21cm Limits on Dark Matter Decay, Dark Matter Bremsstrahlung Annihilation, and Primordial Black Holes

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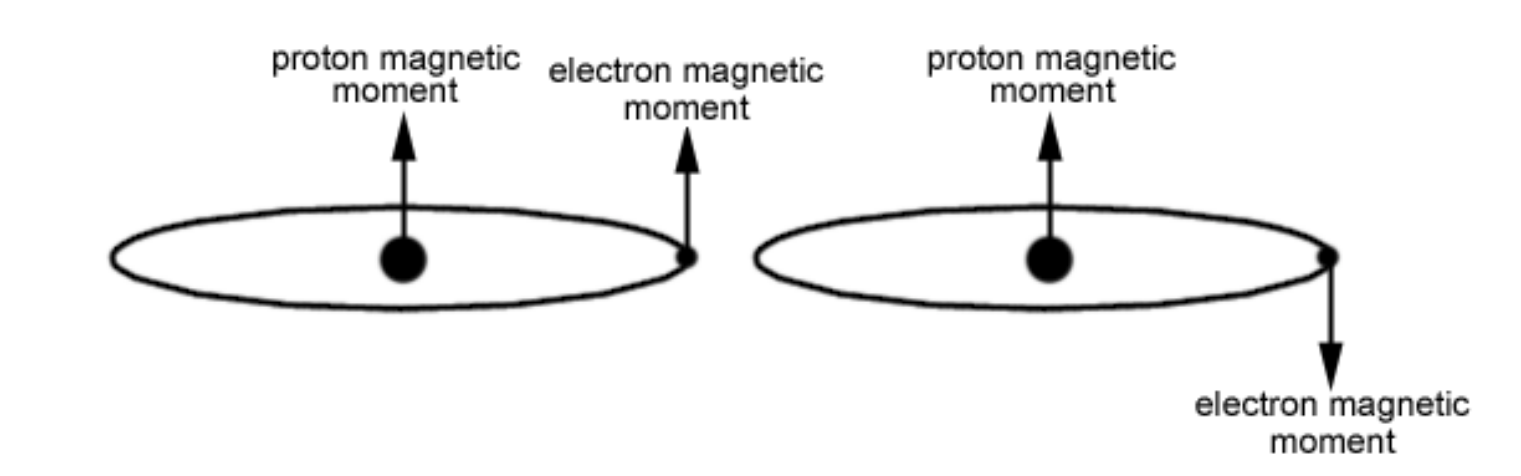
Collaboration with:
B. Dutta, Y. Gao, Y. Ma, and L. Strigari; arXiv:1803.09390
J. Dent, B. Dutta, and L. Strigari; arXiv:1805.XXXXX

Texas A&M University

Motivation behind 21cm line*

Corresponds to the neutral Hydrogen spin transition

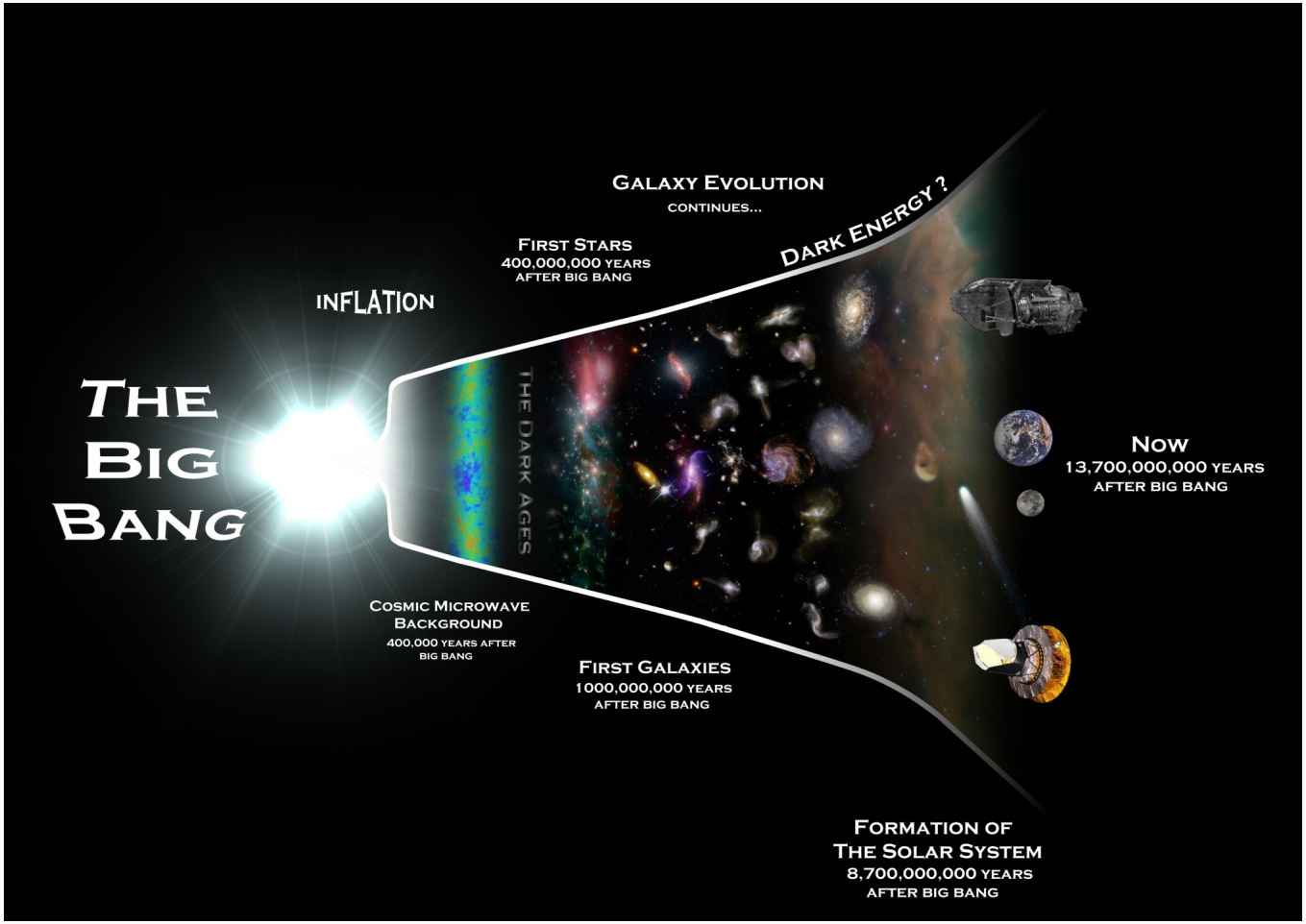
Transition wavelength of 21 cm



*https://web.njit.edu/ gary/728/Lecture2.html

Motivation behind 21cm line*

Occurs during the dark age of the Universe



*http://planck.cf.ac.uk/science/timeline/universe

Approach

Energy Injection into the Universe (Model Dependent)

Energy Absorption through Various Channels

-Effective Efficiency (Model Dependent)

Energy Effects Evolution of the Intergalactic Medium Altered

Evolution Leaves a Measurable Imprint

Energy Injection

Decay - density dependent

$$\left(\frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t}\right)_{\mathrm{dec}} = \frac{1}{\tau_\chi}\rho_{\mathrm{c}}c^2\Omega_{\chi,0}(1+z)^3$$

Annihilation - density^2 dependent*

$$\left(\frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t}\right)_{\mathrm{ann}} = \rho_{\mathrm{c}}^2c^2\Omega_{\chi,0}^2\frac{\langle\sigma v\rangle_\chi}{M_\chi}(1+z)^6$$

Primordial Black Holes (PBH) - density dependent†

$$\left(\frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t}\right)_{\mathrm{BH}} = \frac{\dot{M}_{\mathrm{BH}}}{M_{\mathrm{BH}}}\rho_{\mathrm{c}}c^2\Omega_{\mathrm{BH},0}(1+z)^3$$

$$\dot{M}_{\mathrm{BH}} = -5.34\times10^{25}F(M_{\mathrm{BH}})M_{\mathrm{BH}}^{-2}\,\mathrm{g}^3\,\mathrm{s}^{-1}$$

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*Madhavacheril, Sehgal,and Slatyer; arXiv:1604.02457

†Carr, Kohri, Sendouda, and Yokoyama; arXiv:0912.5297

Gas Evolution*†‡

Ionization Fraction

$$\frac{\mathrm{d}x_e}{\mathrm{d}z} = \left(\frac{\mathrm{d}x_e}{\mathrm{d}z}\right)_{\mathrm{orig}} - \frac{1}{(1+z)H(z)}\left(I_{\mathrm{i}}(z) + I_{\alpha}(z)\right)$$

Medium Temperature

$$\frac{\mathrm{d}T_{\mathrm{IGM}}}{\mathrm{d}z} = \left(\frac{\mathrm{d}T_{\mathrm{IGM}}}{\mathrm{d}z}\right)_{\mathrm{orig}} - \frac{2}{3k_{\mathrm{B}}(1+z)H(z)}\frac{K_{\mathrm{h}}(z)}{1+f_{\mathrm{He}}+x_e}$$

Hydrogen Ionization

$$I_{\mathrm{i}}(z) = f_{\mathrm{i}}(E,z)\frac{\mathrm{d}E/\mathrm{d}V\mathrm{d}t}{n_{\mathrm{H}}(z)E_{\mathrm{i}}}$$

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*Liu, Slatyer, and Zavala; arXiv:1604.02457

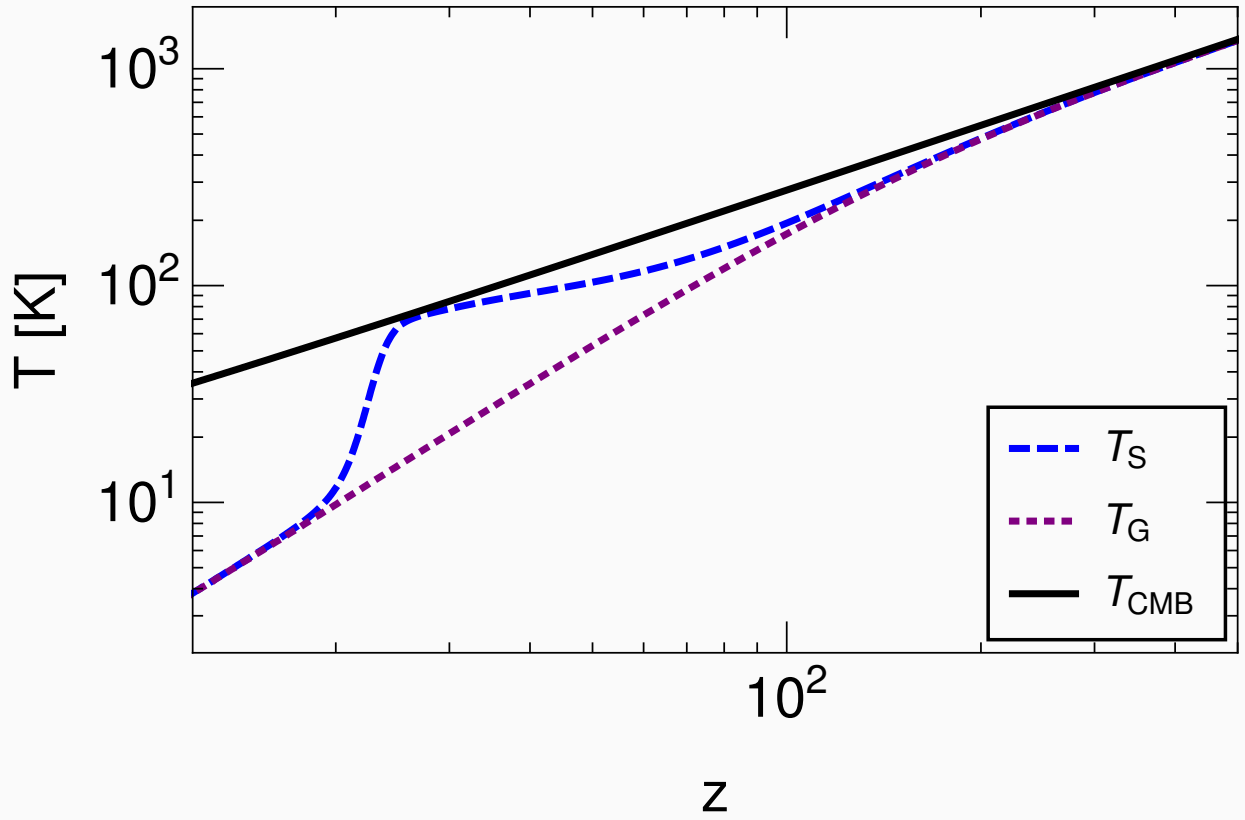
†Belotsky and Kirillov; arXiv:1409.8601

‡Slatyer; arXiv:1211.0283

Wouthuysen-Field Effect*

$$T_{\rm S} = \frac{T_{\rm CMB} + y_{\rm c} T_{\rm IGM} + y_{\rm Ly\alpha} T_{\rm Ly\alpha}}{1 + y_{\rm c} + y_{\rm Ly\alpha}} \qquad T_{21} \approx \tau \frac{T_{\rm S} - T_{\rm CMB}}{1+z}$$

Set Constraints by demanding $T_{21} < -100(-50)\mathrm{mK}$

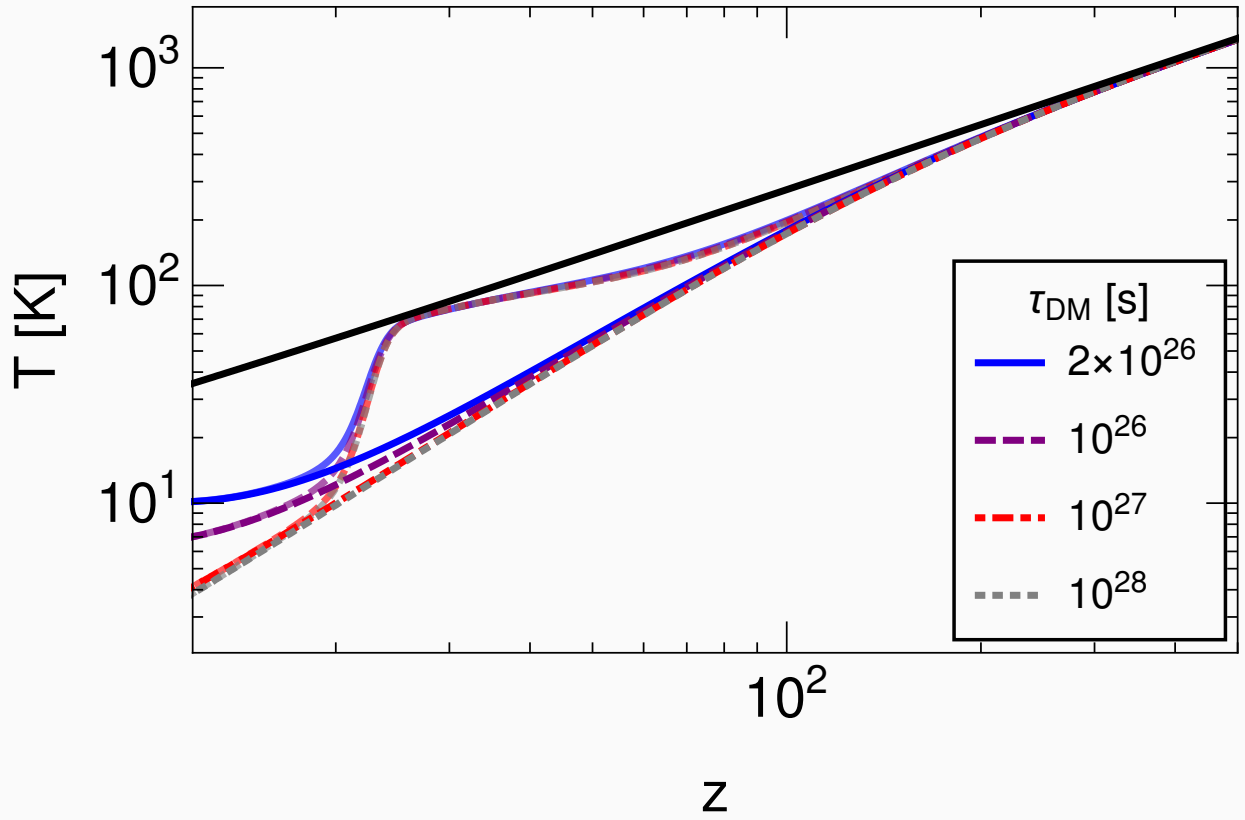


*Zaldarriaga, Furlanetto, and Hernquist; arXiv:astro-ph/0311514

Wouthuysen-Field Effect*

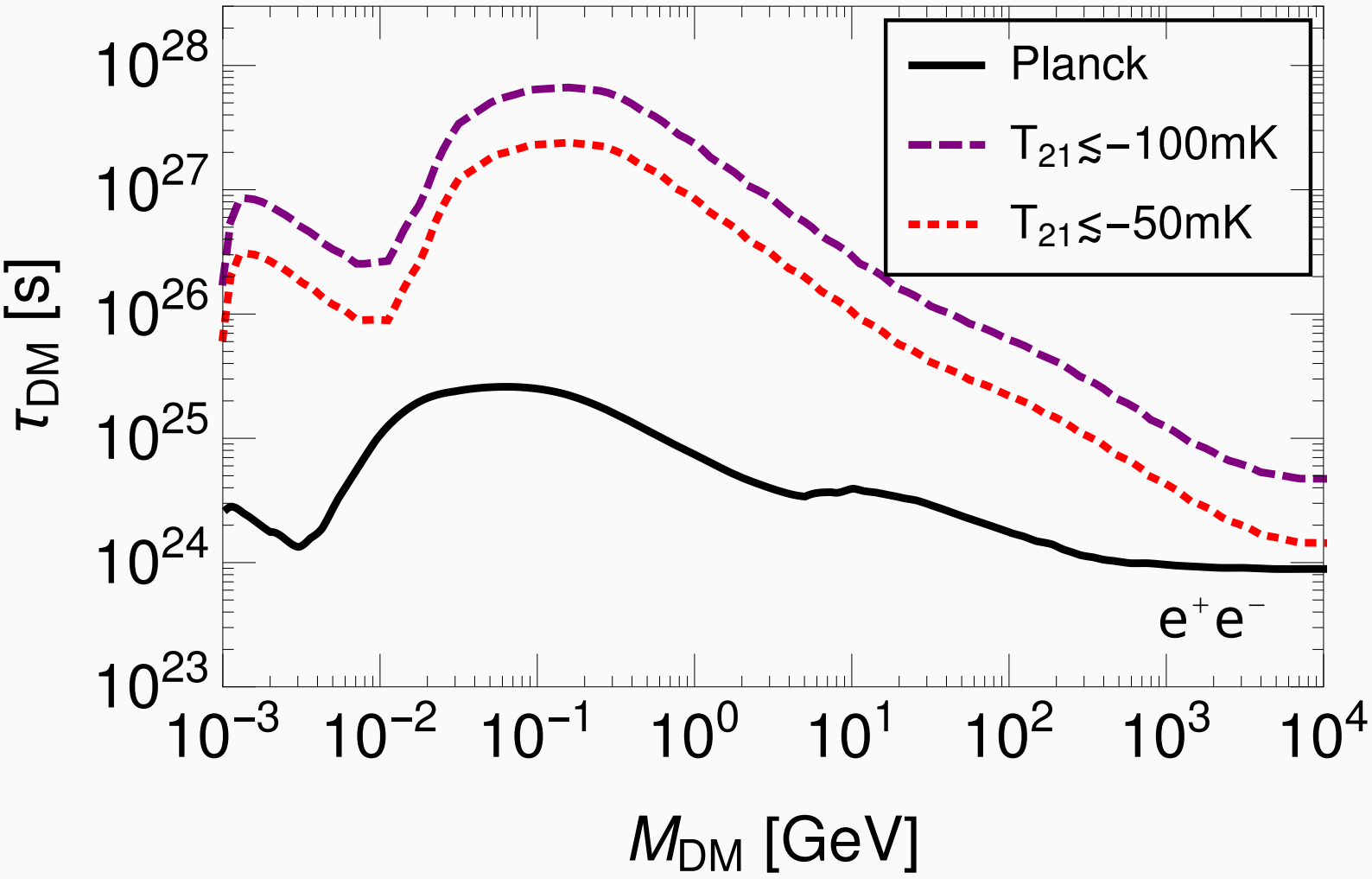
$$T_S = \frac{T_{CMB} + y_c T_{IGM} + y_{Ly\alpha} T_{Ly\alpha}}{1 + y_c + y_{Ly\alpha}} \qquad T_{21} \approx \tau \frac{T_S - T_{CMB}}{1+z}$$

Set Constraints by demanding $T_{21} < -100(-50)\mathrm{mK}$

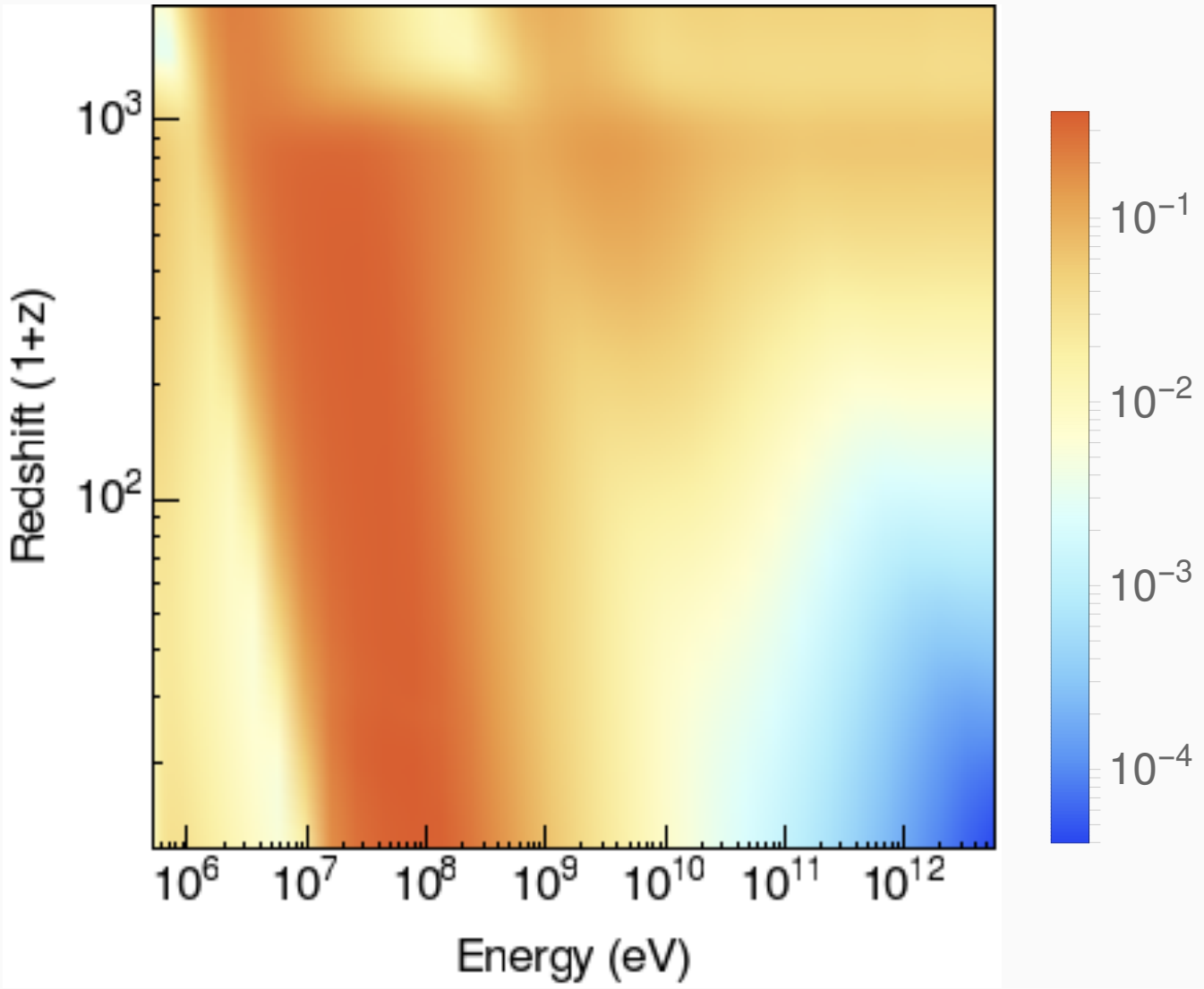


*Zaldarriaga, Furlanetto, and Hernquist; arXiv:astro-ph/0311514

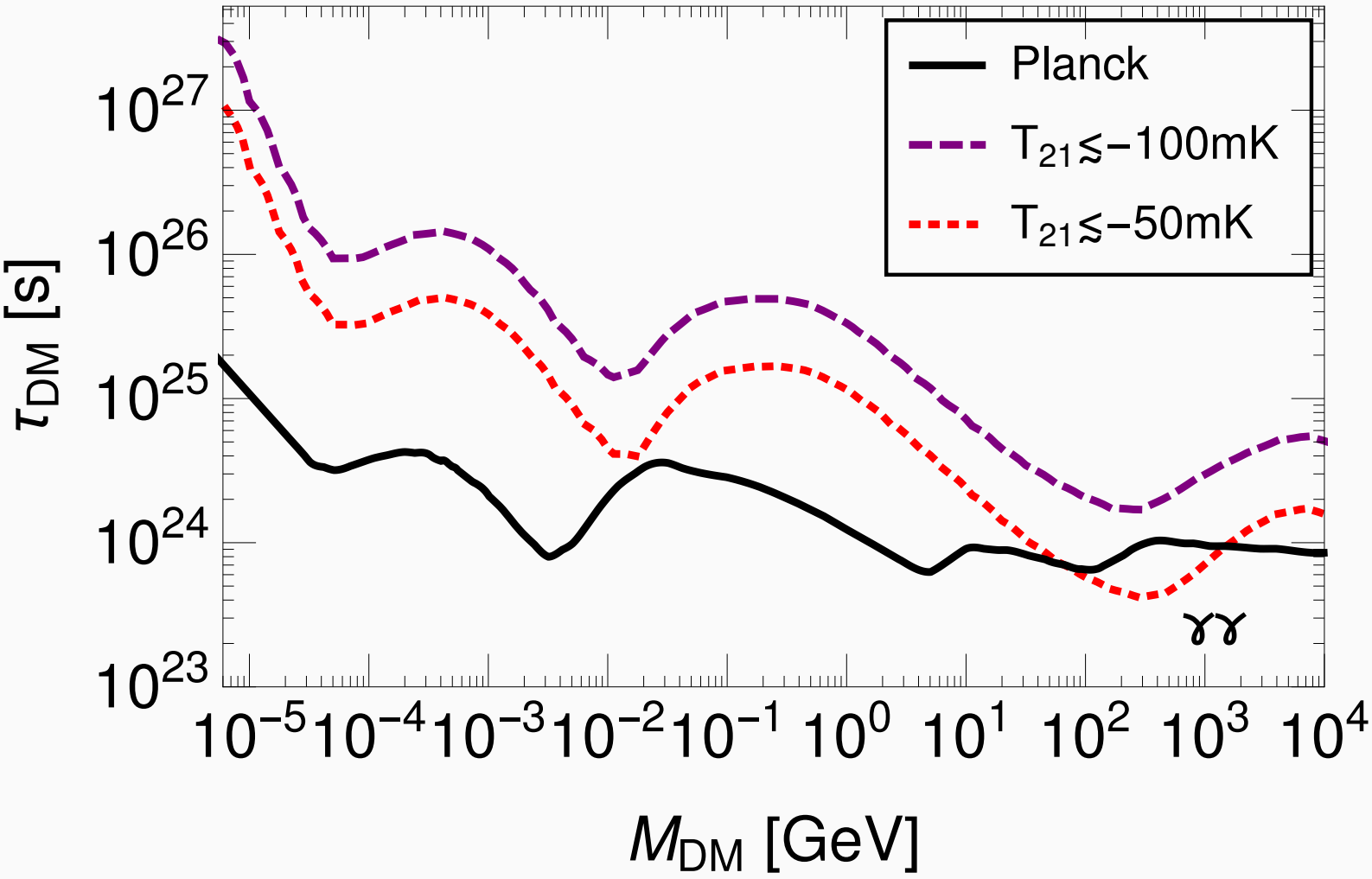
Decaying Dark Matter Constraints



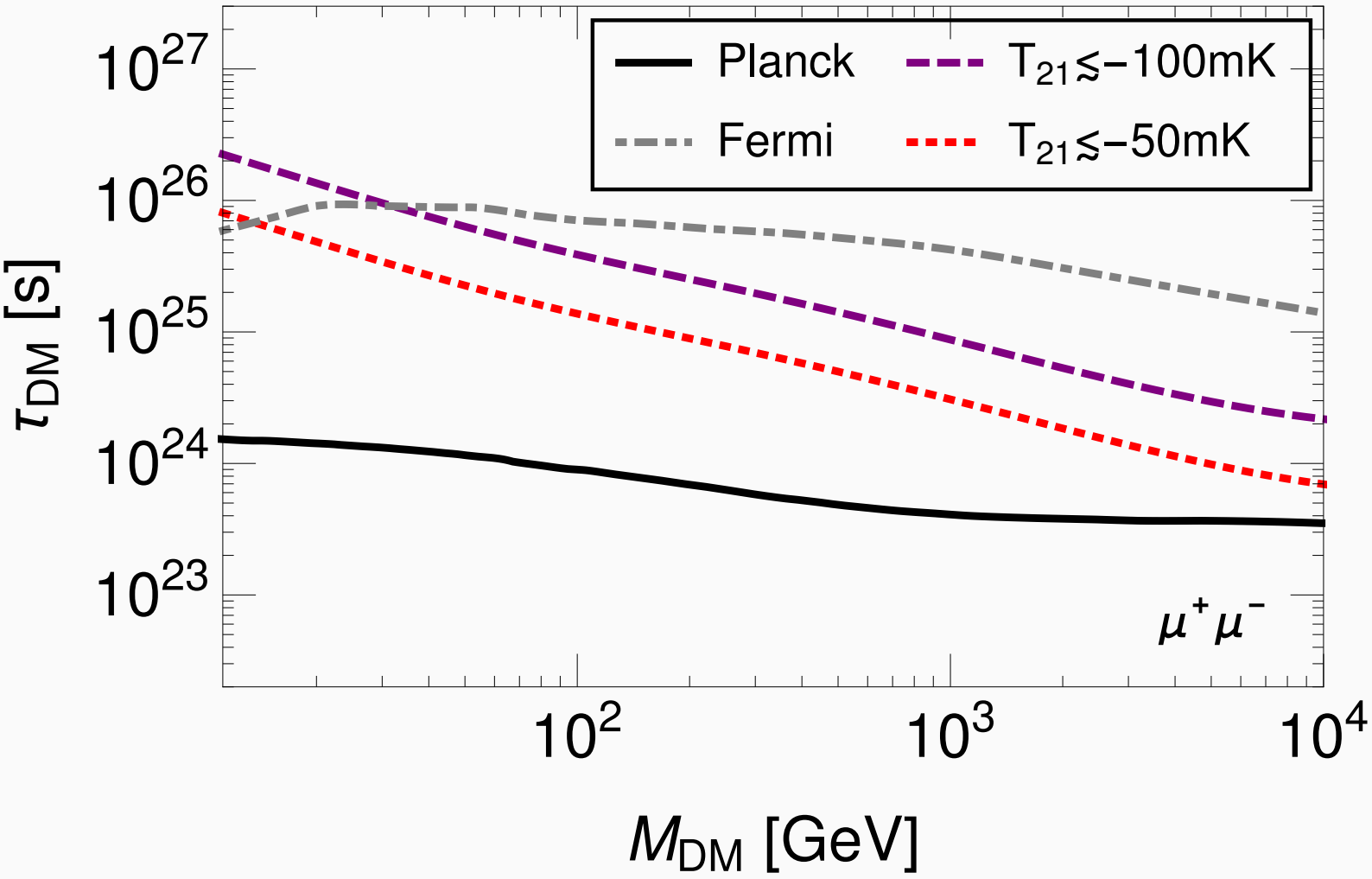
Decaying Dark Matter Constraints



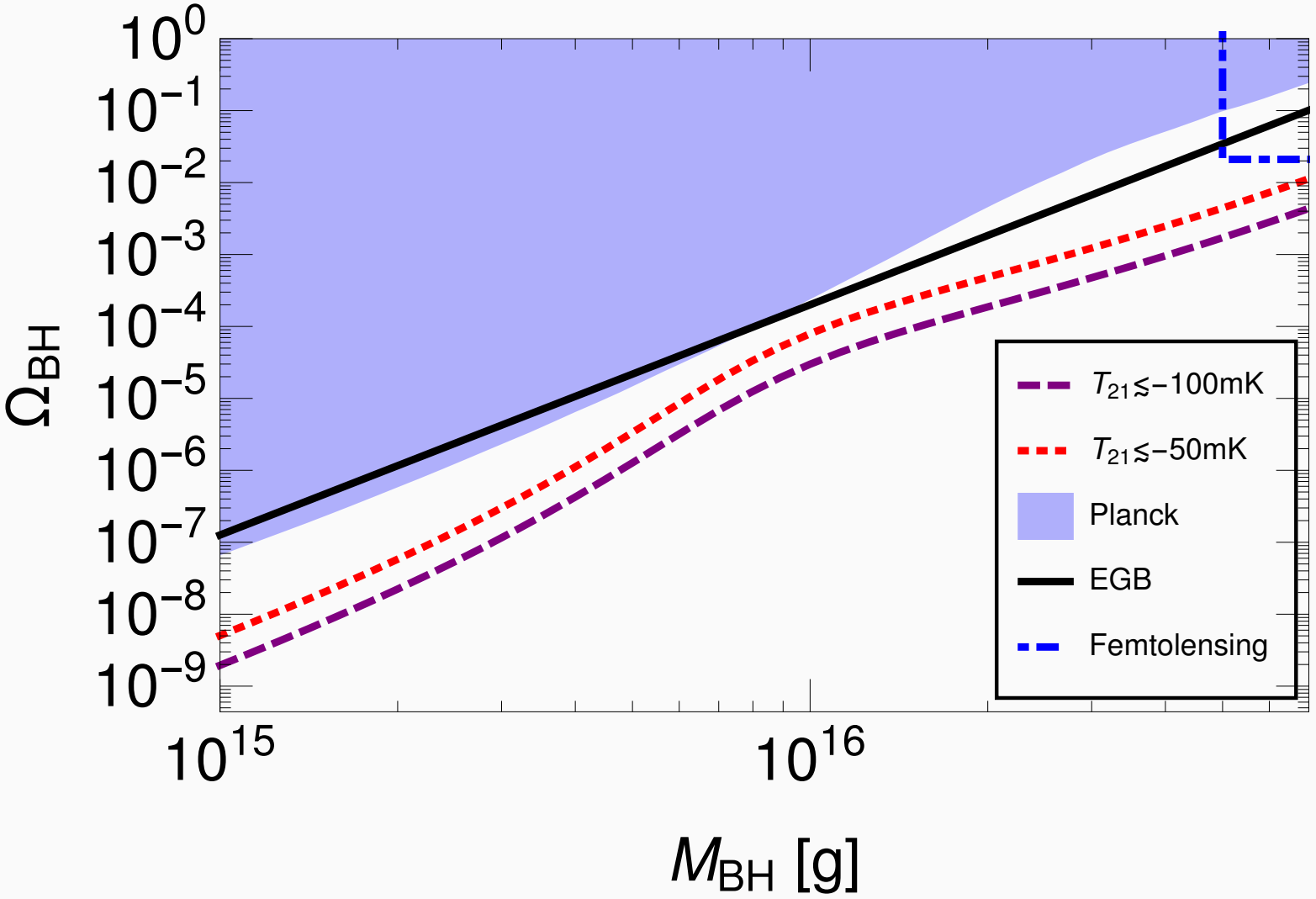
Decaying Dark Matter Constraints



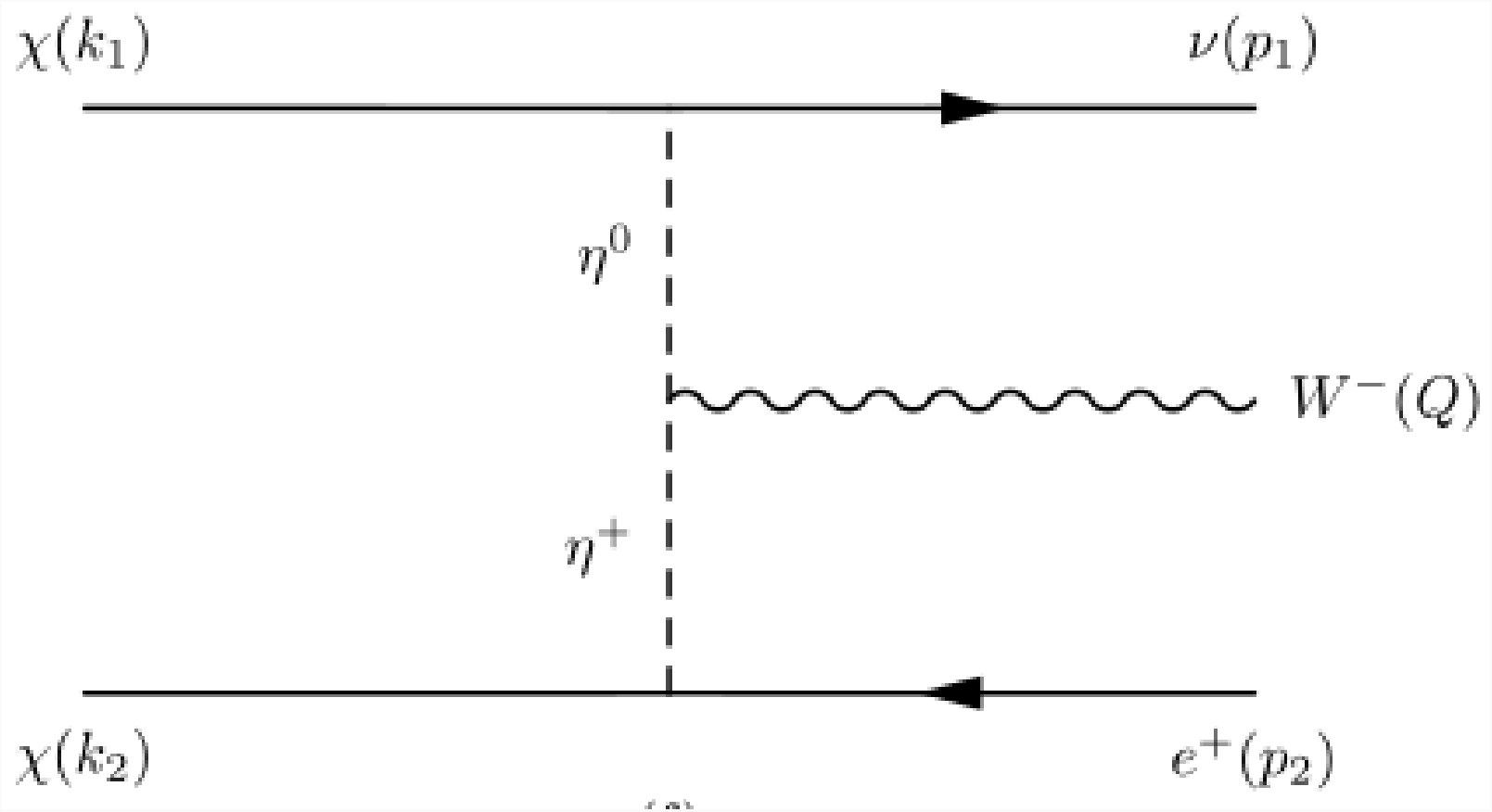
Decaying Dark Matter Constraints



PBH Constraints

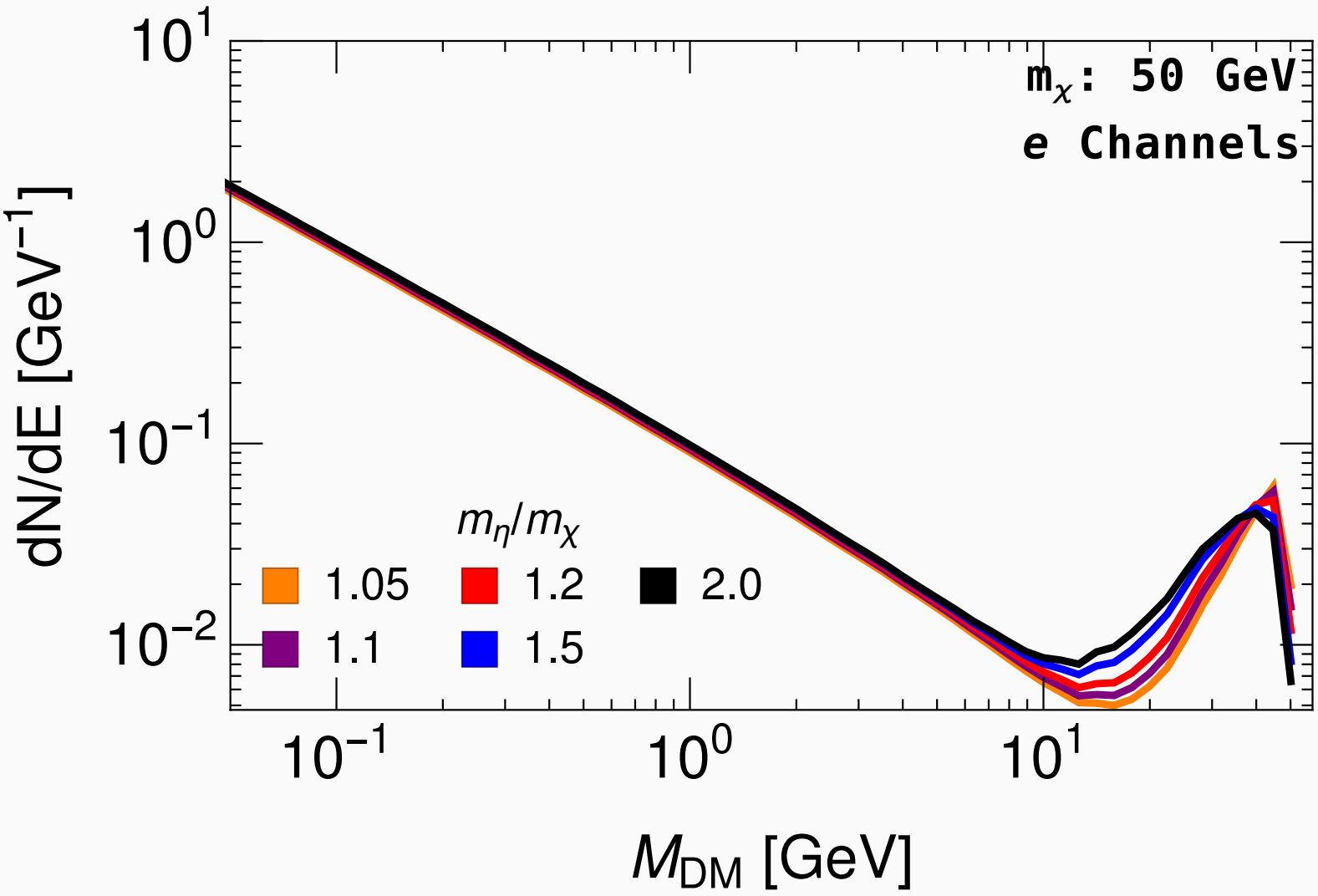


Bremsstrahlung*

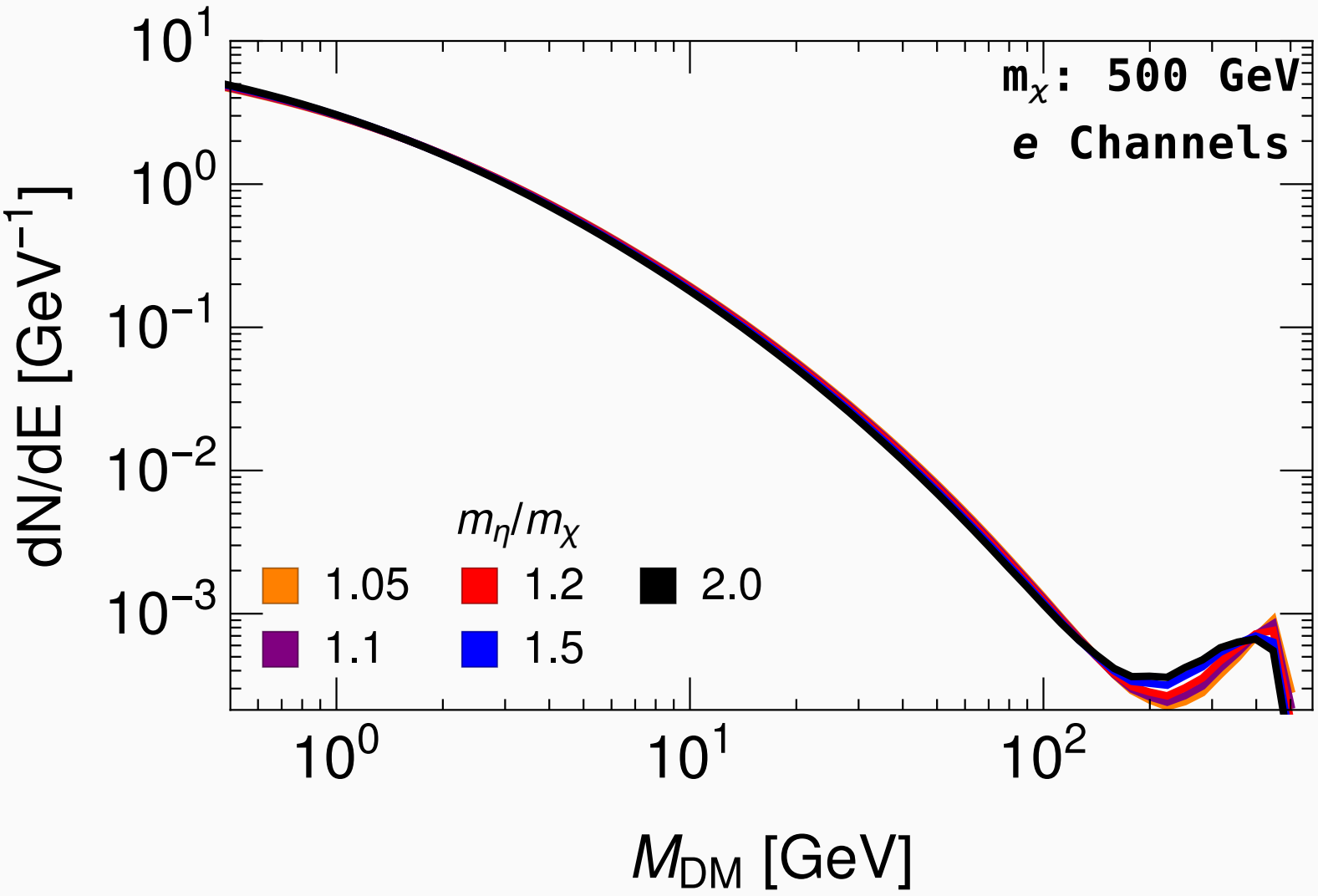


*Bell, Dent, Galea, Jacques, Krauss, and Weiler; arXiv:1104.3823

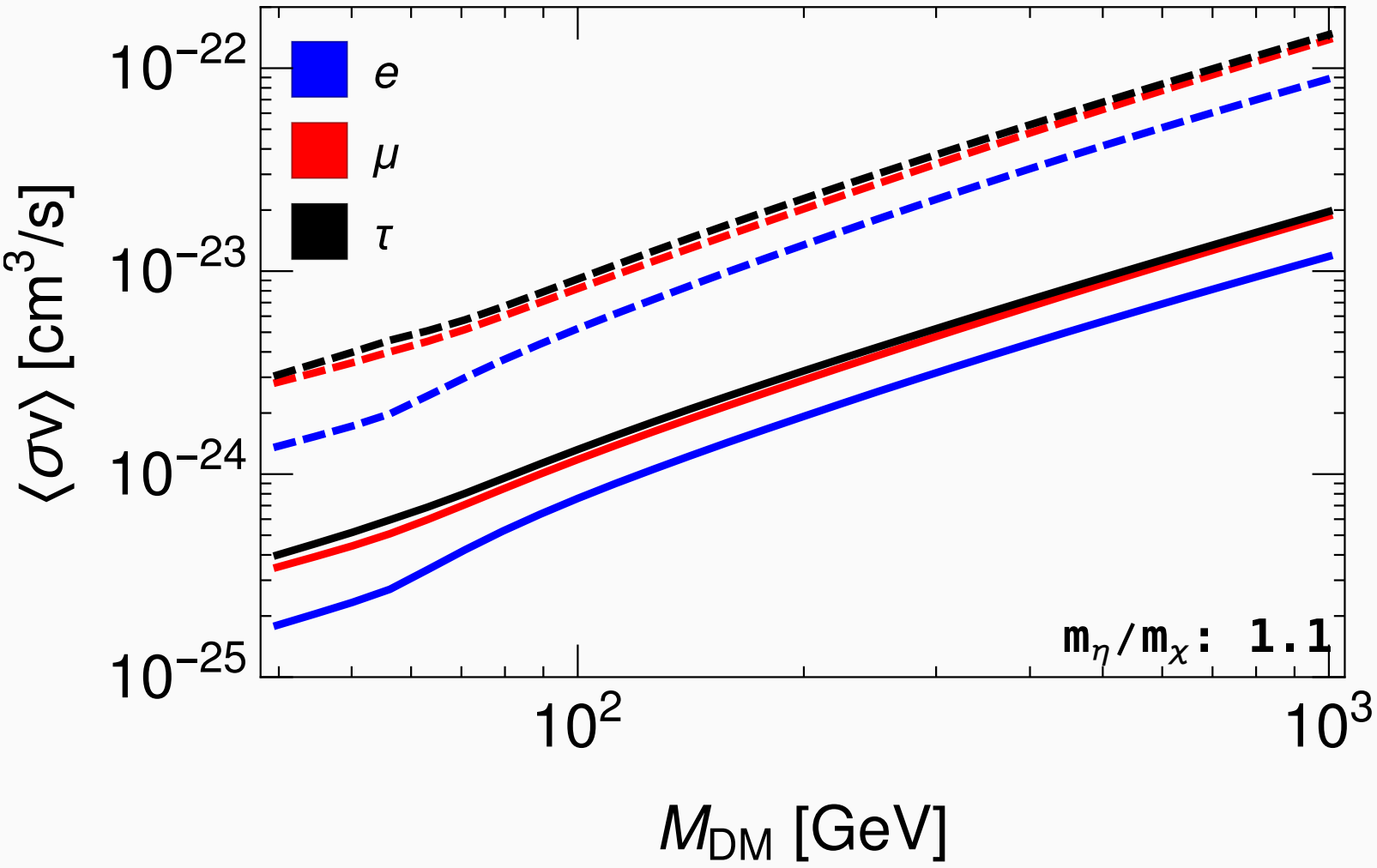
Bremsstrahlung



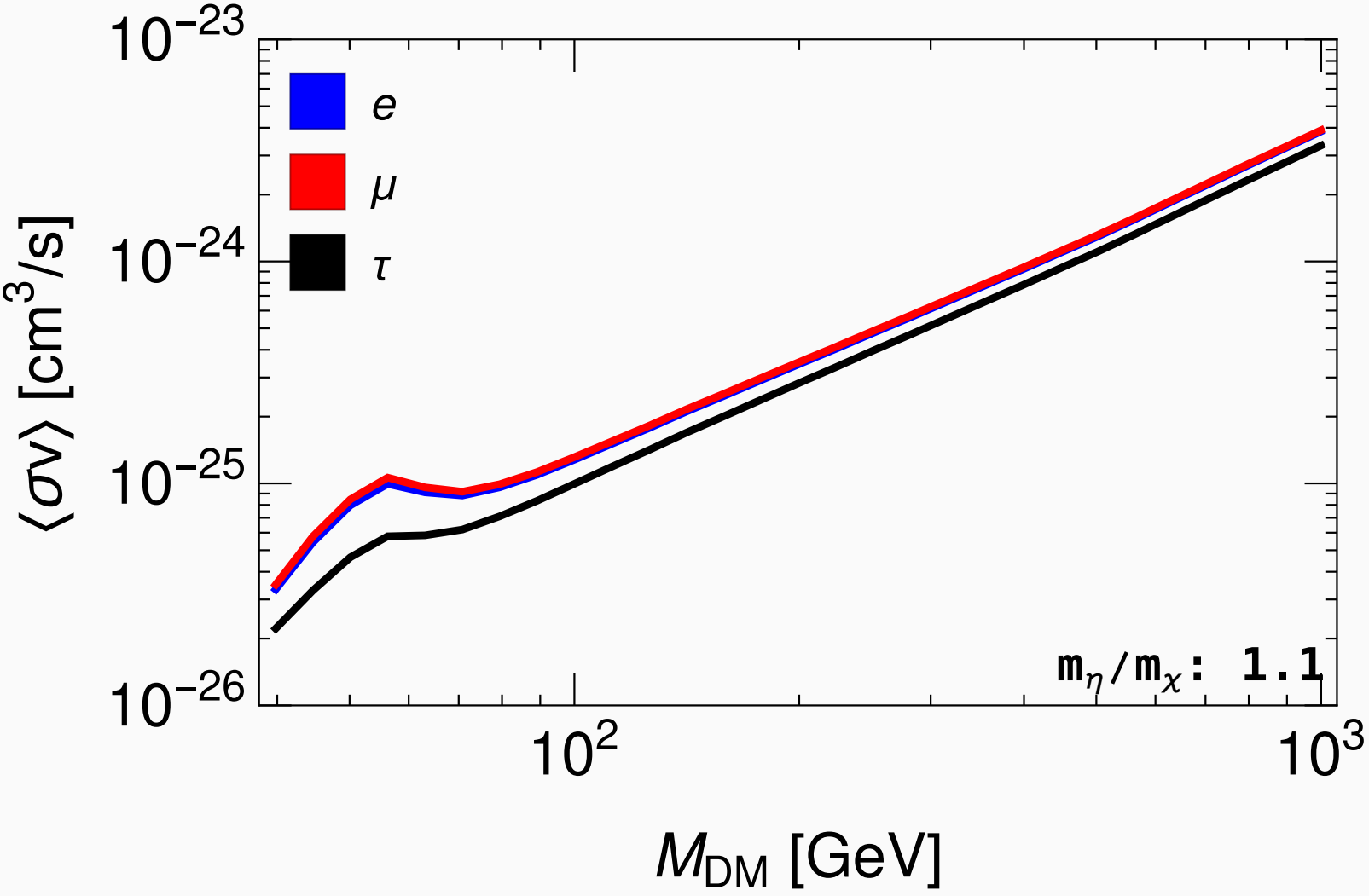
Bremsstrahlung



Bremsstrahlung: 21 cm Constraint



Bremsstrahlung: dSph Constraint



Conclusions

21cm allow for measurements during the classically dark age of the Universe.

21cm measurements can place stringent constraints for decaying dark matter and PBH models.

Bremsstrahlung adds additional constraining power to some models.

Thank You

Supplementary: Absorption Channels*†‡

Hydrogen Ionization

$$I_{\mathrm{i}}(z) = f_{\mathrm{i}}(E, z)\frac{\mathrm{d}E/\mathrm{d}V\mathrm{d}t}{n_{\mathrm{H}}(z)E_{\mathrm{i}}}$$

Lyman-Alpha Excitation

$$I_{\alpha}(z) = f_{\alpha}(E, z)(1 - C)\frac{\mathrm{d}E/\mathrm{d}V\mathrm{d}t}{n_{\mathrm{H}}(z)E_{\alpha}}$$

Gas Heating

$$K_{\mathrm{h}}(z) = f_{\mathrm{h}}(E, z)\frac{\mathrm{d}E/\mathrm{d}V\mathrm{d}t}{n_{\mathrm{H}}(z)}$$

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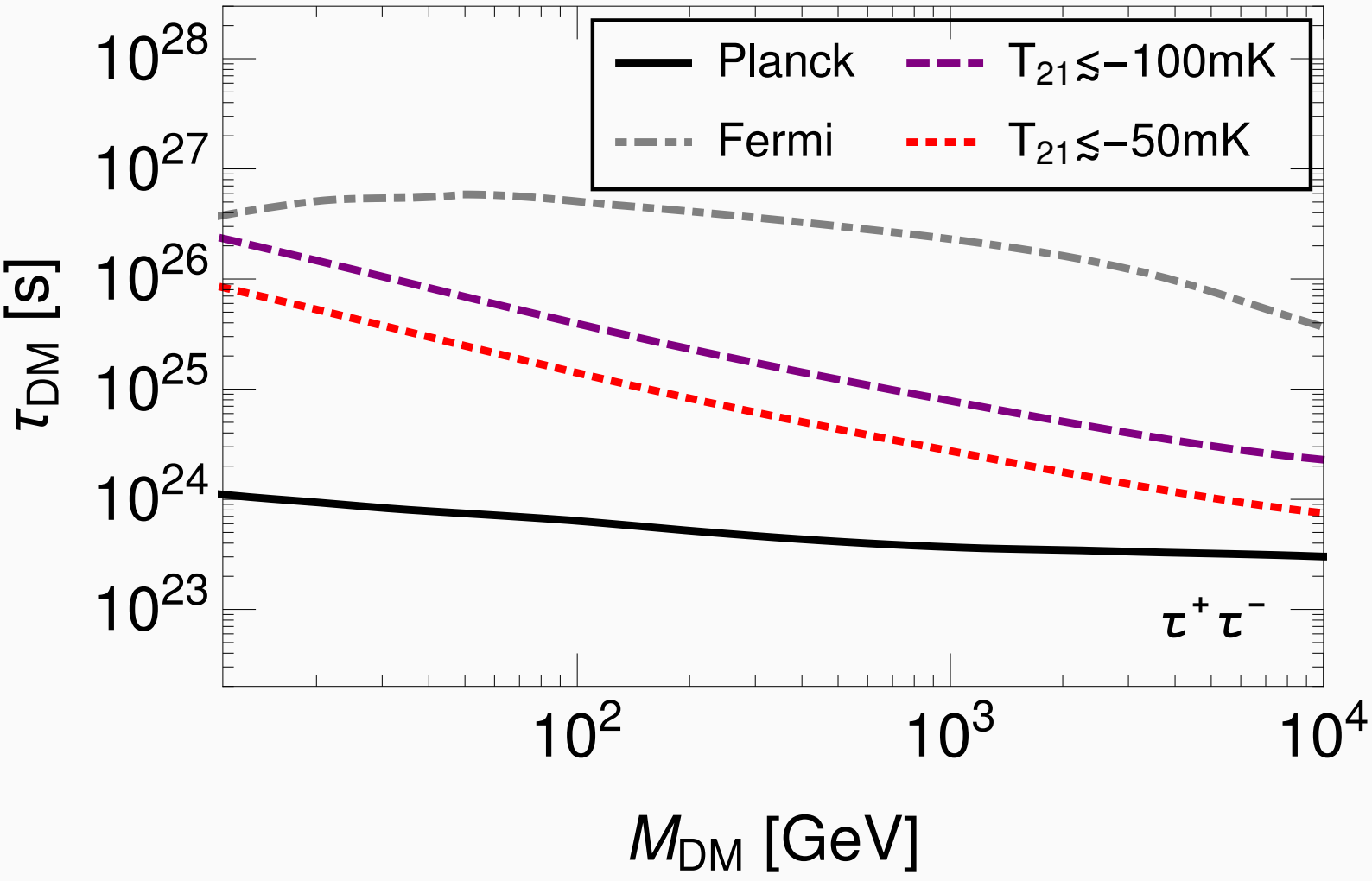
*Liu, Slatyer, and Zavala; arXiv:1604.02457

†Belotsky and Kirillov; arXiv:1409.8601

‡Slatyer; arXiv:1211.0283

Supplementary: Decaying Dark Matter Constraints



Supplementary: Decaying Dark Matter Constraints