MULTI-COMPONENT MULTISCATTER CAPTURE OF DARK MATTER

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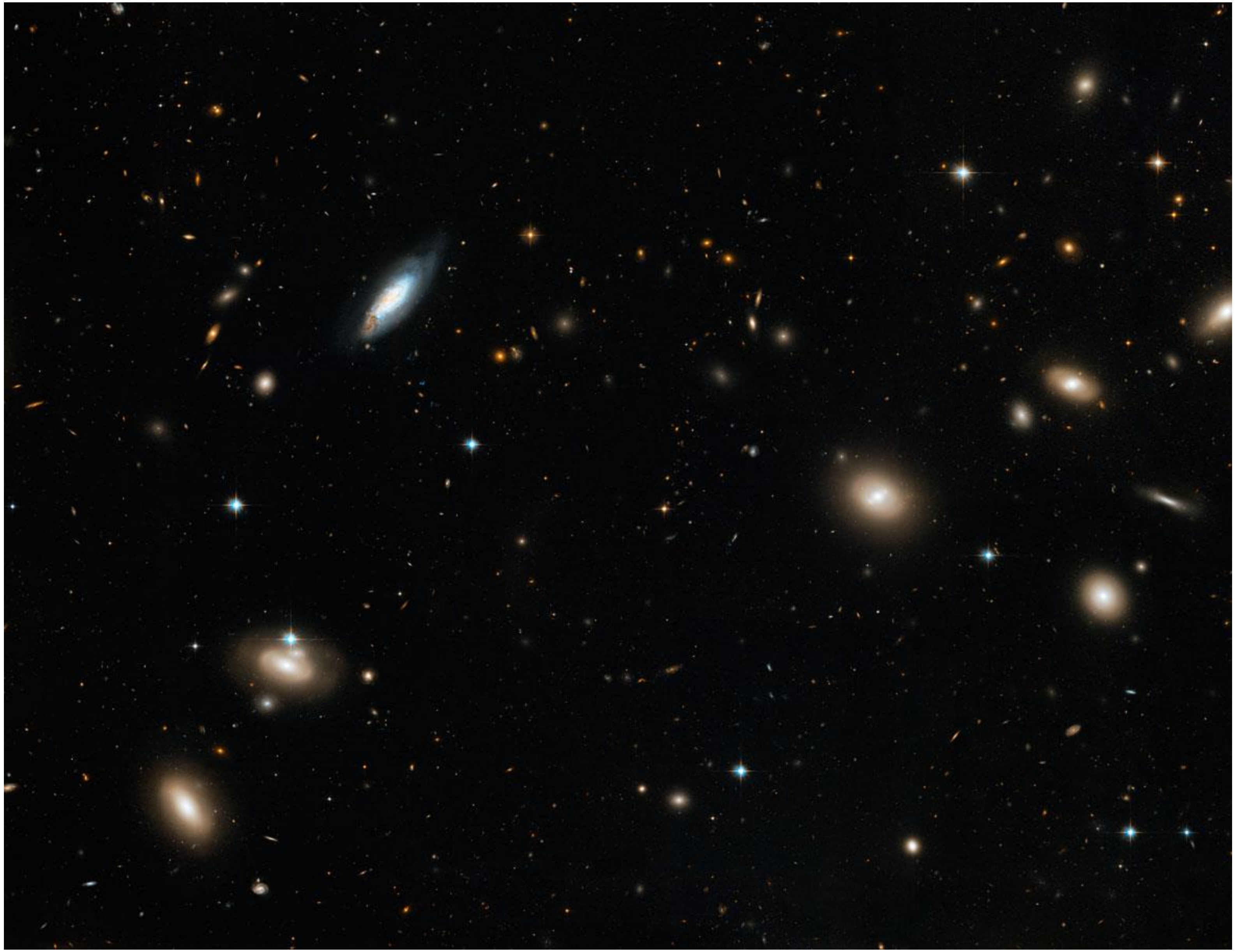
https://arxiv.org/abs/2105.09765

OUTLINE

- Introduction
- Dark Matter Capture
- Helium Capture in Pop. III Stars
- Conclusion

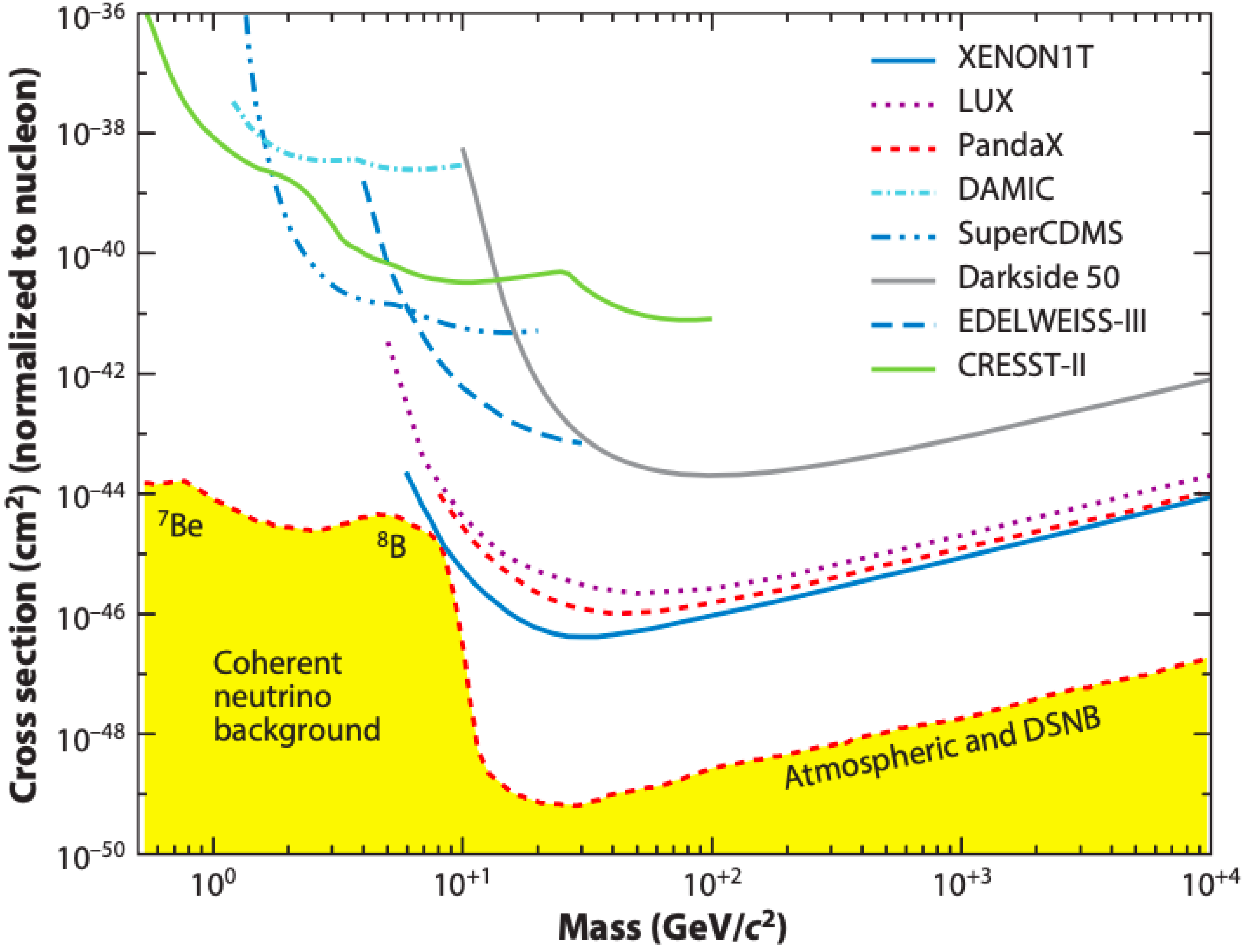
ORIGINS OF DARK MATTER

- Idea was first introduced in 1930s by astronomer Fritz Zwicky
- Coma Cluster - galaxies moved too rapidly



DETECTING DARK MATTER

- Direct detection
  - Approaching Neutrino Floor
- Indirect detection
- Particle creation
- Astrophysical bodies



Click Dutta, Bhaskar, and Louis E. Strigari. "Neutrino Physics with Dark Matter Detectors." Annual Review of Nuclear and Particle Science 69.1 (2019): 137–161.

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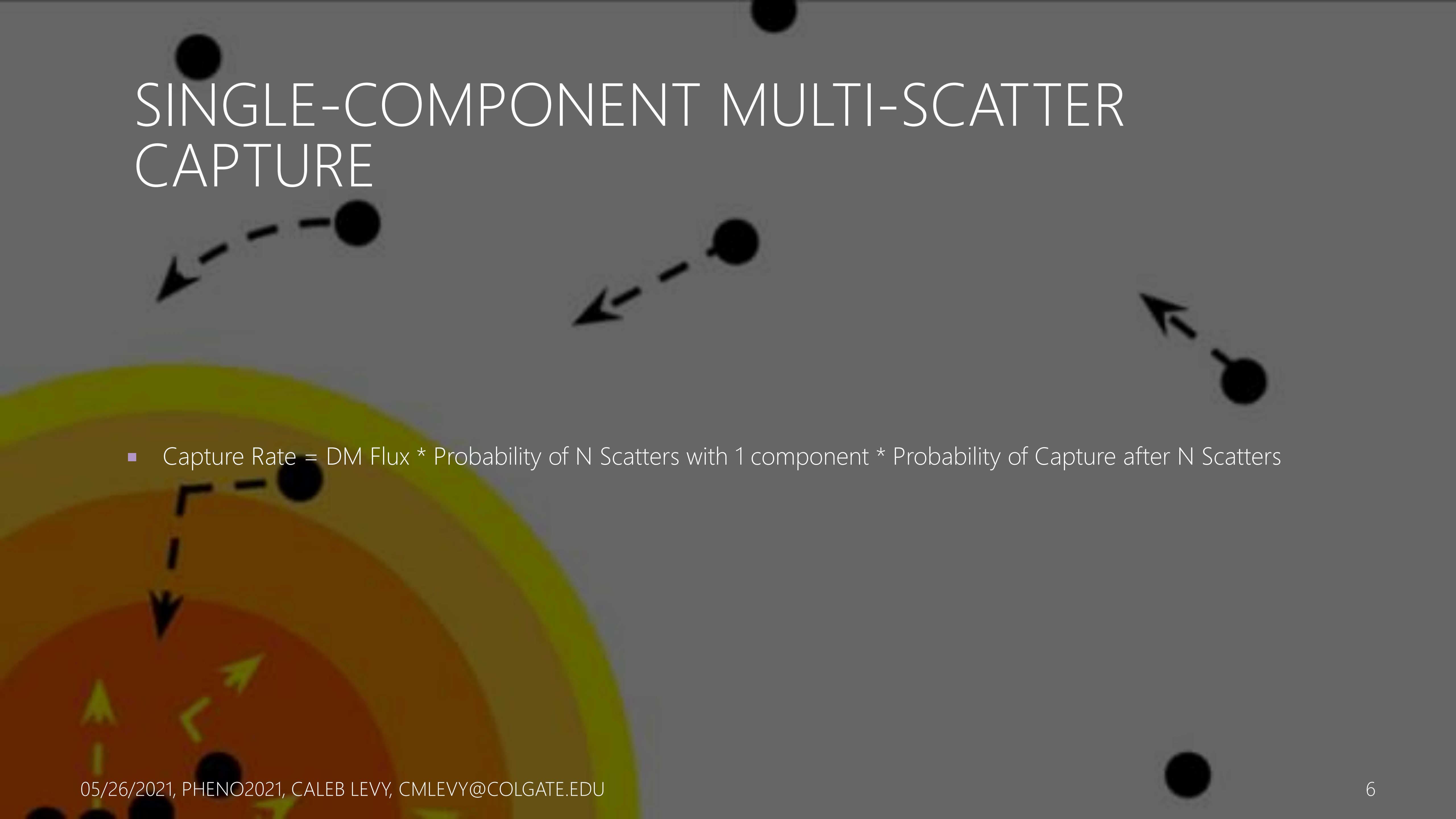
SINGLE-COMPONENT MULTI-SCATTER CAPTURE



- Capture Rate = DM Flux * Probability of N Scatters with 1 component * Probability of Capture after N Scatters

$$C_{tot} = \sum_{N=1}^{\infty} C_N = \sum_{N=1}^{\infty} \underbrace{\pi R_\star^2}_{\text{capture area}} \times \underbrace{n_X \int_0^\infty \frac{f(u)du}{u}(u^2+v_{esc}^2)}_{\text{DM flux}} \times \underbrace{p_N(\tau)}_{\text{prob. for } N \text{ collisions}} \times \underbrace{g_N(u)}_{\text{prob. of capture}}$$

Optical Depth

$$\tau = 2R_\star \times \underbrace{\sigma}_{\text{DM-target cross section}} \times \overbrace{n_T}^{\text{Num. Density of Targets}}$$

SINGLE-COMPONENT MULTI-SCATTER CAPTURE

J. Bramante, A. Delgado, and A. Martin, Phys. Rev. D 96, 063002 (2017), arXiv:1703.04043 [hep-ph].

$$p_N(\tau) = \frac{2}{\tau^2}\left(N + 1 - \frac{\Gamma(N+2,\tau)}{N!}\right)$$

$$g_N(w) = \Theta\left(v_{esc}(1 - \langle z_i\rangle\beta_+)^{-N/2} - w\right)$$

SINGLE-COMPONENT MULTI-SCATTER CAPTURE

SINGLE TO 2-COMPONENT

Single-Component

$$C_{tot} = \sum_{N=1}^{\infty} C_N = \sum_{N=1}^{\infty} \underbrace{\pi R_\star^2}_{\text{capture area}} \times \underbrace{n_X \int_0^\infty \frac{f(u)du}{u}(u^2 + v_{esc}^2)}_{\text{DM flux}} \times \underbrace{p_N(\tau)}_{\text{prob. for } N \text{ collisions}} \times \underbrace{g_N(u)}_{\text{prob. of capture}}$$

N = i + j

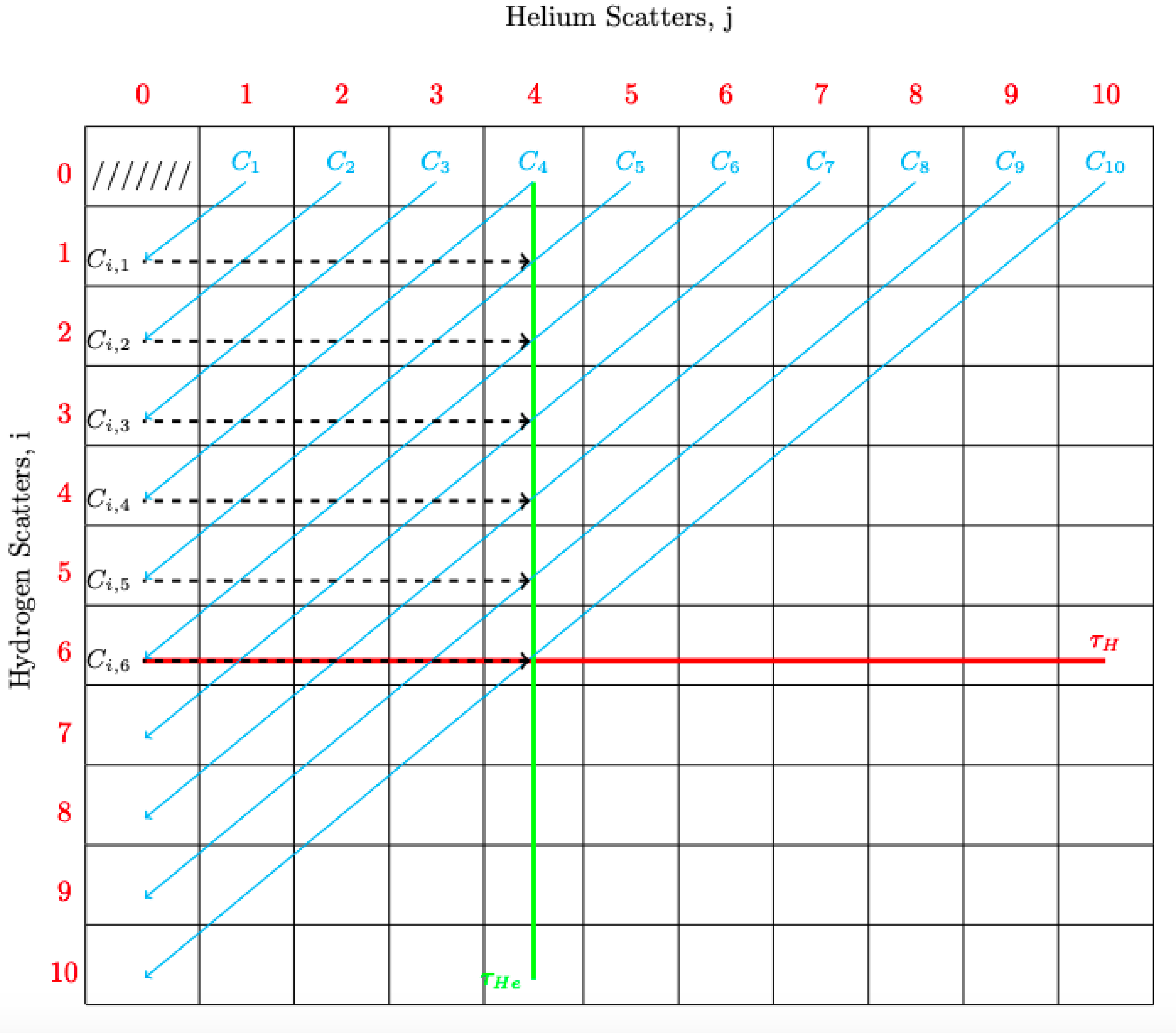
Two-Component

$$C_{tot} = \sum_{N=1}^{\infty} C_N = \sum_{N=1}^{\infty} \sum_{i=0}^{N} \underbrace{\pi R^2}_{\text{Capture Area}} \times \underbrace{n_X \int_0^\infty \frac{f(u)du}{u}(u^2 + v_{esc}^2)}_{\text{DM Flux}} \times \underbrace{p_i(\tau_A)p_j(\tau_B)}_{\text{2-Comp Prob. of Collisions}} \times \underbrace{g_{ij}(u)}_{\text{2-Comp Prob. of Capture}}$$

$$C_{tot} = \sum_{i=0}^{\infty} \sum_{j=0}^{\infty} C_{ij}$$

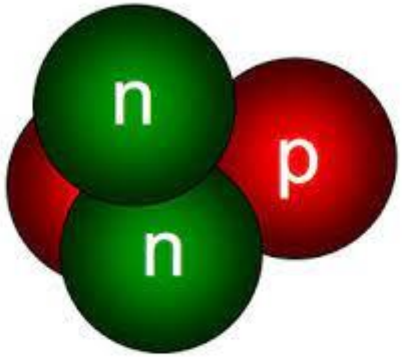
$$C_{ij} = \pi R_\star^2 n_X \int_0^\infty \frac{f(u)du}{u} (u^2 + v_{esc}^2) p_i(\tau_A) p_j(\tau_B) g_{ij}(u)$$

ALTERNATE FORM

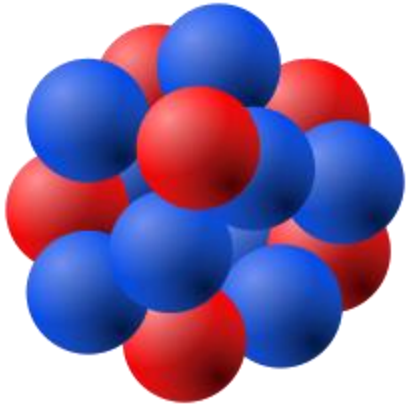


TWO TECHNIQUES FOR TOTAL CAPTURE ESTIMATIONS

GENERALIZED MULTI-COMPONENT CAPTURE



Component I, α scatters



Component II, β scatters

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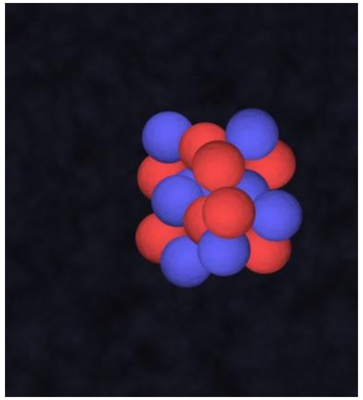

Component n, ω scatters

$$C(\alpha,\beta,\gamma,...,\omega) = \pi R^2 p_\alpha(\tau_I) p_\beta(\tau_{II}) \times ... \times p_\omega(\tau_n) \int_{v_{esc}}^{\infty} dw \frac{f(u)}{u^2} w^3 g(w,\alpha,\beta,\gamma,...,\omega).$$

$$C_{tot} = \sum_{\alpha=0}^{\infty} \sum_{\beta=0}^{\infty} ... \sum_{\omega=0}^{\infty} C(\alpha,\beta,\dots,\omega)$$

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$$\sigma \equiv \sigma_H = \sigma_0^{SI-p},$$

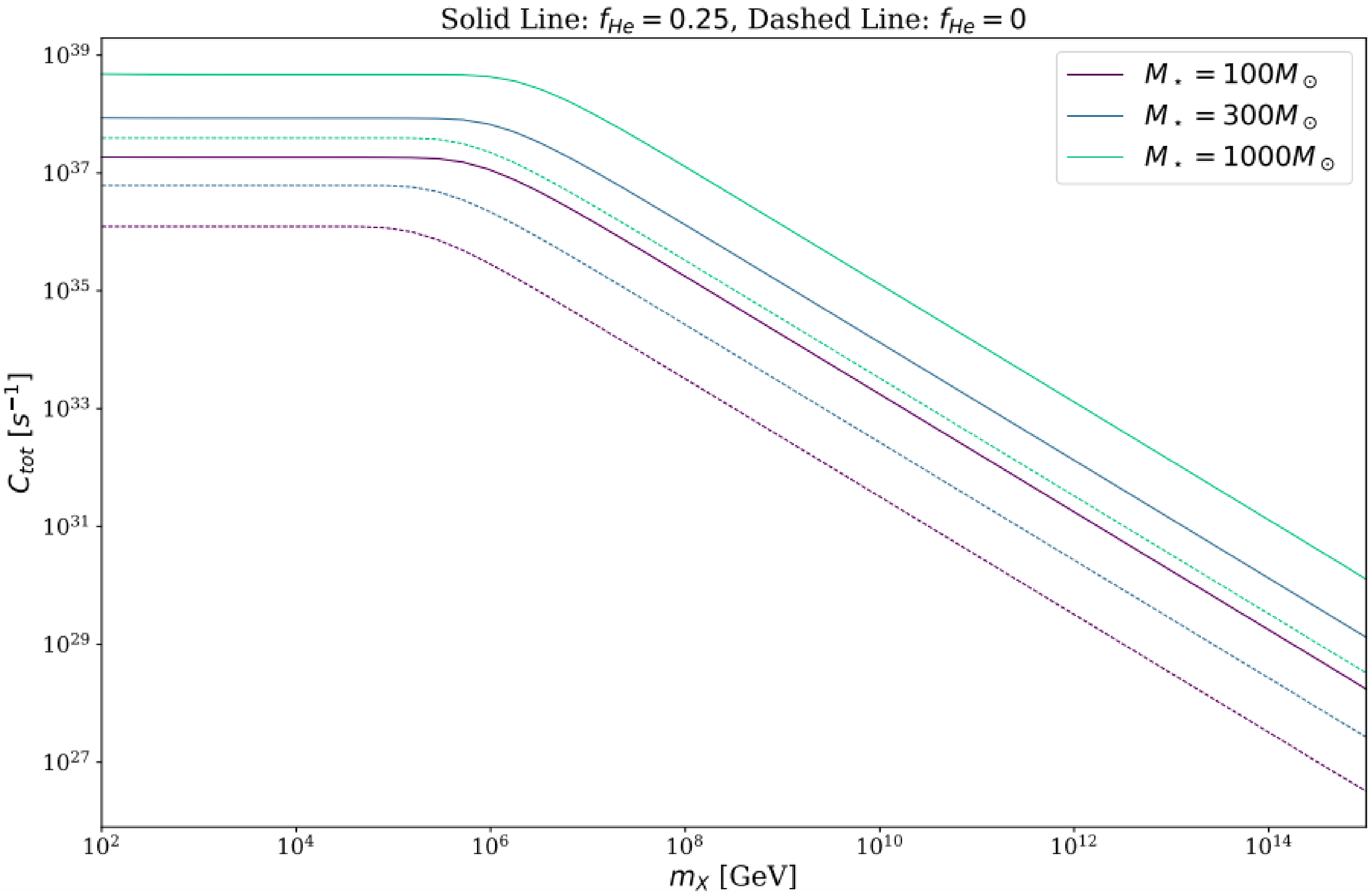
$$\sigma_{He} = 4^4 \sigma_0^{SI-p} \langle F^2(E_R) \rangle,$$

$$\tau_H = 10^{-5} \left(\frac{\sigma_H}{1.26 \times 10^{-40}} \right) \left(\frac{M_\star}{M_\odot} \right) \left(\frac{R_\odot}{R_\star} \right)^2 \left(\frac{f_H}{0.75} \right),$$

$$\tau_{He} = 10^{-3} \left(\frac{\sigma_H}{1.26 \times 10^{-40}} \right) \left(\frac{M_\star}{M_\odot} \right) \left(\frac{R_\odot}{R_\star} \right)^2 \left(\frac{f_{He}}{0.25} \right) \left(\frac{\langle F^2(E_R) \rangle}{0.99} \right).$$

TALE OF TWO TAUS

ENHANCED CAPTURE



- Cross section taken from XENON1T SI bounds
- Ambient DM density taken as 10^14 GeV/cm^-3

$$\dot{N} = C - \Gamma_A$$

$$L_{DM} = f\Gamma_A m_X = fCm_X$$

DM-DM ANNIHILATION: ADDITIONAL LUMINOSITY

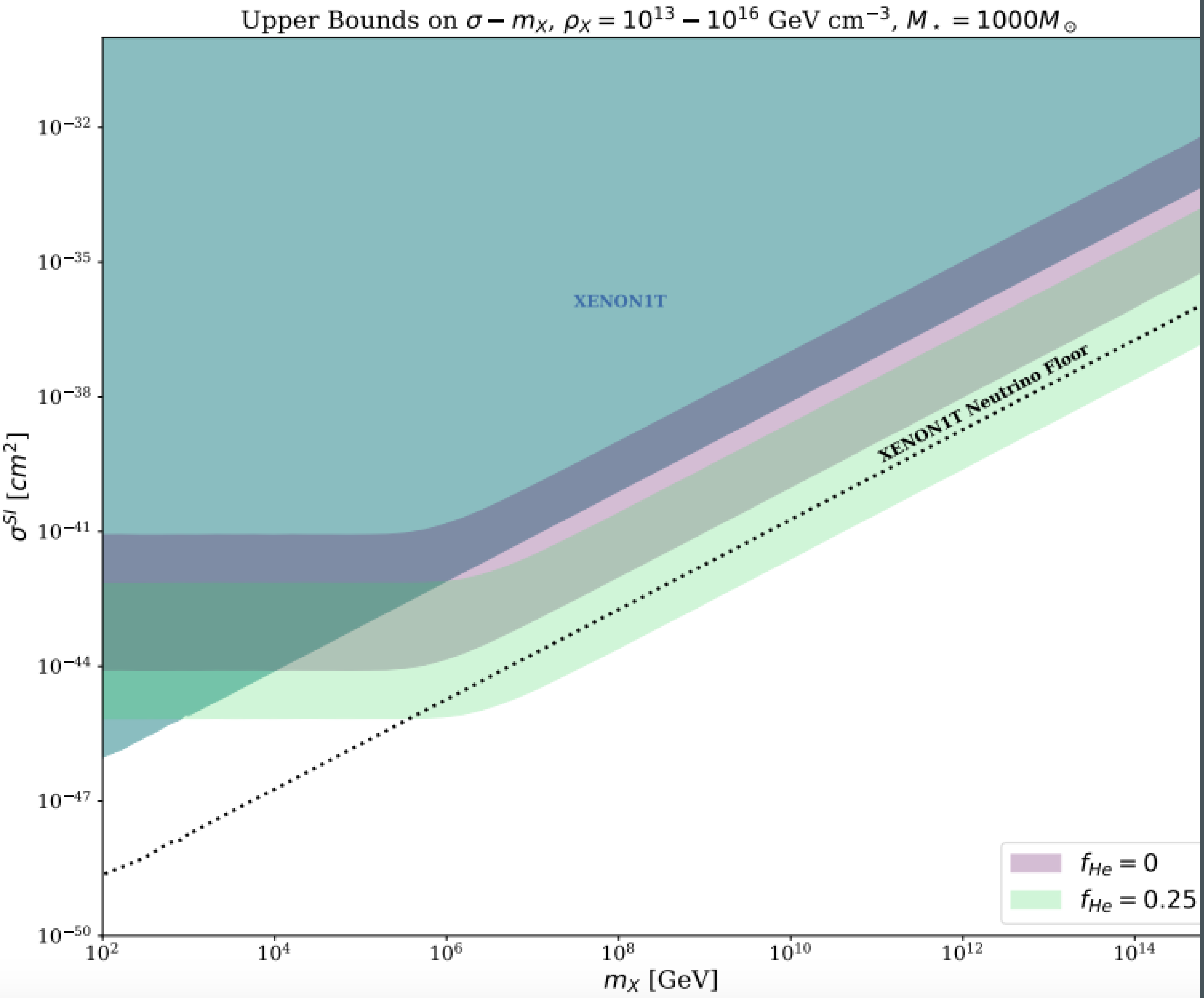
$$L_{DM}(M_\star,\ \text{DM params.}) \leq L_{edd}(M_\star) - L_{nuc}(M_\star)$$

$$C_{tot} \leq \frac{L_{Edd} - L_{Nuc}}{f m_X}$$

PROBING BELOW THE NEUTRINO FLOOR

- What happens if we detect a Pop. III star?
- We can place bounds on DM-nucleon cross section and DM mass parameter space

PROBING BELOW THE NEUTRINO FLOOR



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MAIN TAKEAWAYS

New formalism for multi-component DM capture

Enhanced DM capture and luminosity in Pop. III stars

Abiltiy to constrain DM cross section below the neutrino floor

FUTURE WORK

01

Apply formalism to other multi-component objects, such as white dwarves, exoplanets

02

Relax assumptions of even distributions of nuclei

03

Utilize stellar evolution code to directly implement multi-component capture

QUESTIONS?