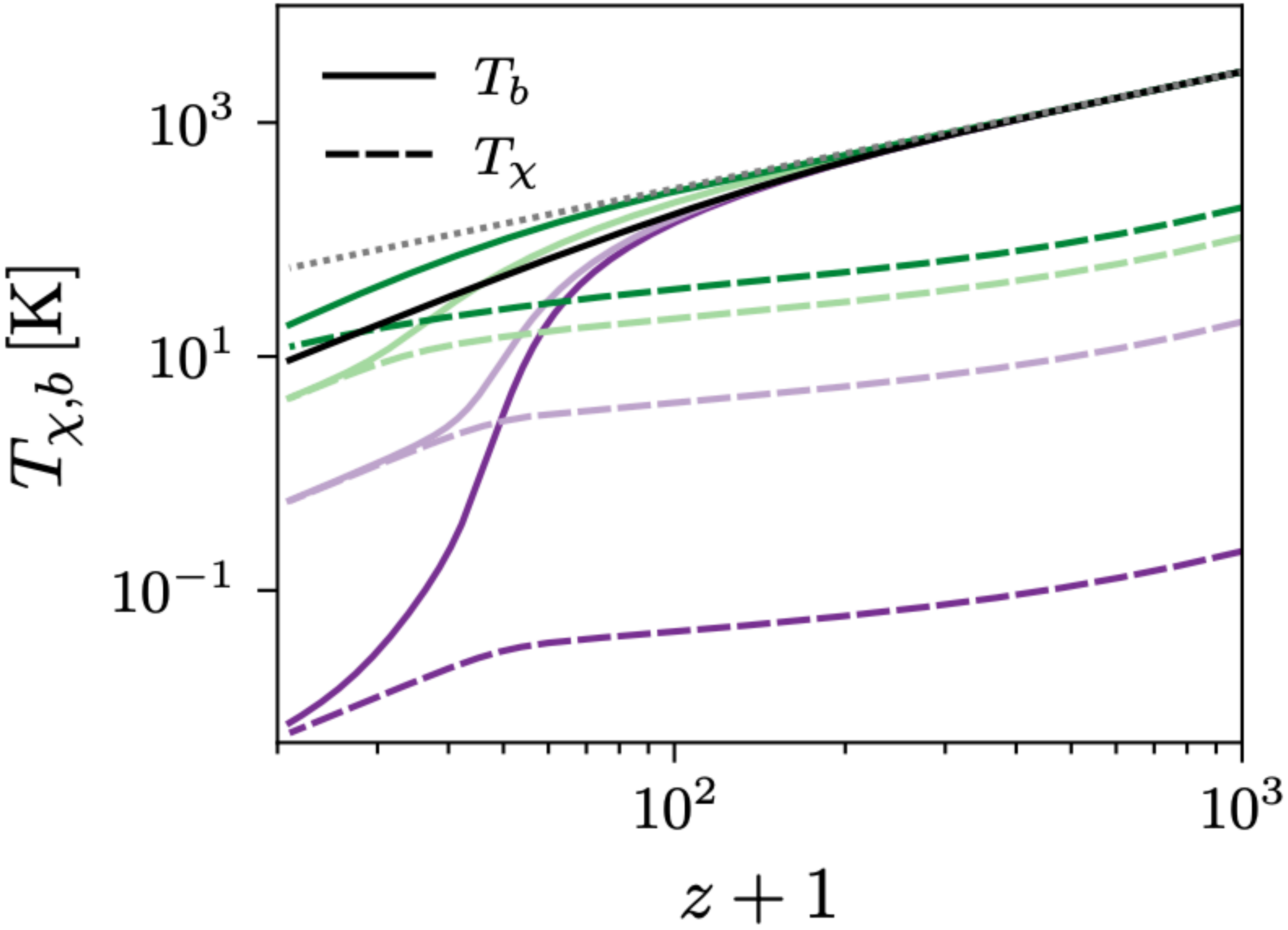


Munoz, Dvorkin, Cyr-Racine (PRD 2020)

Lidz, Hui (PRD 2018)

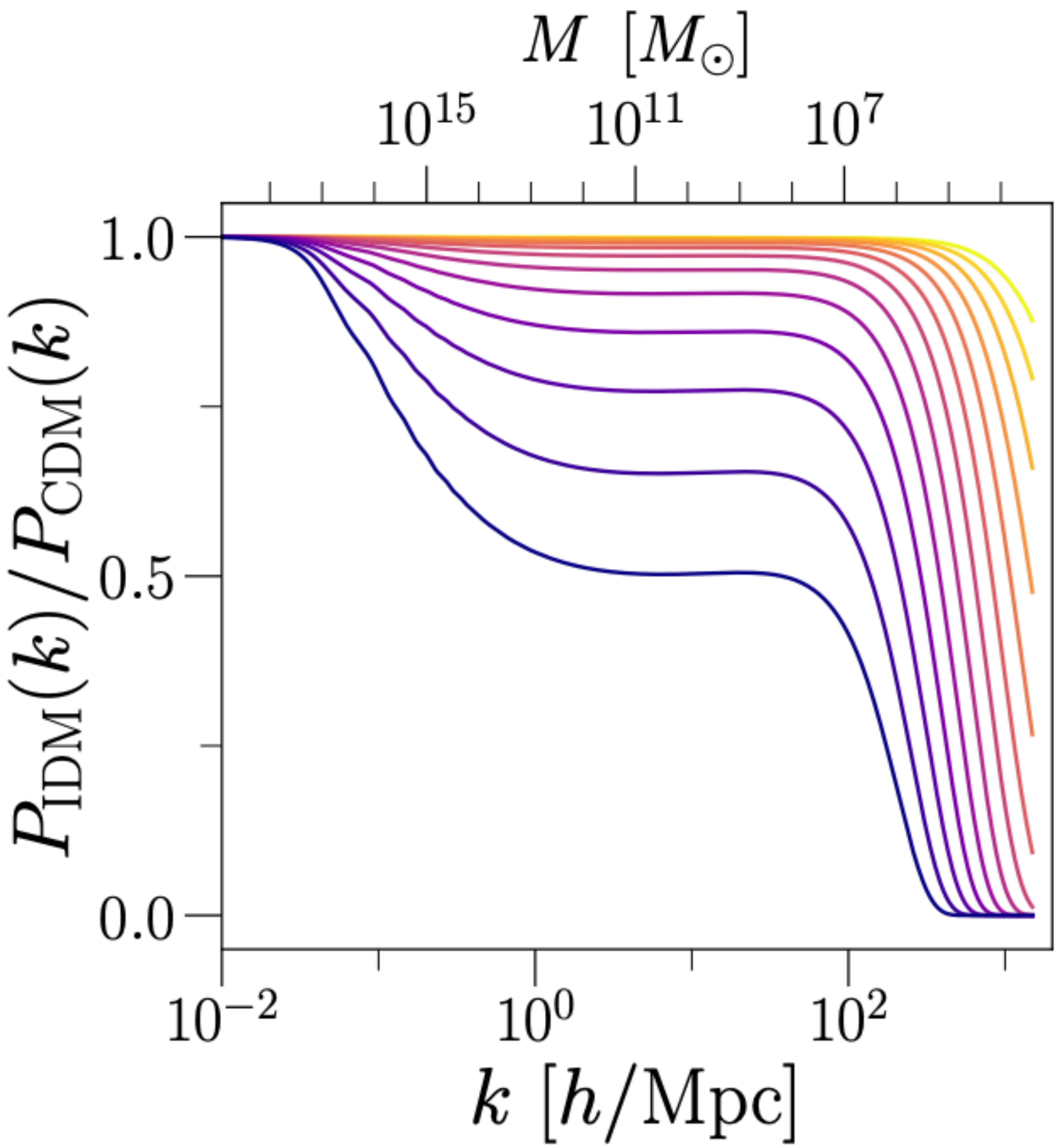
21cm and Late-Time Scattering

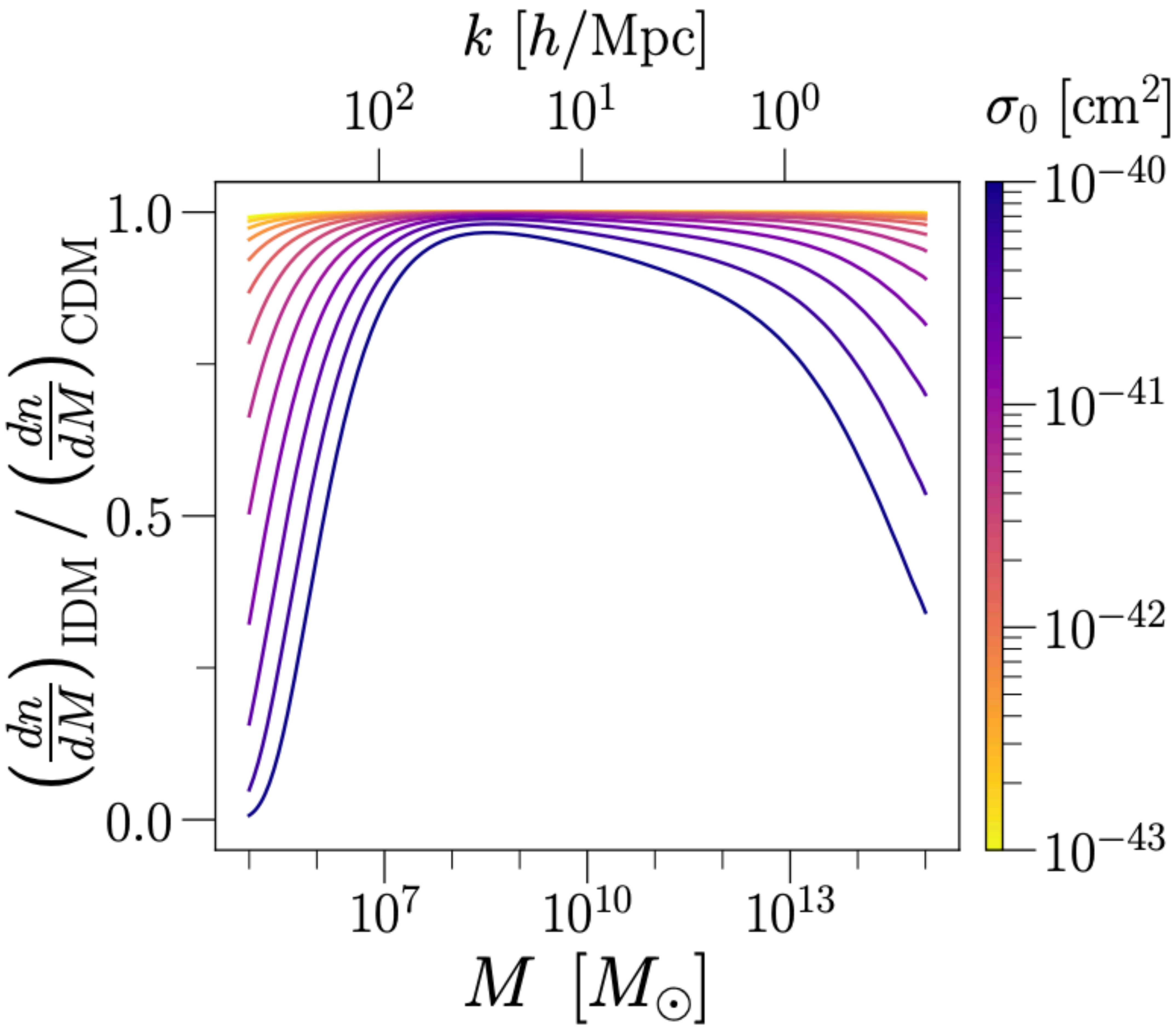
$\sigma \sim v^{-4}$ DM-baryon scattering cools gas



Short, Bernal, Boddy, Gluscevic, Verde (2203.16524)
see also Tashiro, Kadota, Silk (PRD 2014); Muñoz, Kovetz, Ali-Haïmoud (PRD 2015)

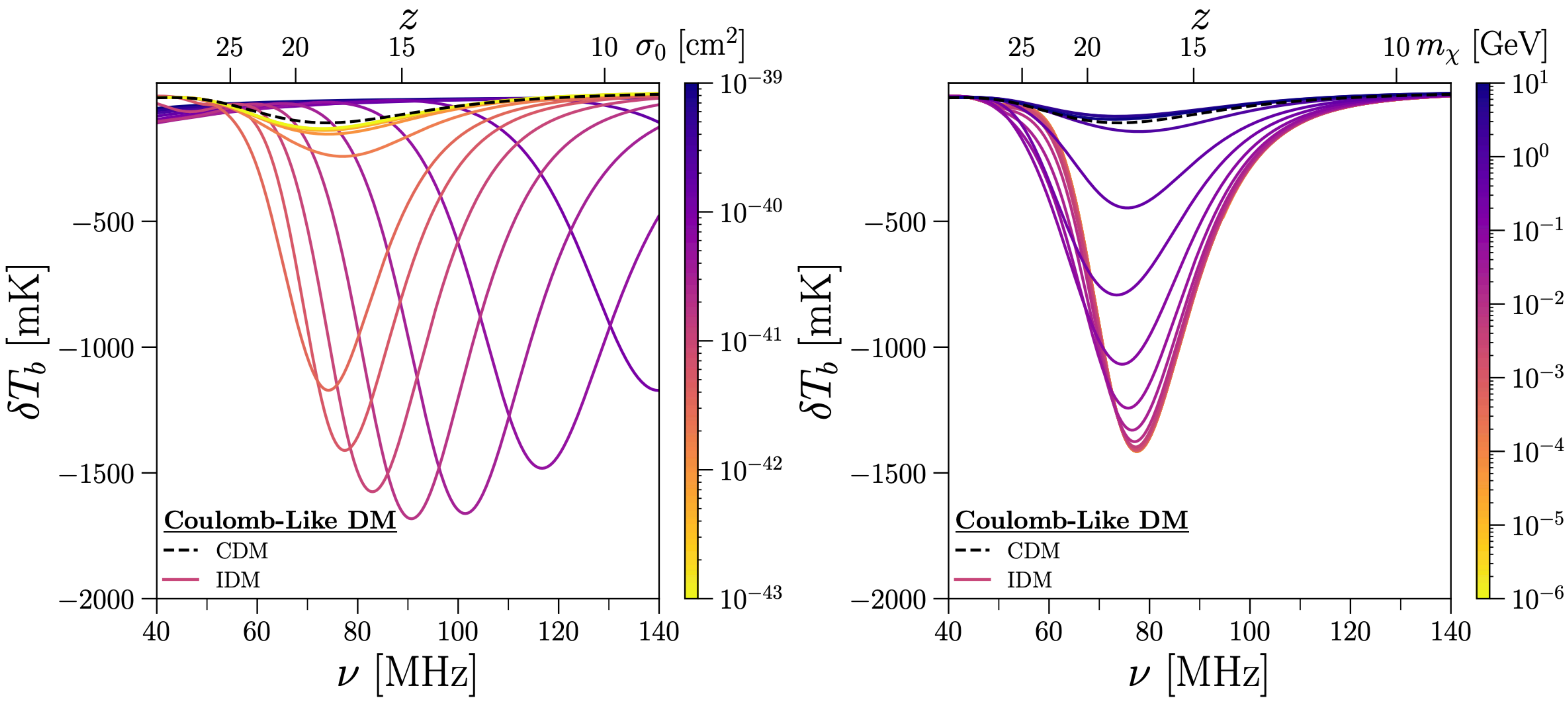
Matter Power Suppression





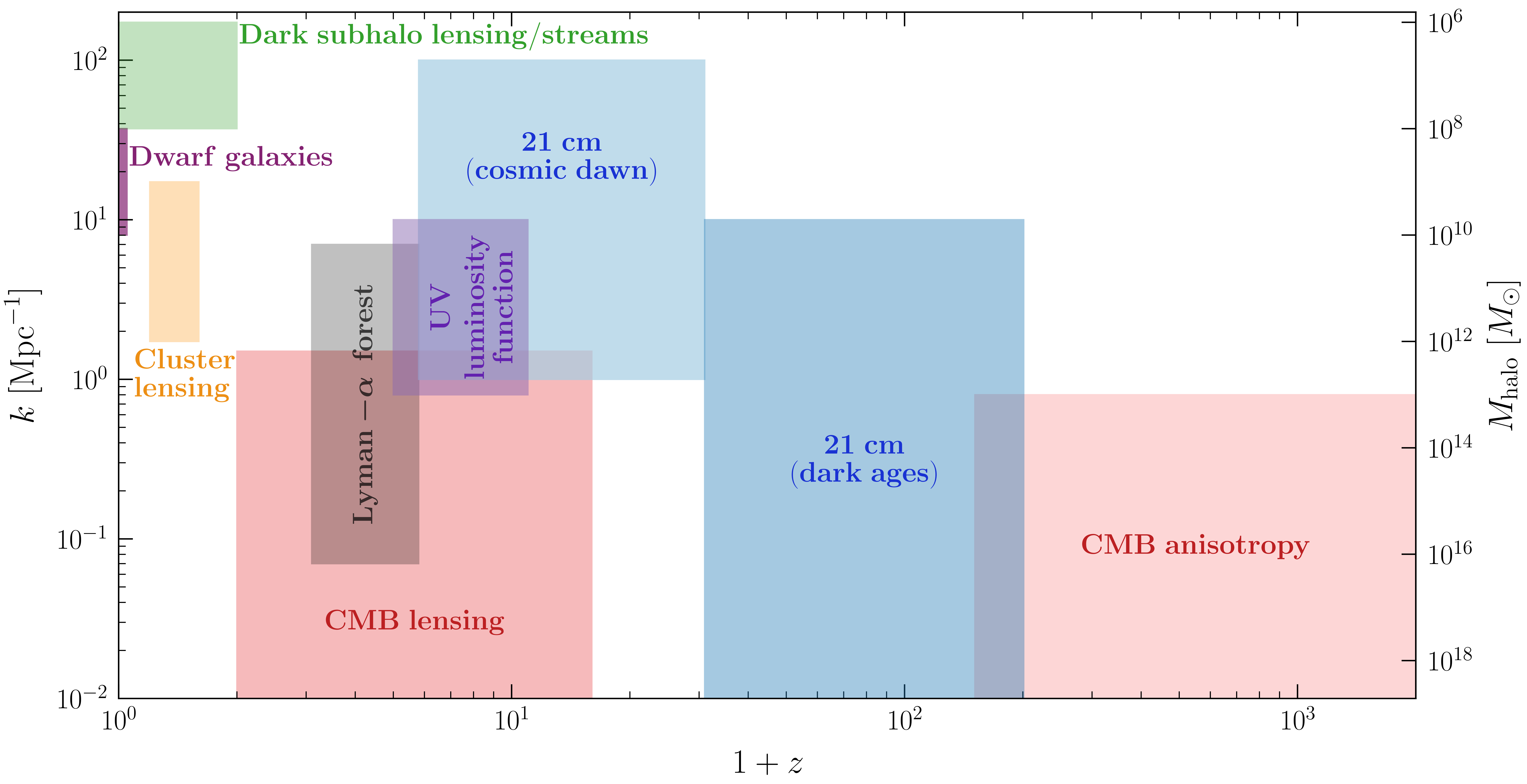
Driskell, Nadler, Mirocha, Benson, KB, Morton, Lashner, An, Gluscevic (PRD 2022)

Impact on 21cm Signal



Driskell, Nadler, Mirocha, Benson, KB, Morton, Lashner, An, Gluscevic (PRD 2022)

Complementarity



Snowmass 2021 Theory Frontier: Astrophysical and Cosmological Probes of Dark Matter
Boddy, Lisanti, McDermott, Rodd, Weniger+ (2203.06380)