Structure Formation and the Global 21-cm Signal with Coulomb-like Dark Matter

(Arxiv link coming soon)

Trey Driskell (USC - Vera Gluscevic)

Collaborators

Ethan Nadler (USC, Carnegie Observatories)

Jordan Mirocha (McGill)

Rui An (USC)

Andrew Benson (Carnegie Observatories)

Kimberly Boddy (UT Austin)

Tim Morton (USC)

Jack Lashner (USC)

Vera Gluscevic (USC)

DM-Baryon Interactions

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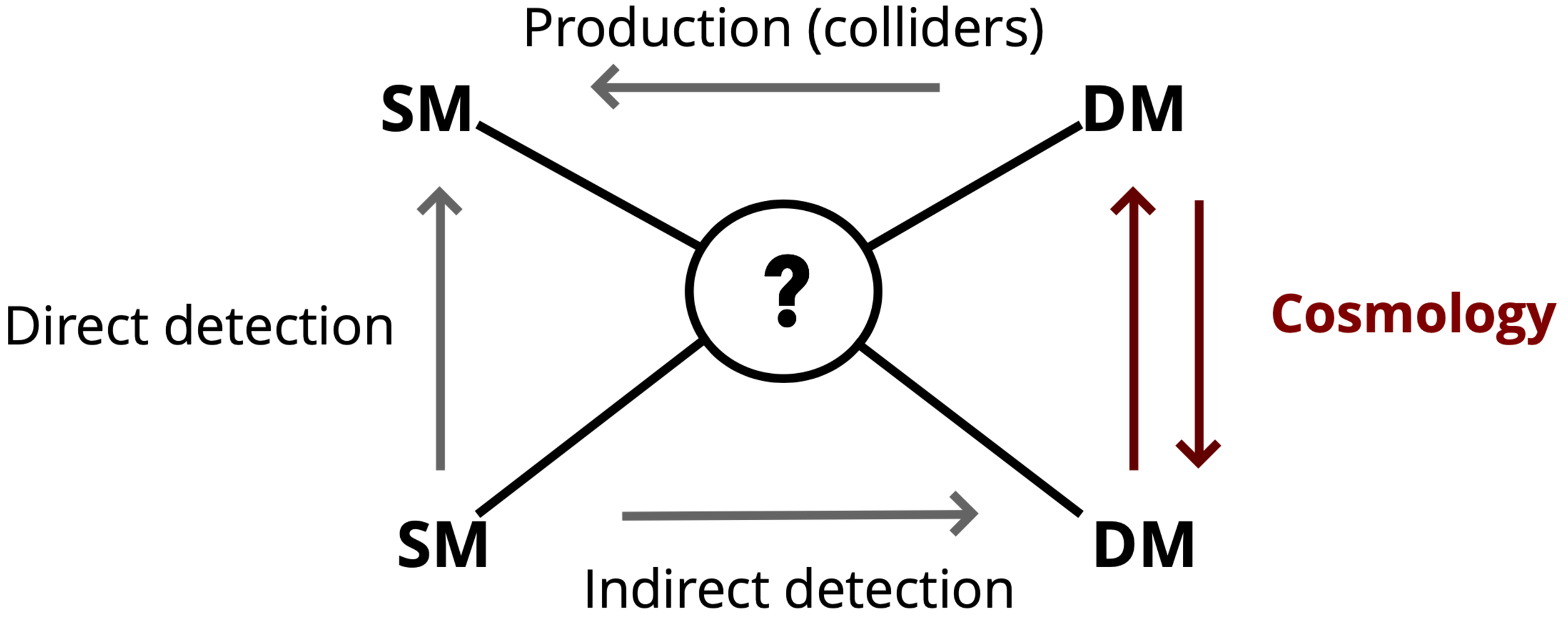
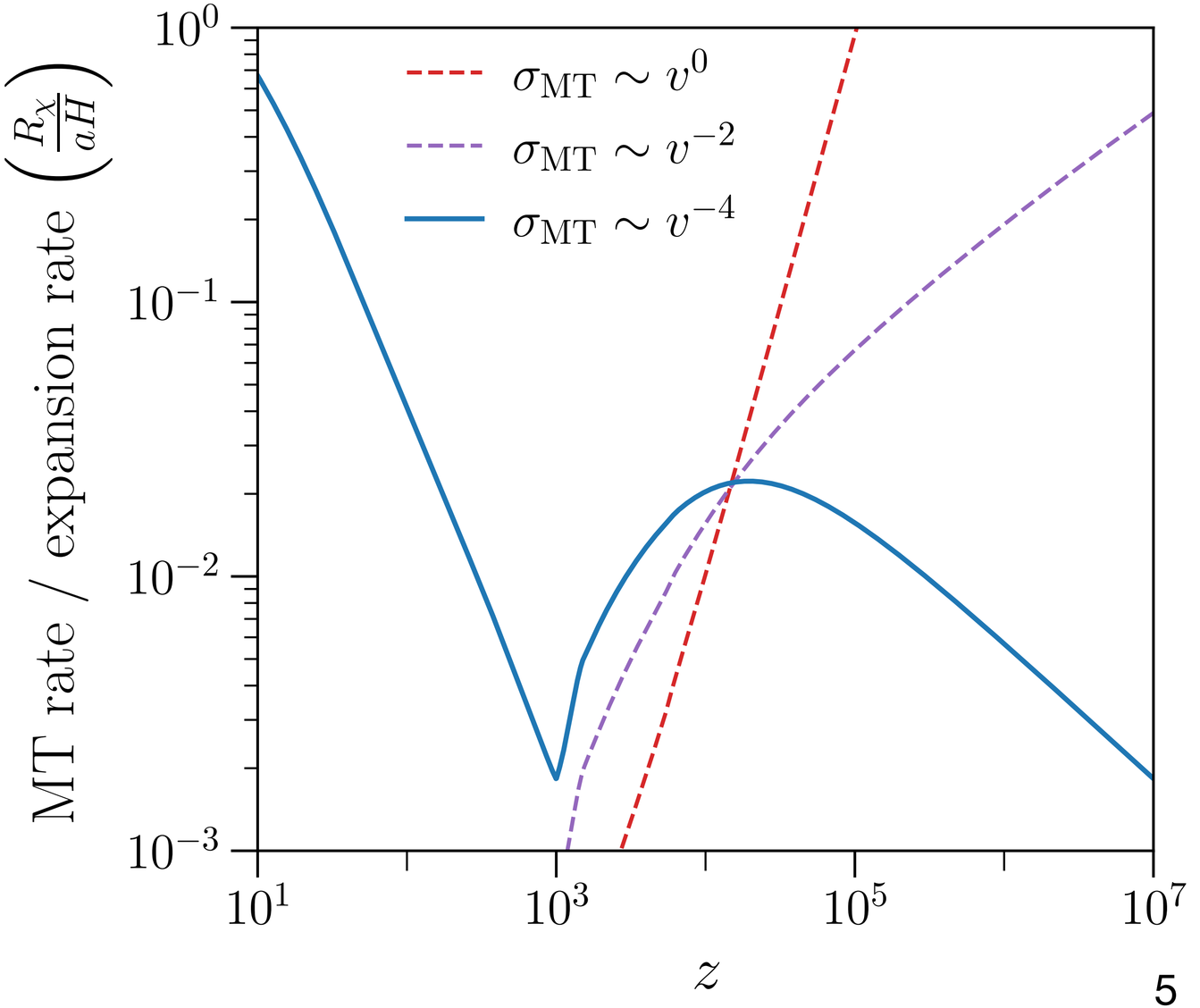


DM-Baryon Interactions

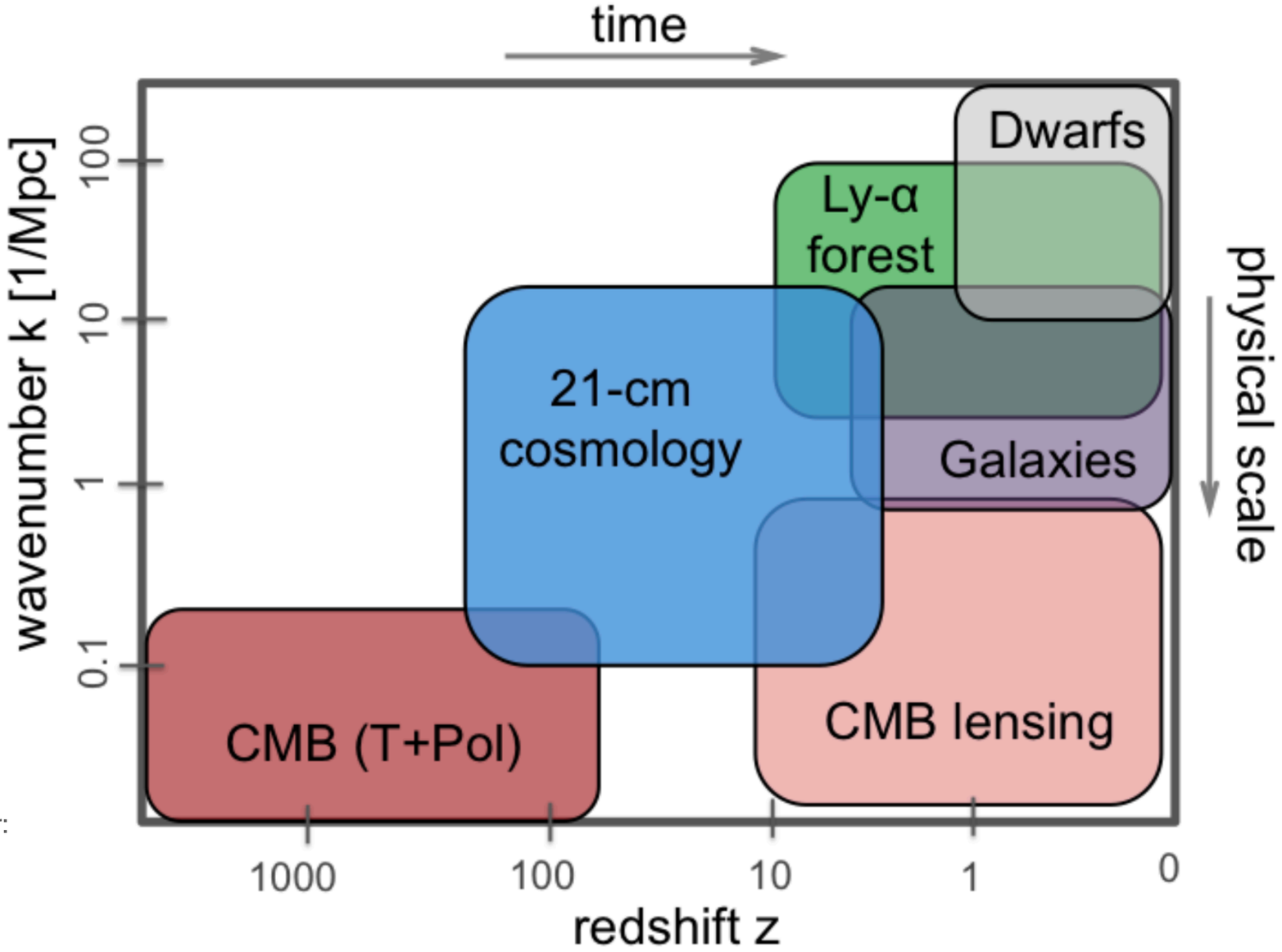
- Scattering of DM and baryons exchanges **heat** and **momentum**
- Momentum-transfer rate cross section depends on relative velocity as:

$$\sigma_{\mathrm{MT}} = \sigma_0 v^n$$

- **Coulomb-like** (millicharge) Interaction scales as $\sim v^{-4}$

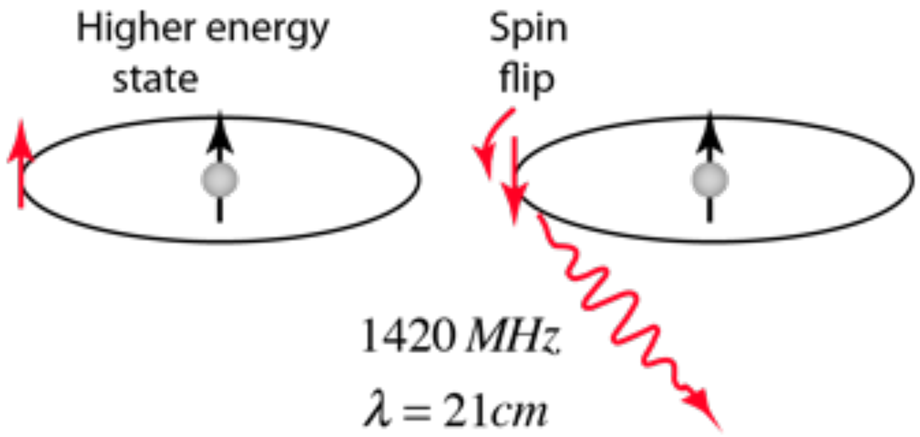


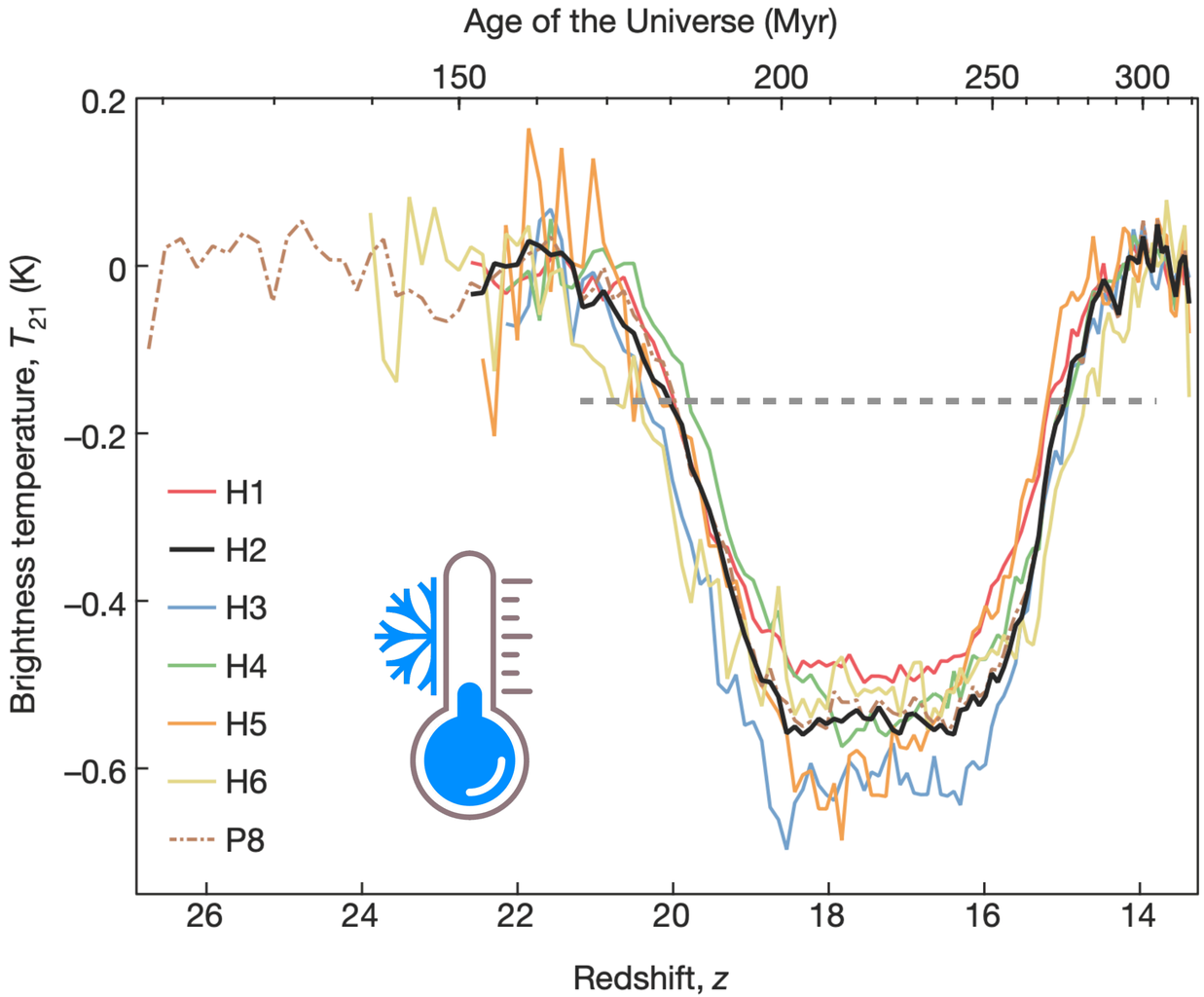
Cosmological Probes



Astro2020 Science White Paper: Cosmological Probes of Dark Matter Interactions: The Next Decade, Gluscevic, et al.

21-cm & EDGES

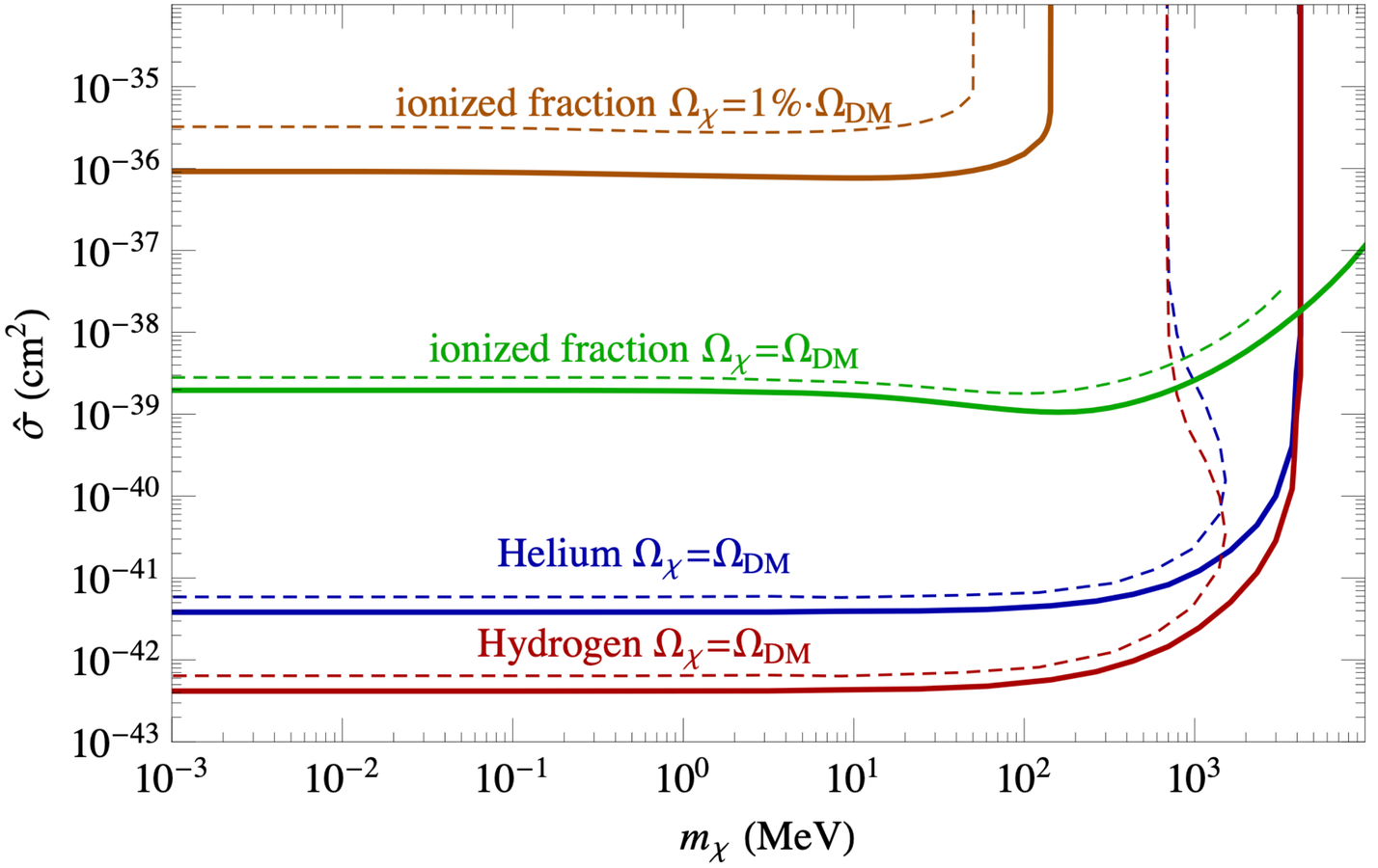




Bowman, J., Rogers, A., Monsalve, R. *et al. Nature* **555,** 67–70 (2018).

Past Work

- What σ_0 can explain the EDGES signal?
- Missing Components:
  - How do Coulomb-like interactions alter the **formation of structure**?
  - How does that effect the timing of the signal?
  - How does astrophysics change the necessary σ_0?



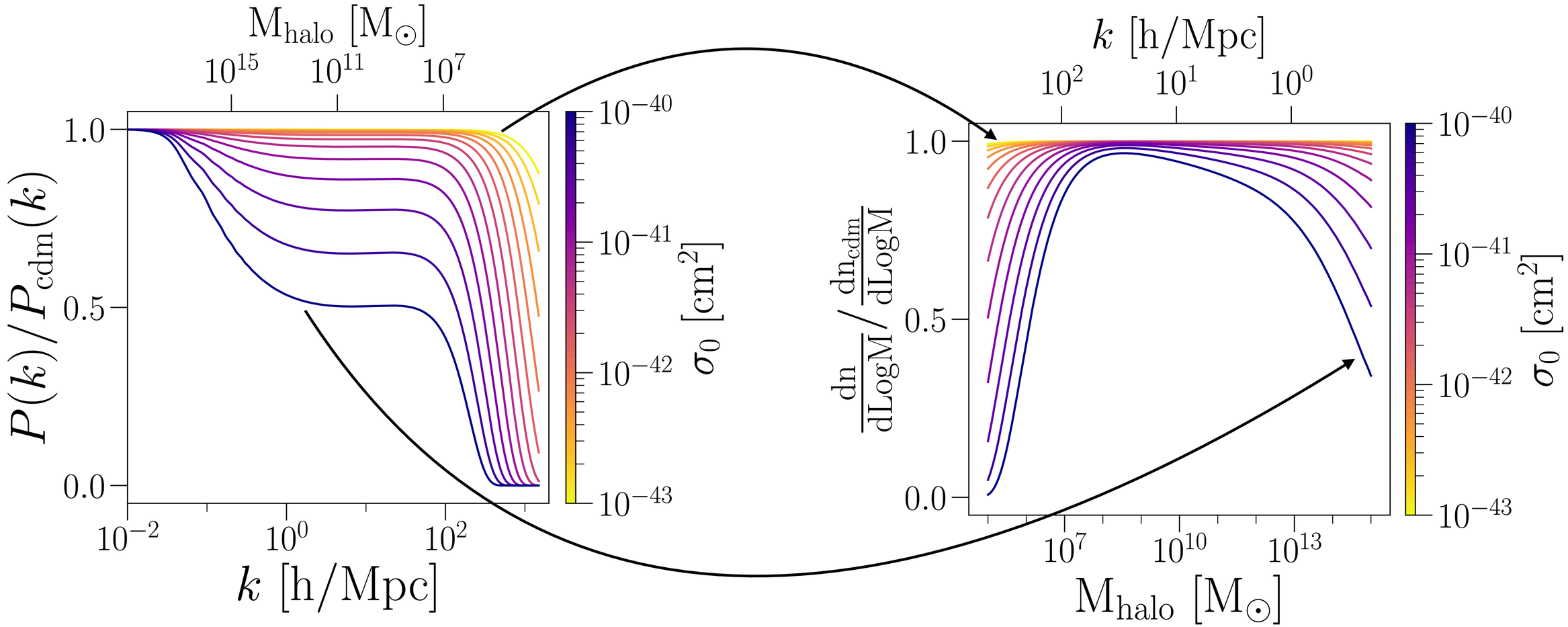
R. Barkana, N. J. Outmezguine, D. Redigolo, and T. Volansky, Phys. Rev. D 98, 103005 (2018).

Structure Formation and Astrophysical Model

Structure Formation

- Want a fast way to convert linear $P(k)$ to non-linear formation of structure
- N-body / Hydro simulations prohibitively slow
- Instead, analytically predict halo abundance using Press-Schechter theory

Structure Formation



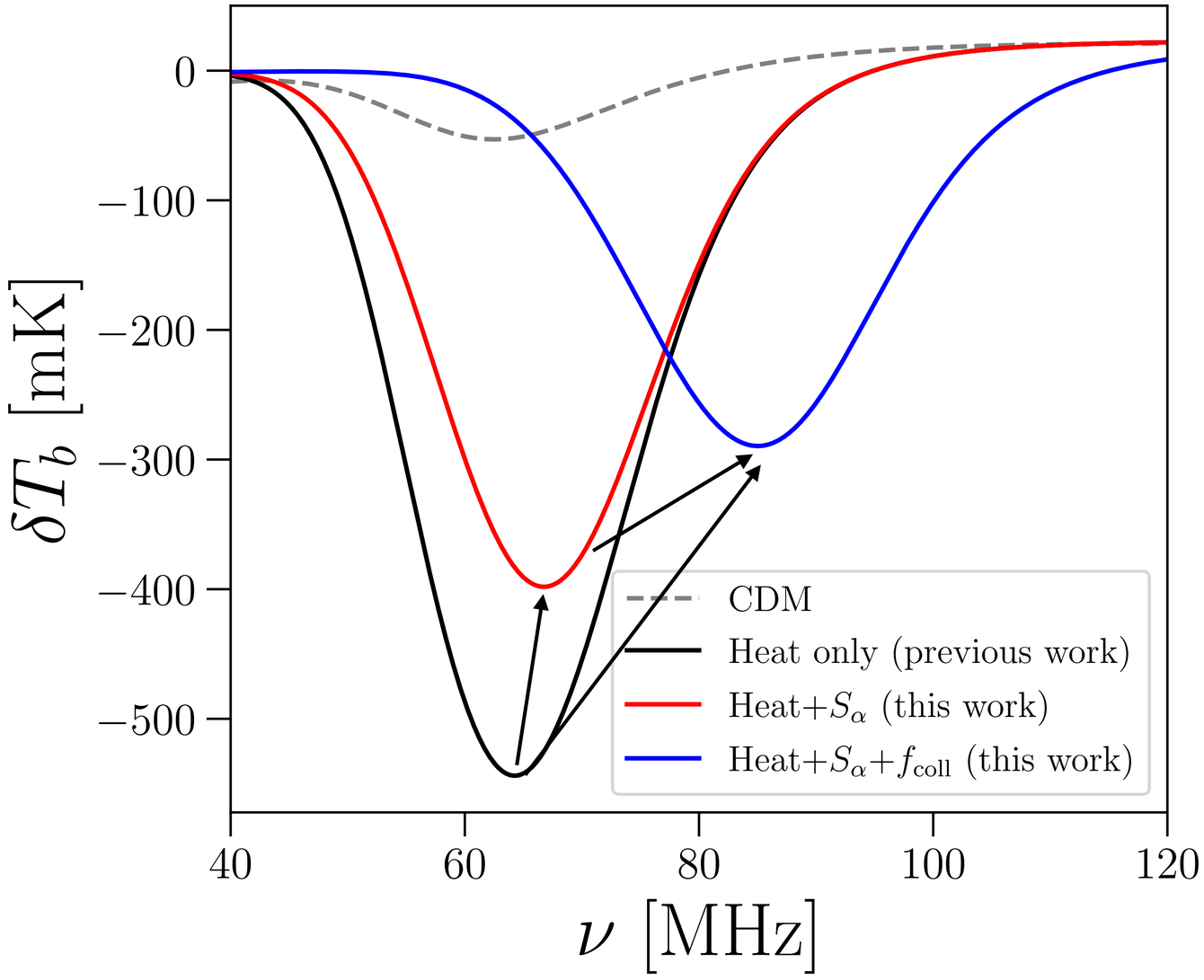
Astrophysical Model

Physical Process	Model / Assumption	Parameterization	Varied Parameters
Galaxy Formation	Every halo with $\mathrm{M_{halo}} > \mathrm{M_{vir}}$ hosts a galaxy	$f_{\mathrm{coll}}\left(\frac{\mathrm{dn}}{\mathrm{dM}}, \mathrm{M_{vir}}\right)$	$T_{\mathrm{vir}} \in \{500\,\mathrm{K}, 10^4\,\mathrm{K}\}$
Star Formation	Constant star formation efficiency	$\dot{\rho}_\star = \rho_{\mathrm{b}} f_\star \dot{f}_{\mathrm{coll}}$	$f_\star \in \{0.01, 0.05\}$
Stellar Emission	Emission in each band $\propto$ SFRD	$\epsilon_\nu = c_i f_i I_\nu \dot{\rho}_\star$	$f_{\mathrm{X}} \in \{1, 10\}$
IGM Evolution	Emitted photons heat the IGM	$\epsilon_{\mathrm{X}}(\widehat{J}_\nu)$	None
	Emitted photons ionize the IGM	$\Gamma_{\mathrm{HI}}(\widehat{J}_\nu),\ \gamma_{\mathrm{HI}}(\widehat{J}_\nu)$	None
	Ly-α photons mediate 21-cm transition	$x_\alpha \propto \widehat{J}_\alpha S_\alpha(T_{\mathrm{K}})$	None

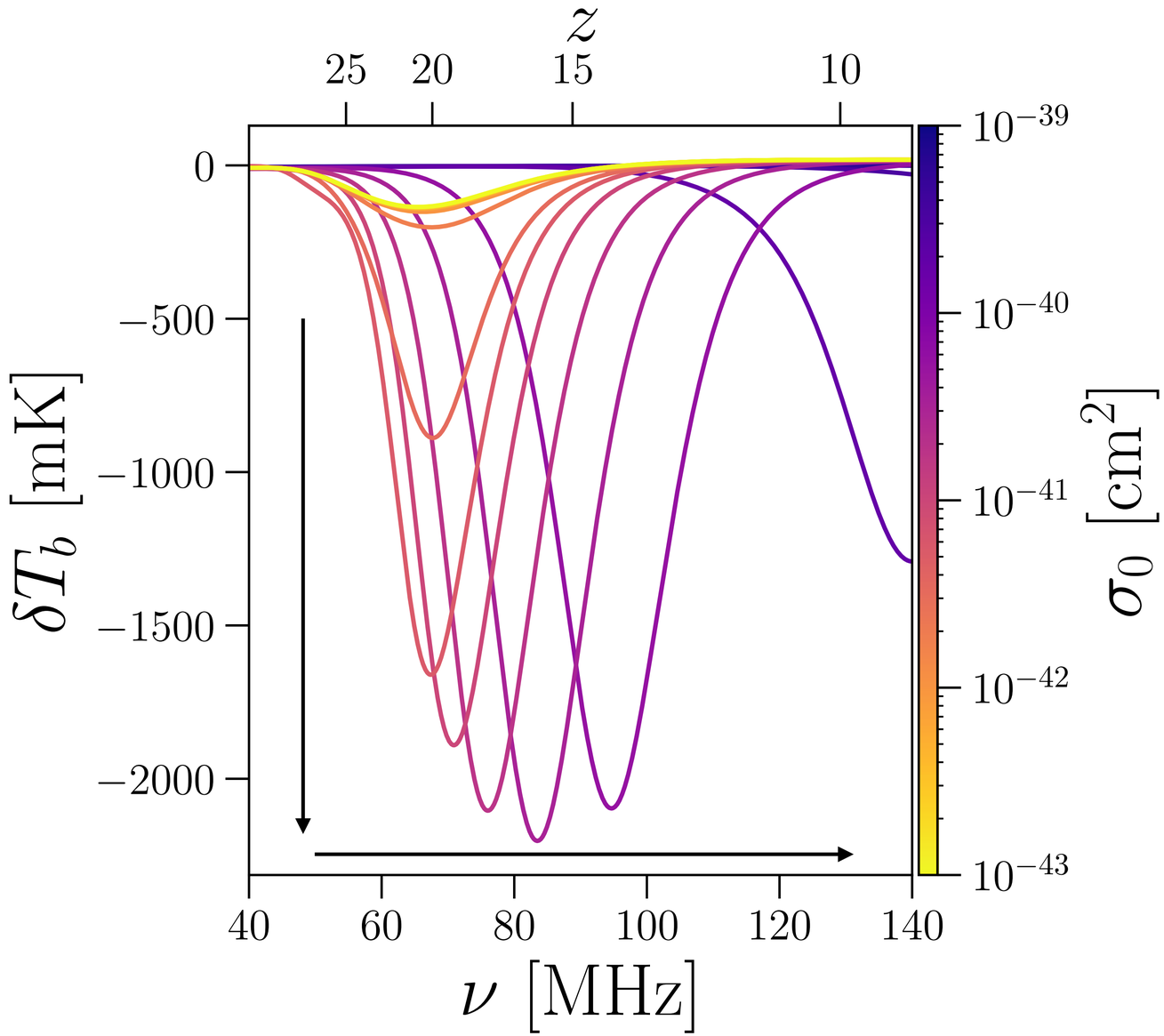
Results

Coulomb-Like Global Signal

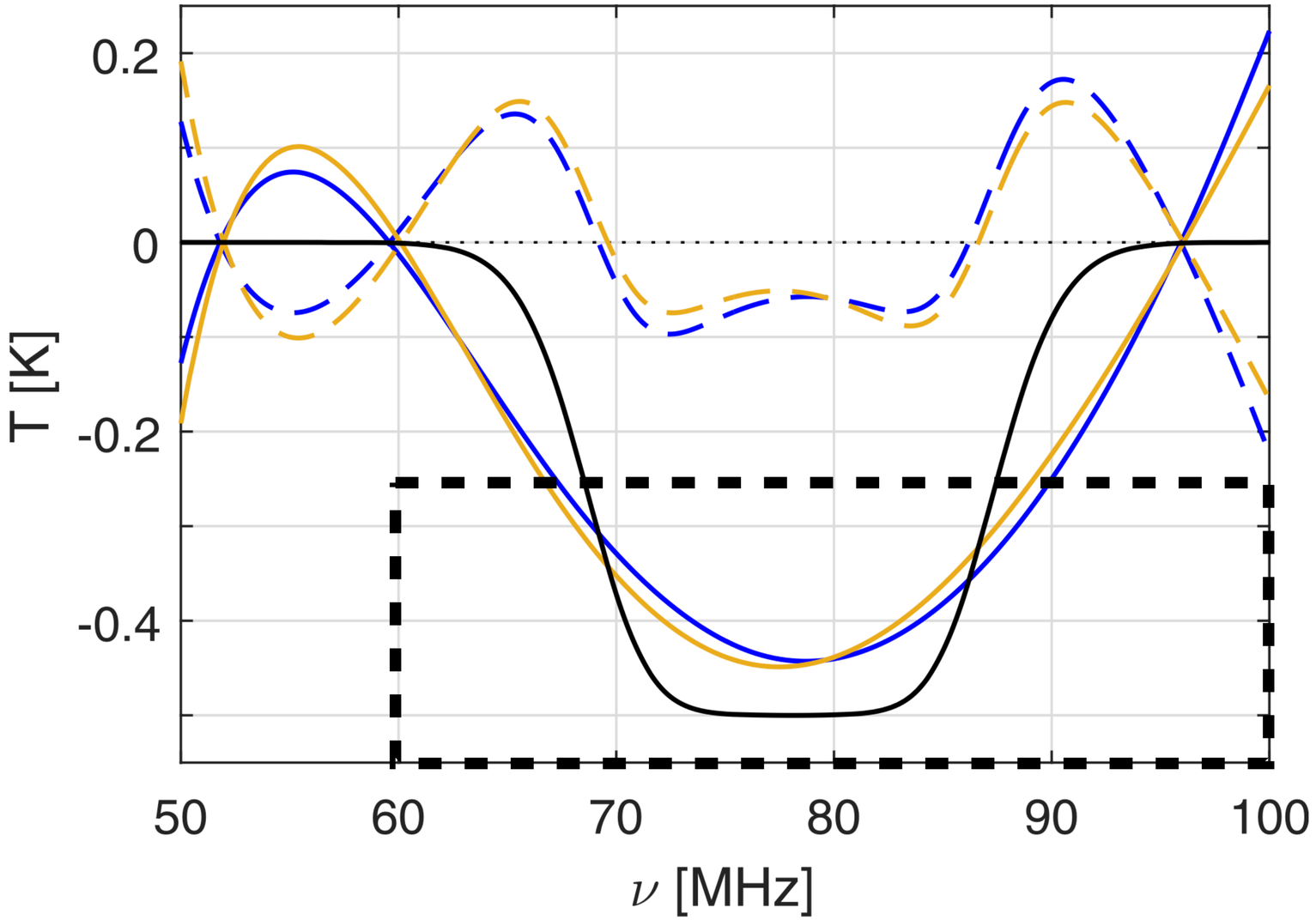
- Heat exchange cools baryons, deepening δT_b
- Scattering Correction S_α reduces the amplitude
- Delayed formation of structure redshifts the signal to later times



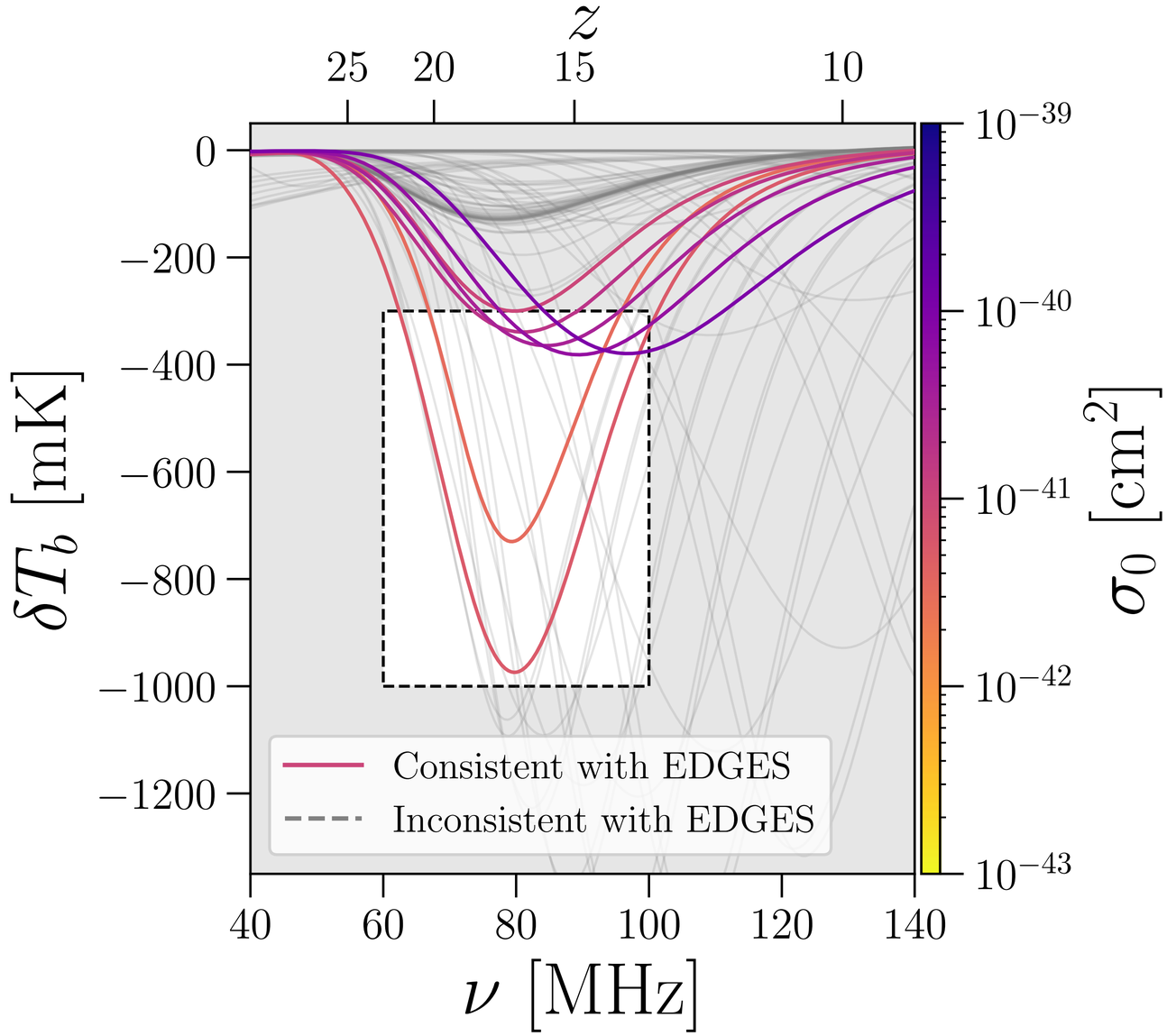
DM-b Interaction Strength



EDGES-based Window

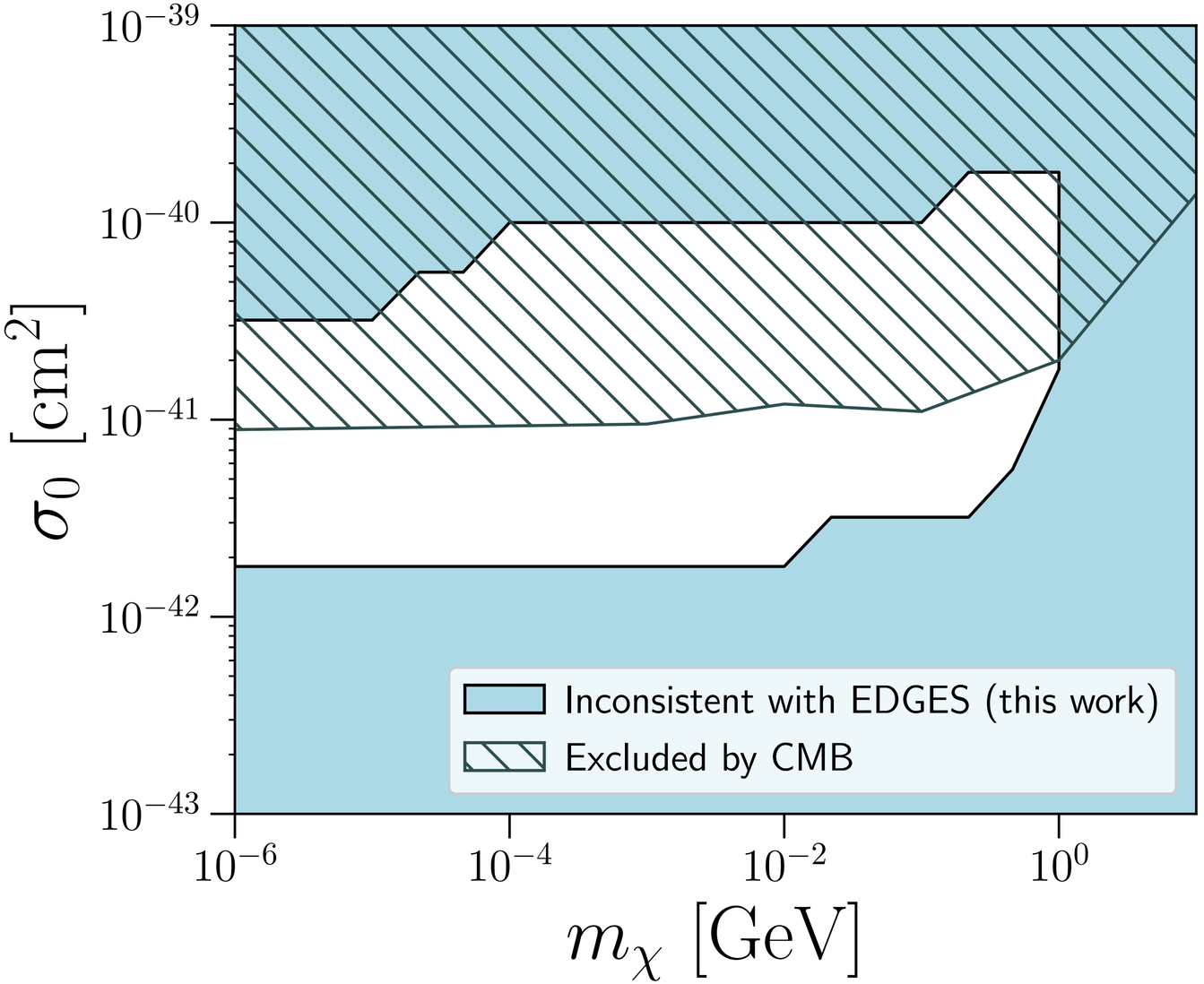


“Consistent” Predictions



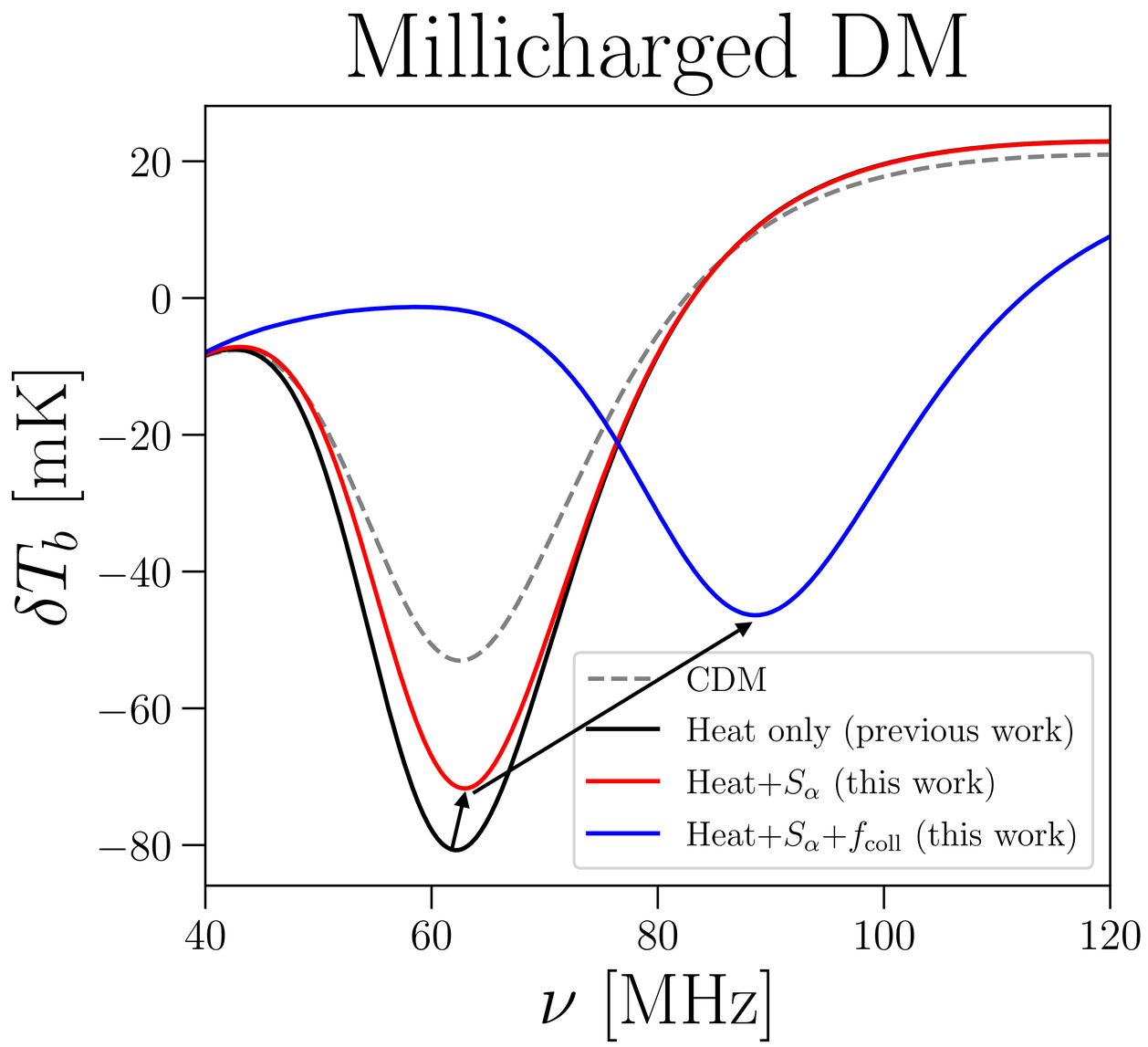
DM-b Parameter Space

- First “upper limit” on σ_0 from 21-cm alone
- “Lower limit” nearly x10 higher in σ_0 than previous results due to x_α correction



Millicharged DM

- Thermal evolution suppressed by ionized fraction
- Suppression of power spectrum mostly pre-recombination, same delay as Coulomb-like DM
- **No consistent region for 100% Millicharged DM**



Conclusion

- First prediction of structure formation (HMF) in Coulomb-like DM models
- First “self-consistent” prediction of the 21-cm Global Signal in Coulomb-like DM by including the impact on structure formation
  - Scattering correction is essential ingredient to 21-cm in IDM
- Future:
  - Accelerate the code to enable sampling of astrophysical parameters & sampling of full likelihood
  - Future 21-cm experiments will update/improve EDGES prediction