King's College London

Listening for ultra-heavy DM with underwater acoustic detectors

Damon Cleaver, Christopher McCabe and Ciaran A.J. O'Hare

YTF 2024, 19/12/24

What is Dark Matter?

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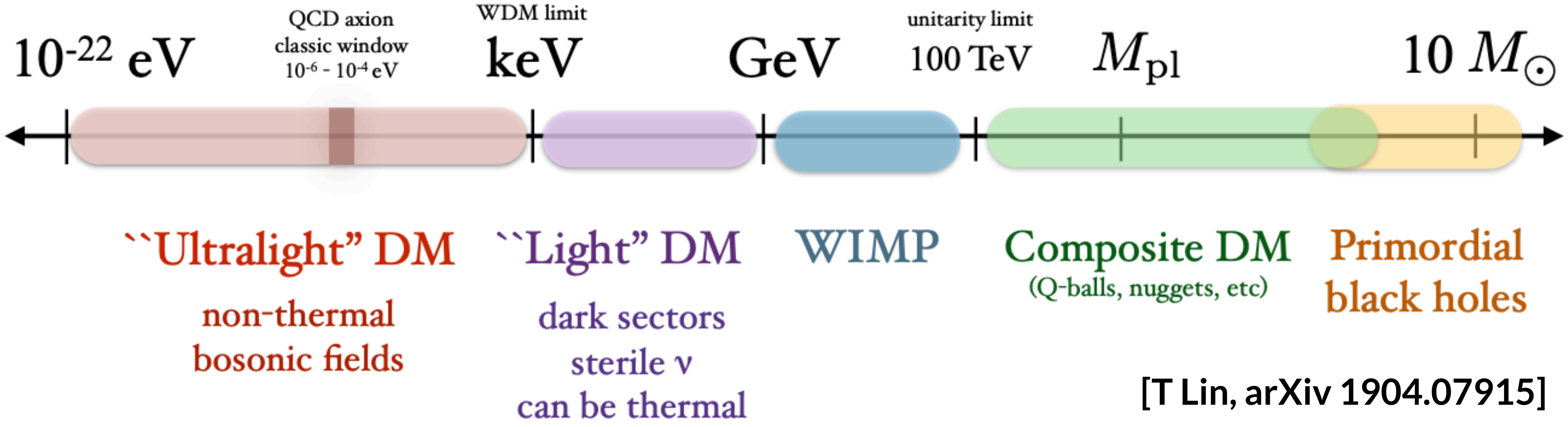

[T Lin, arXiv 1904.07915]

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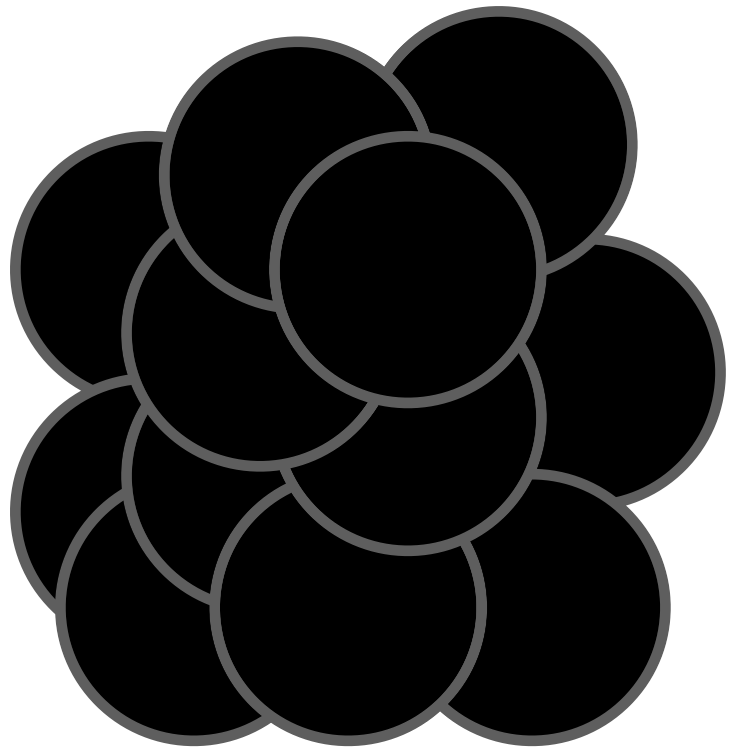

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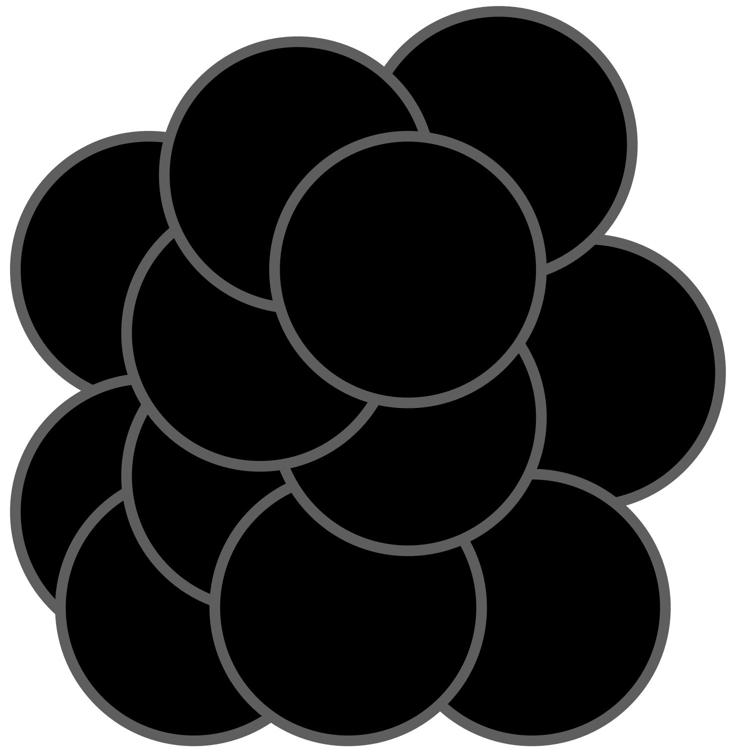

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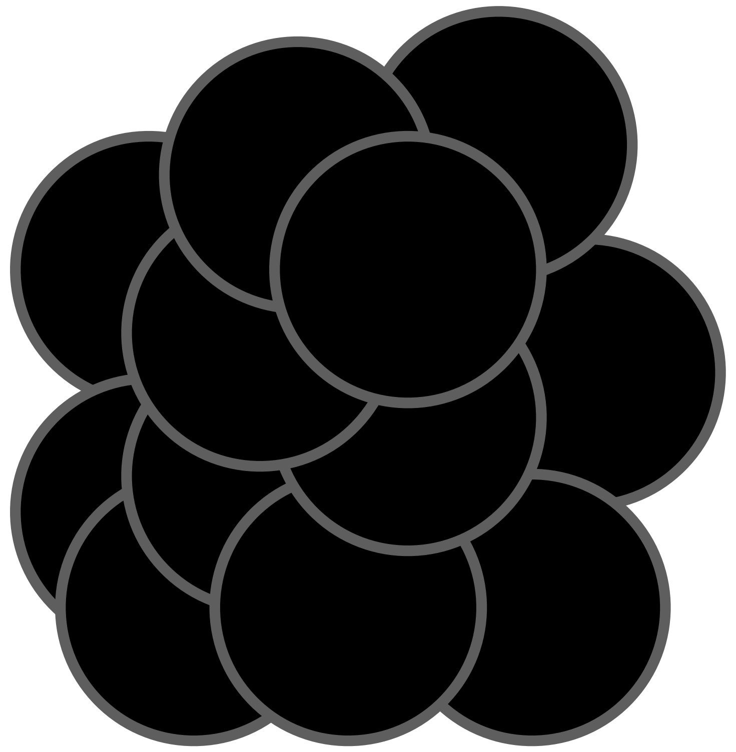

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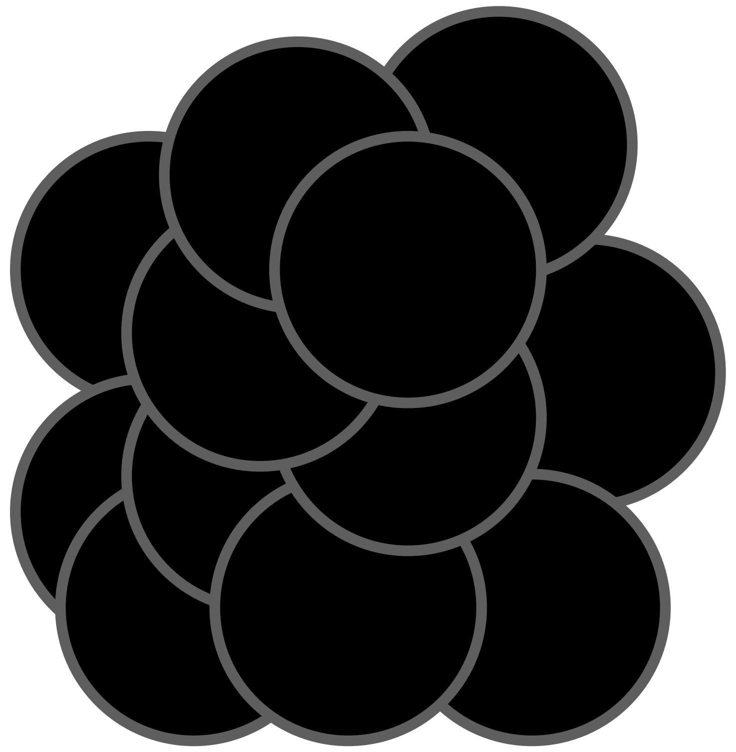

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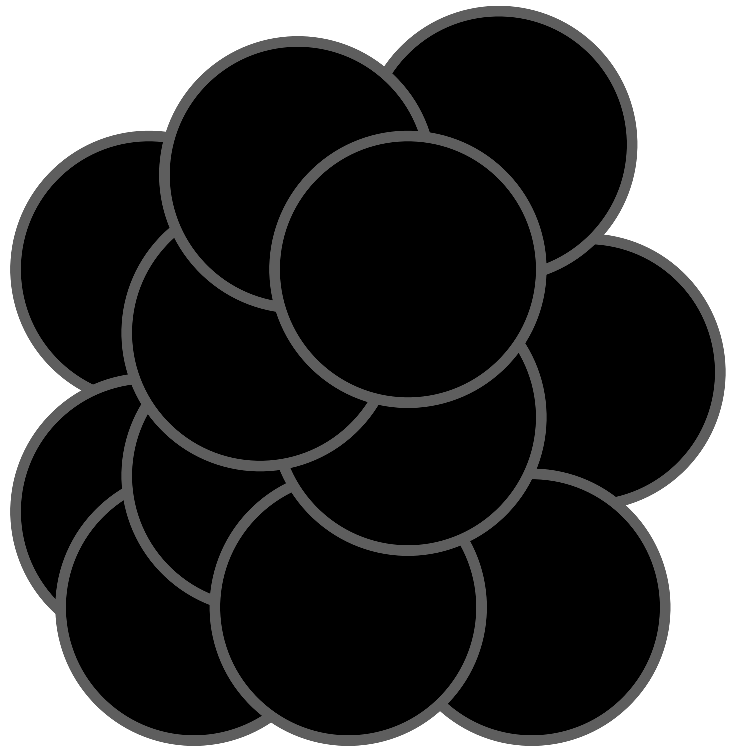

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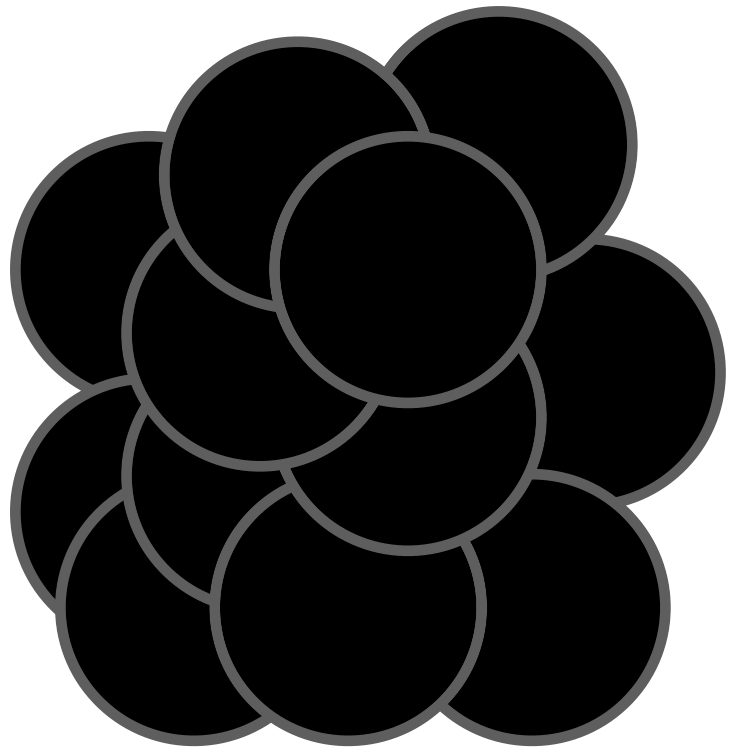

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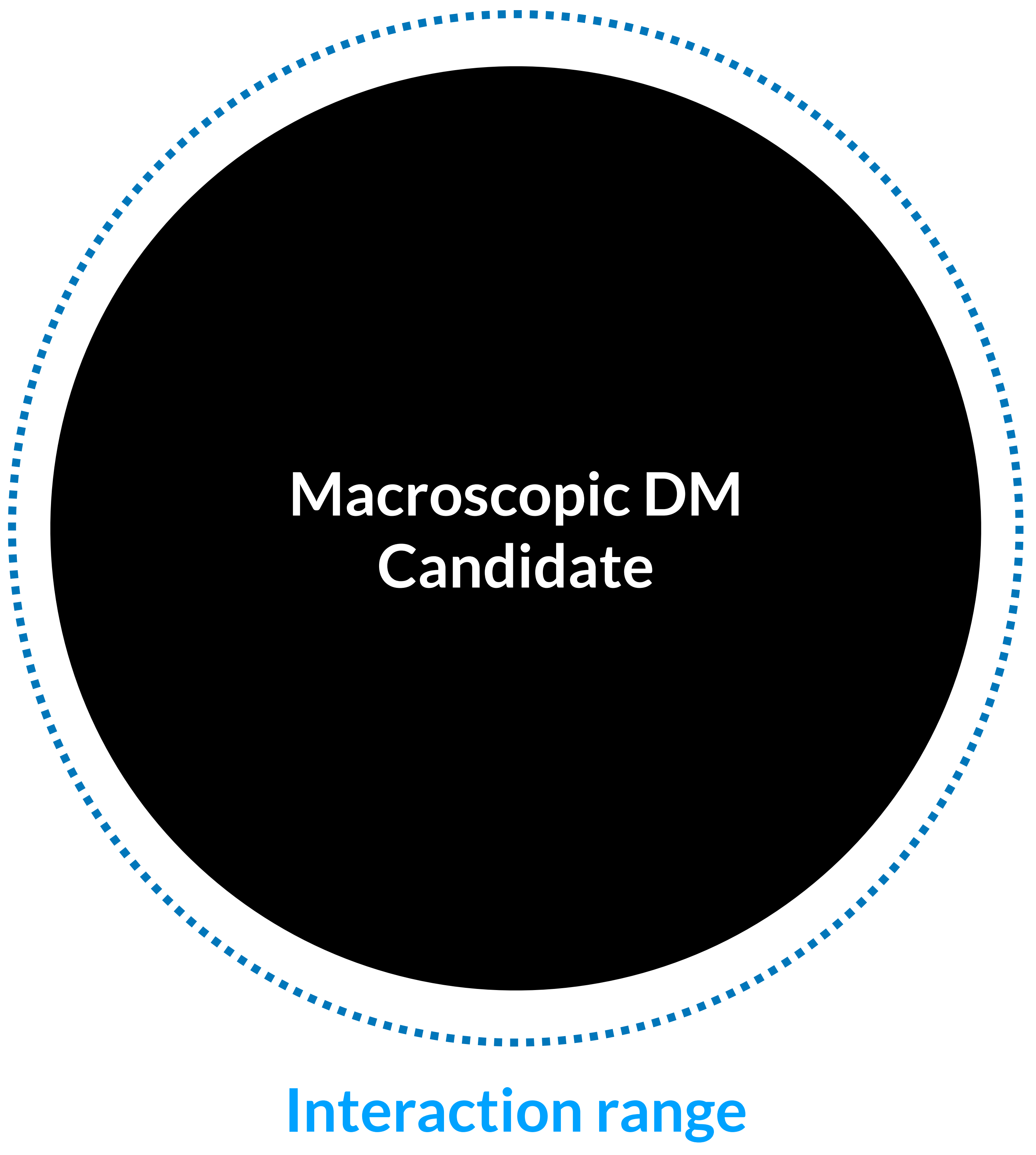

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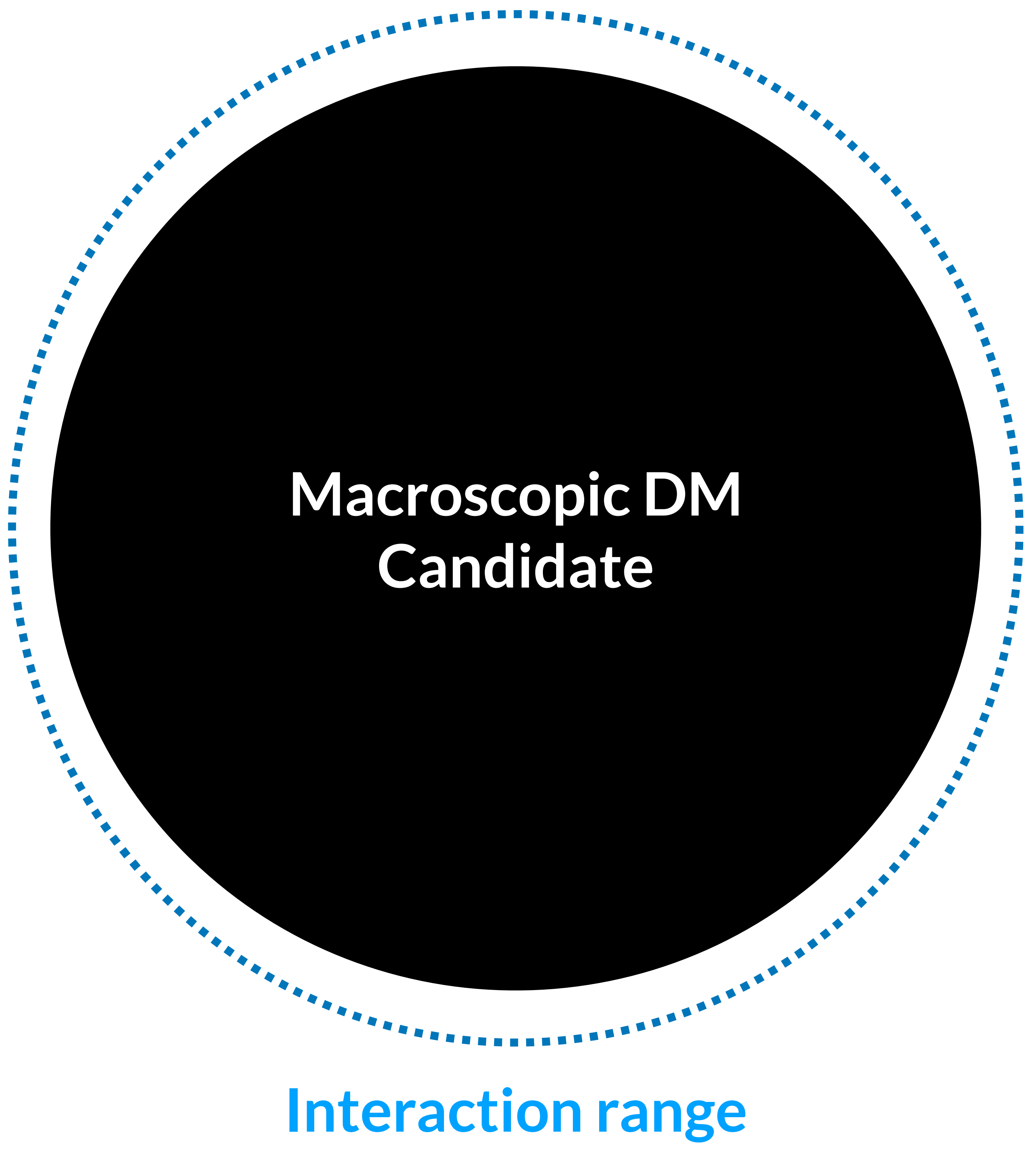

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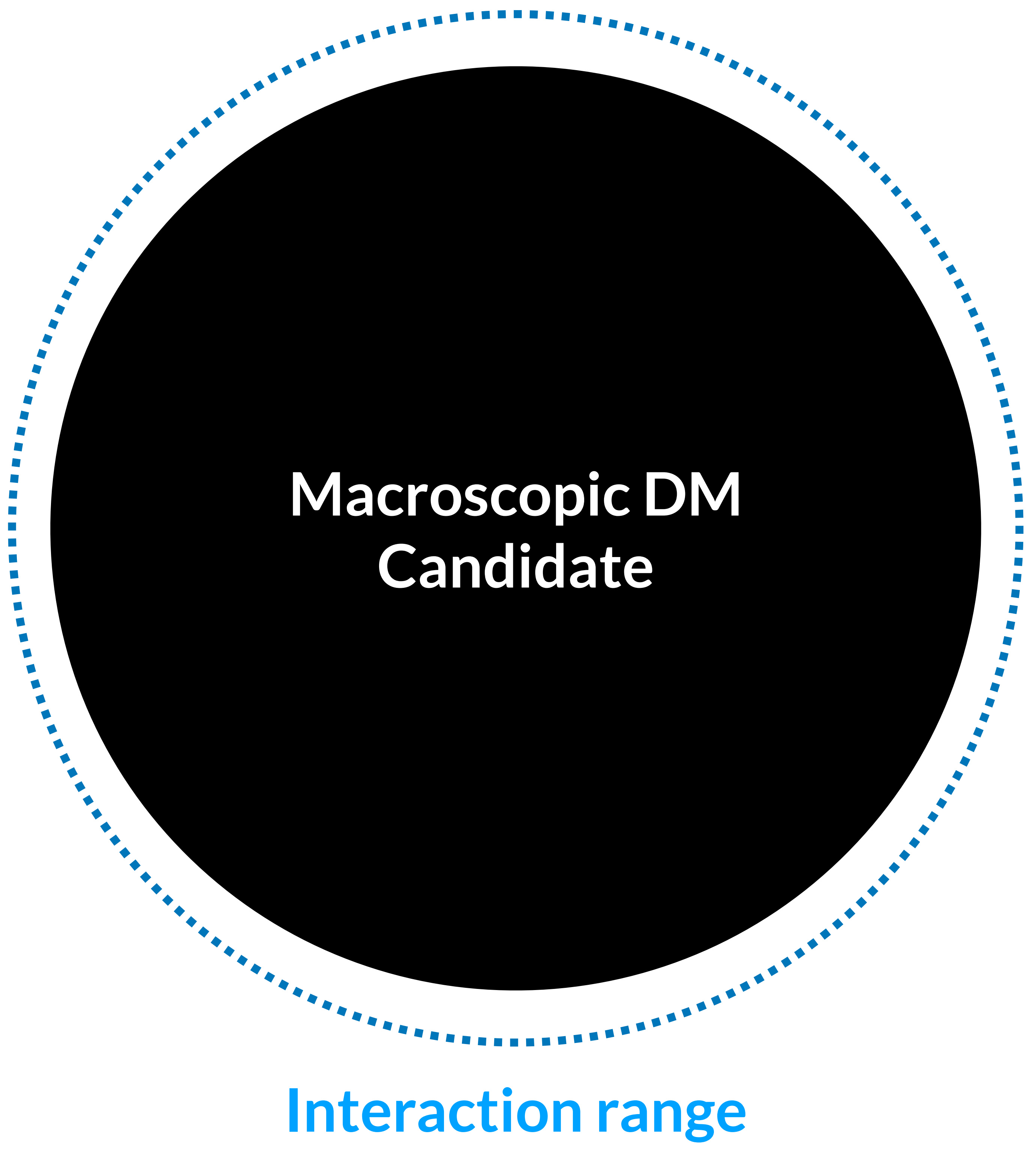

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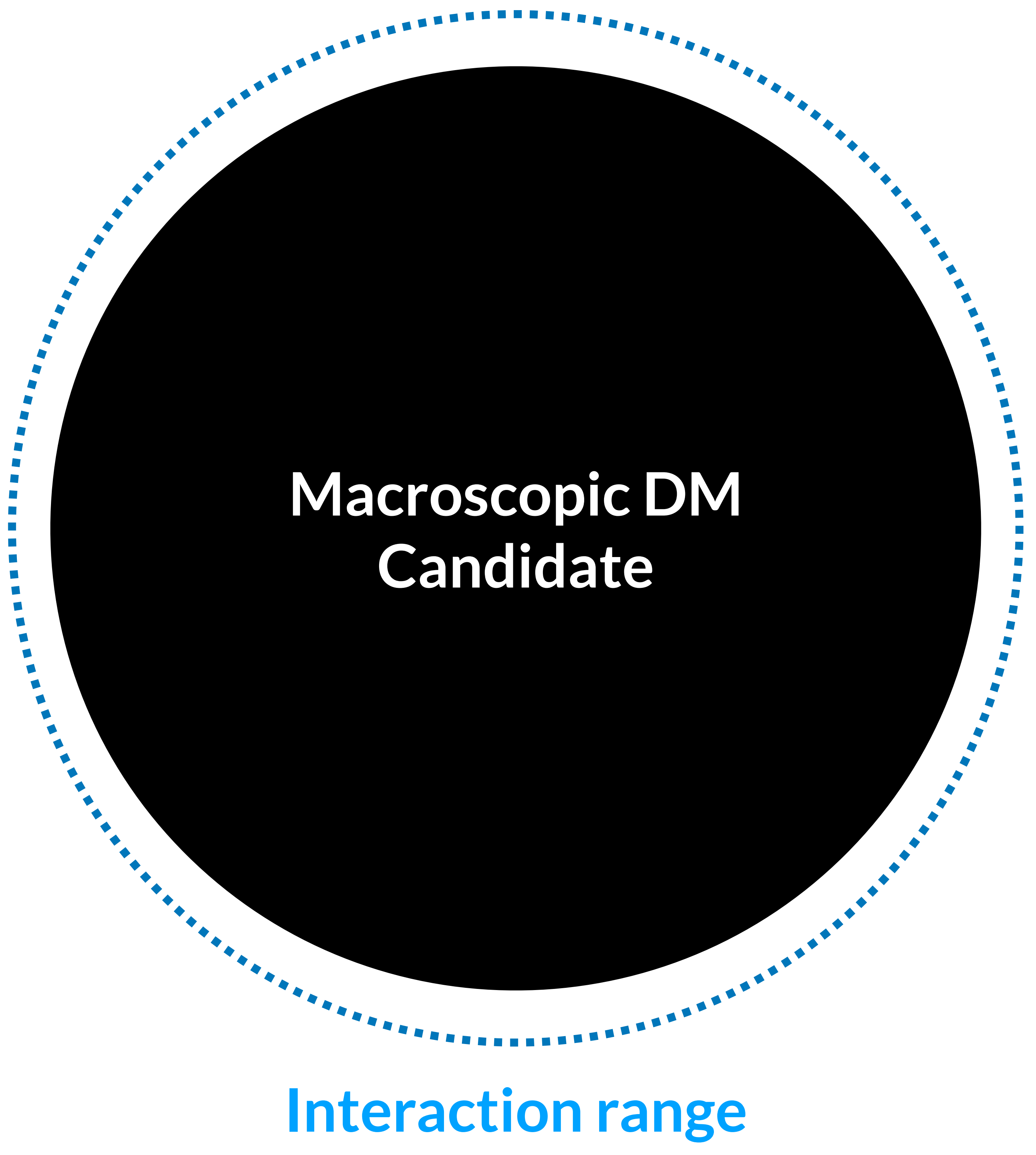

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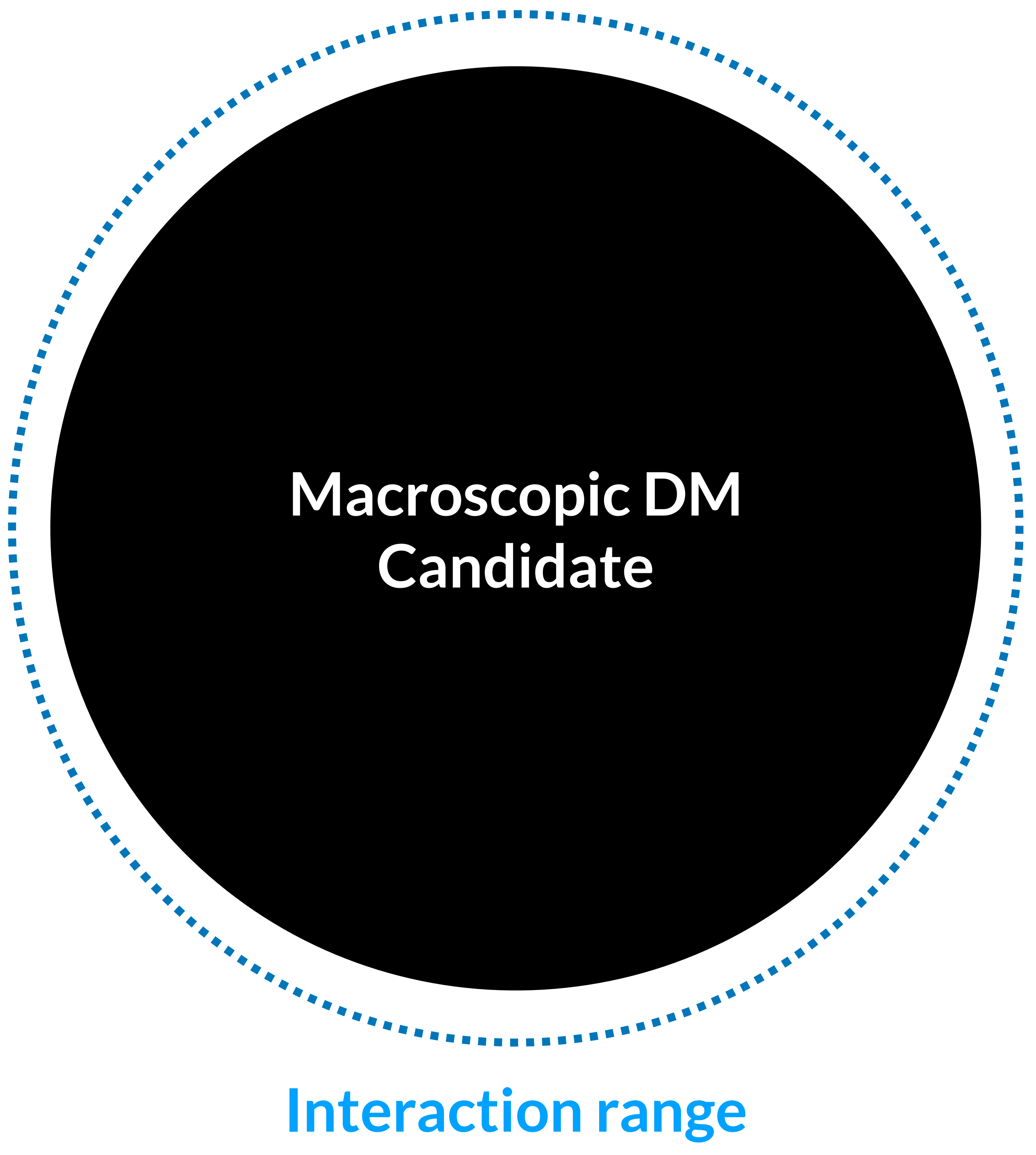

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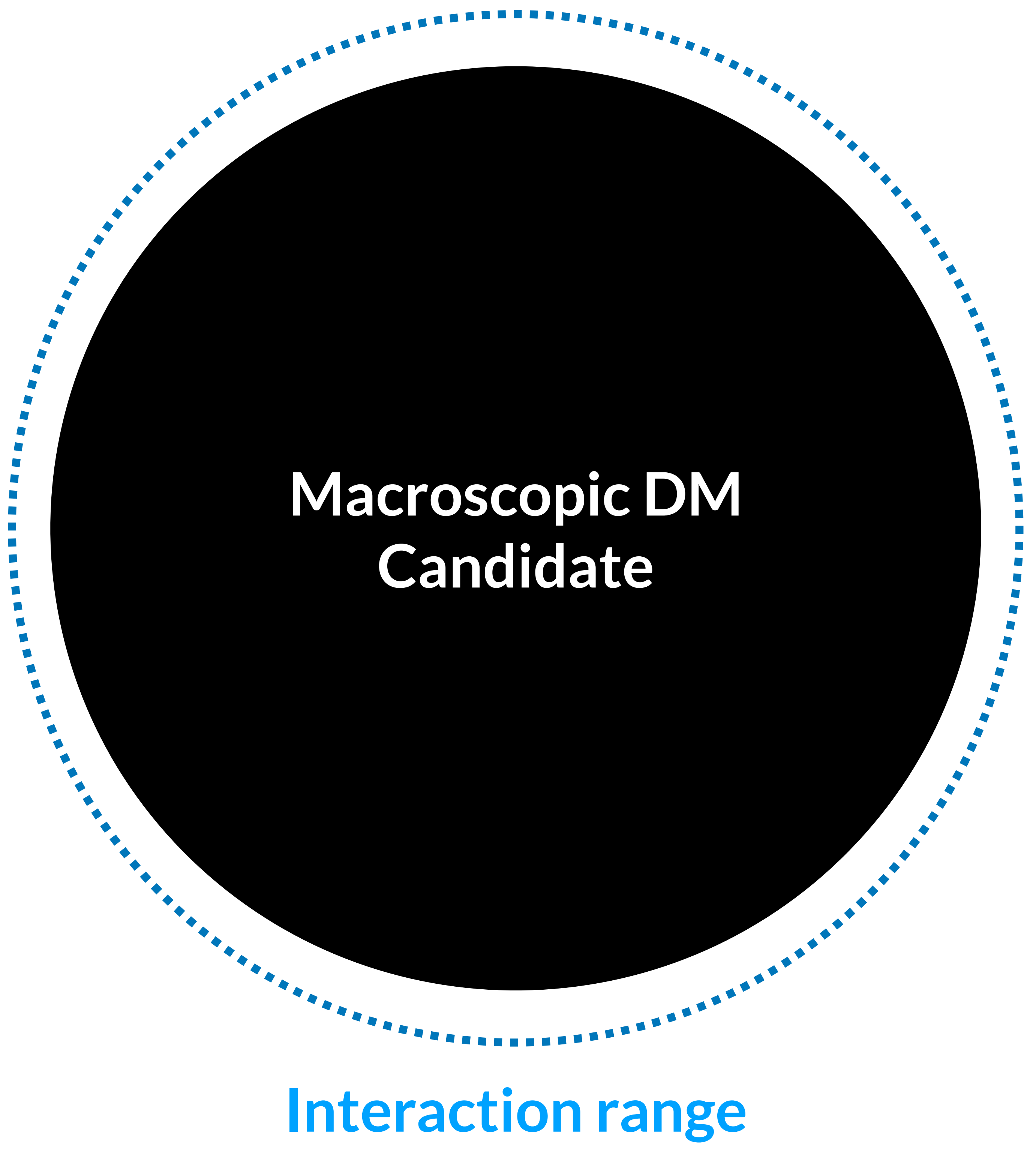

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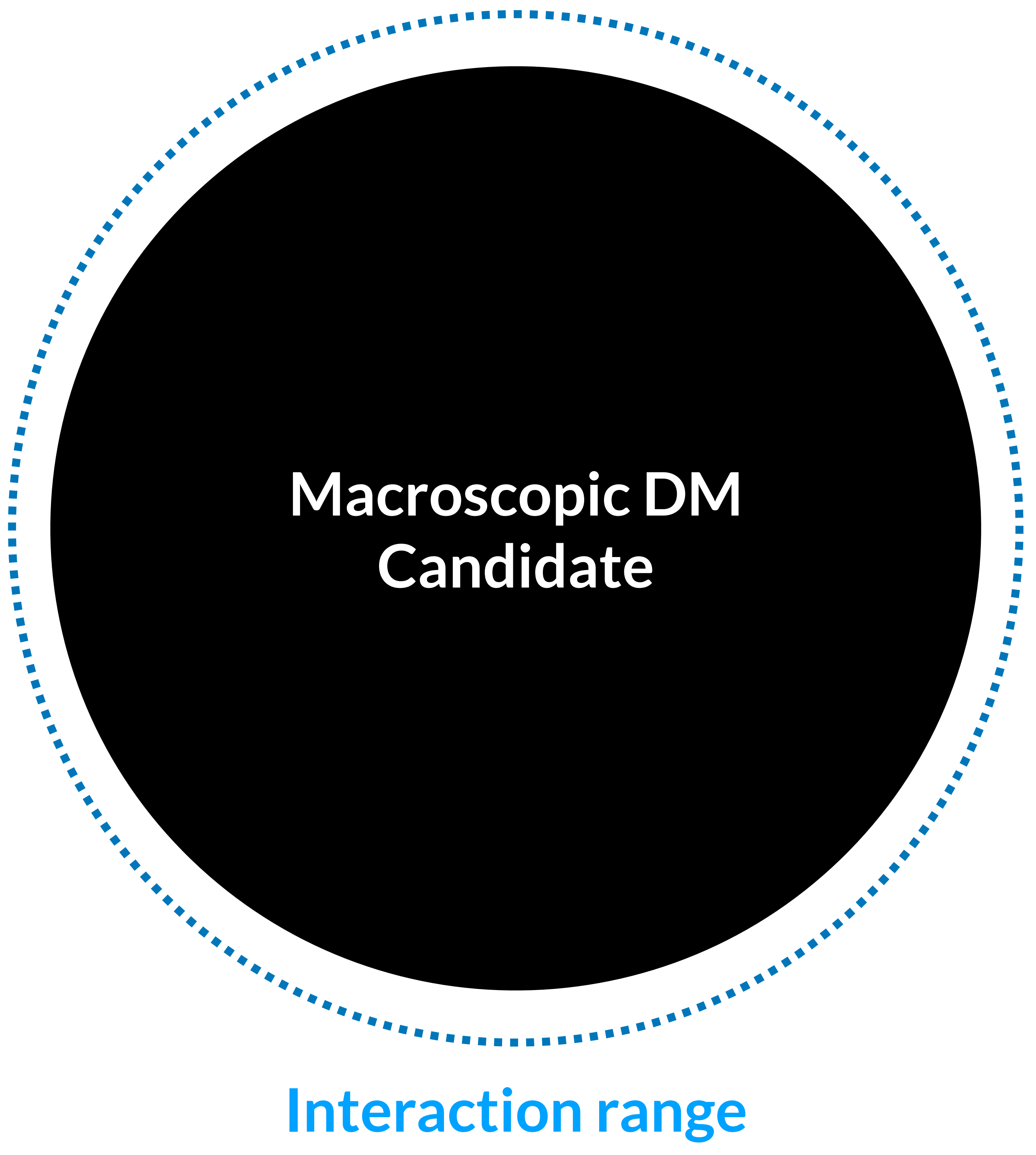

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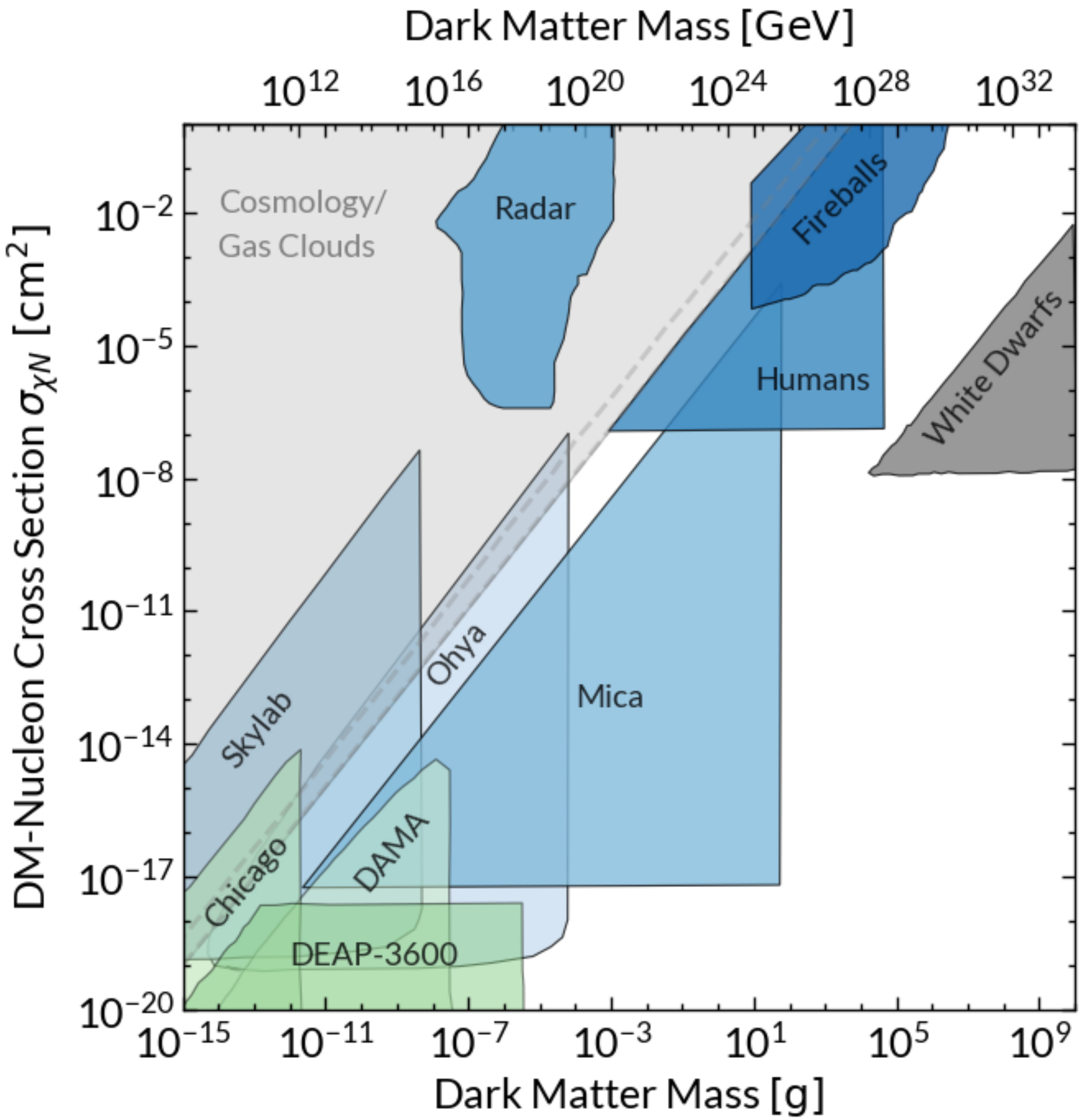

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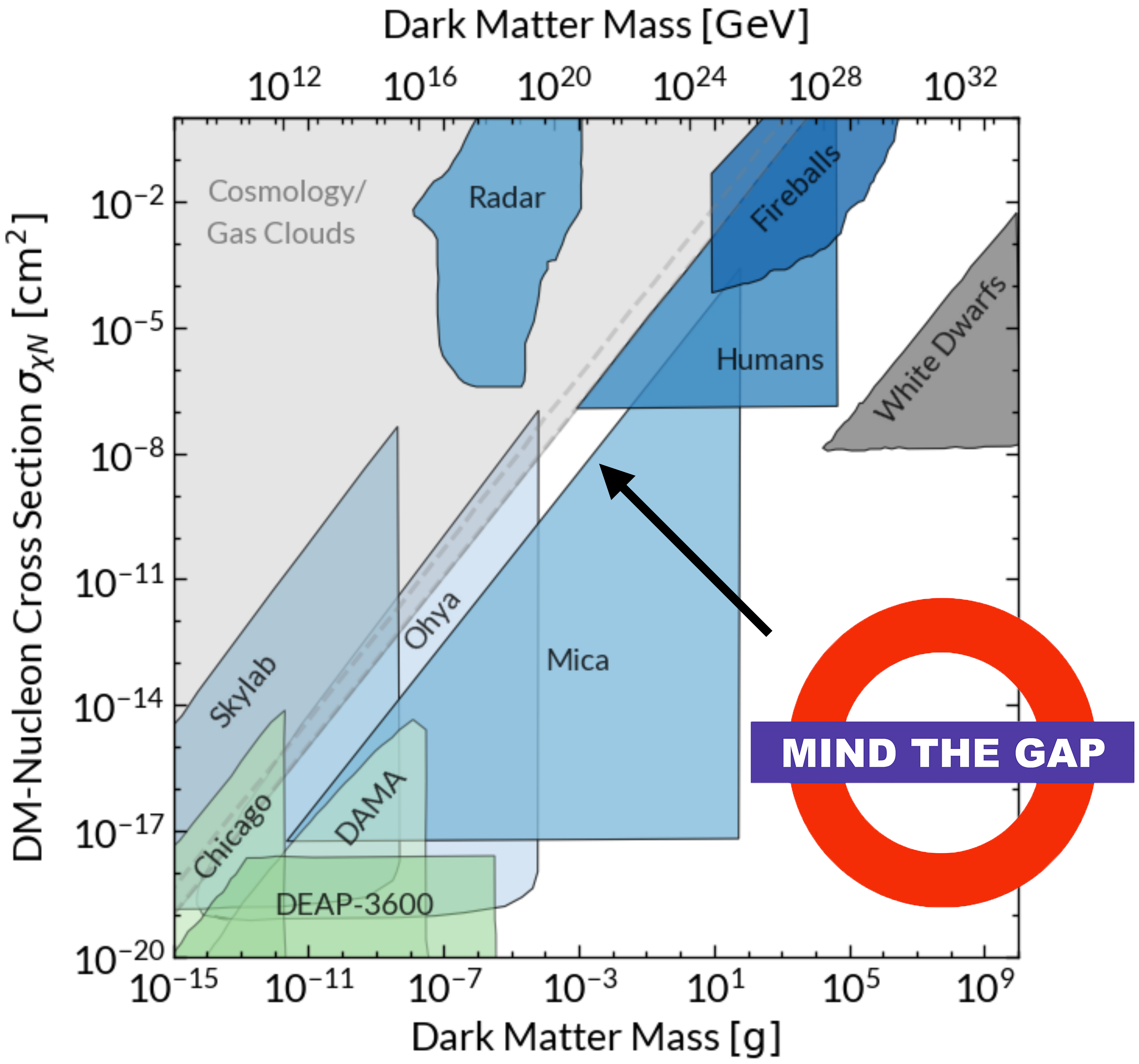

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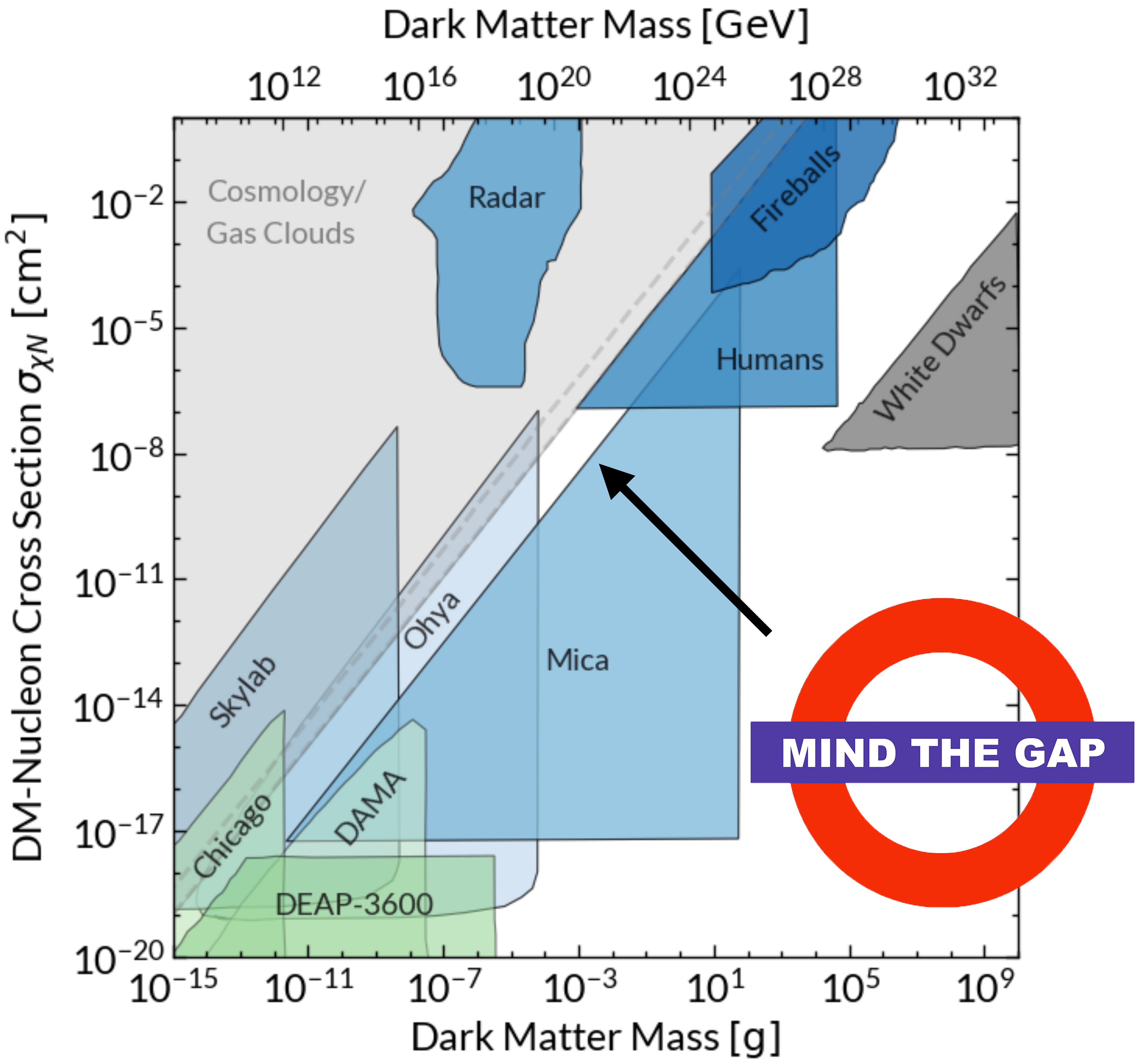

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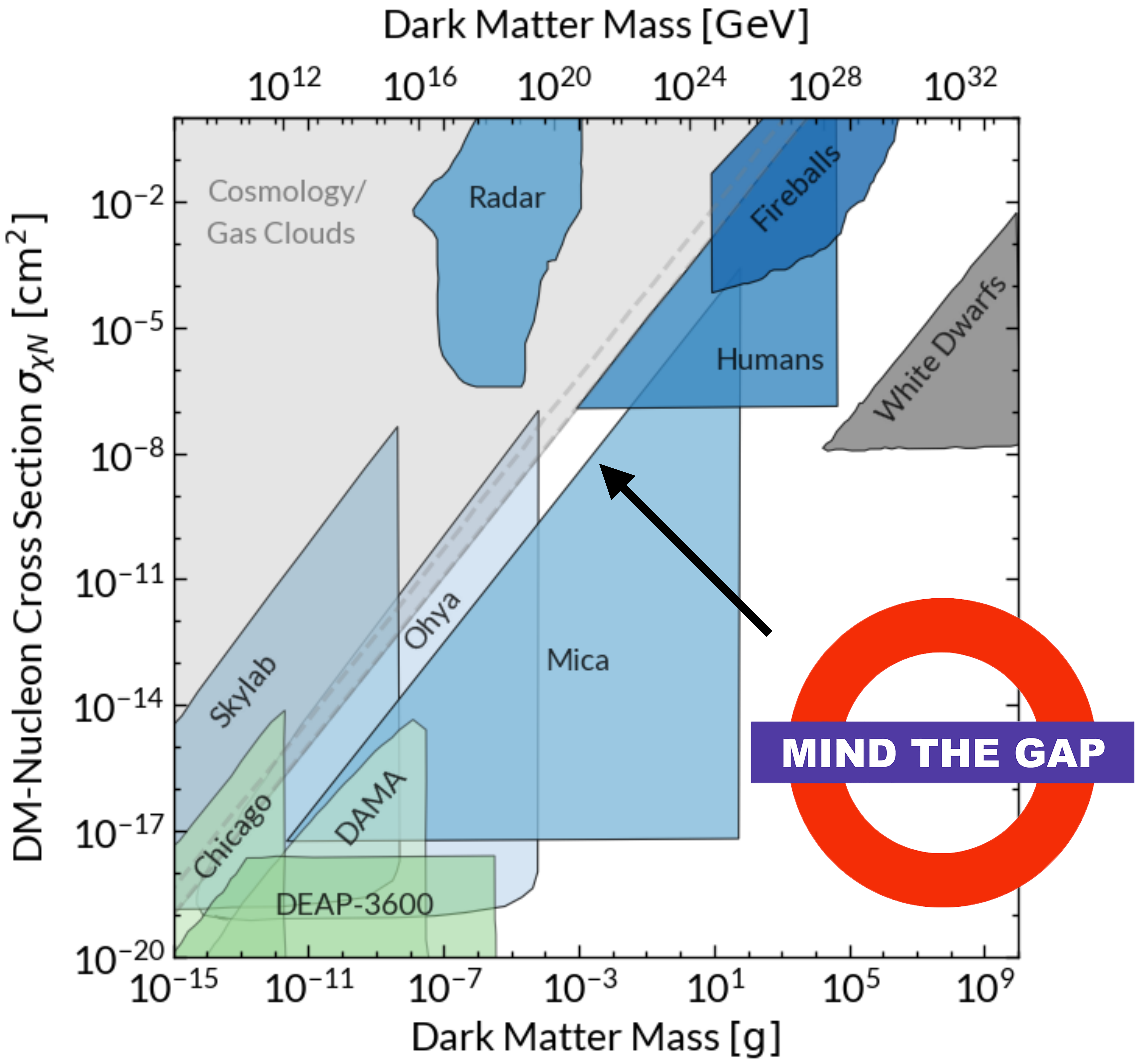

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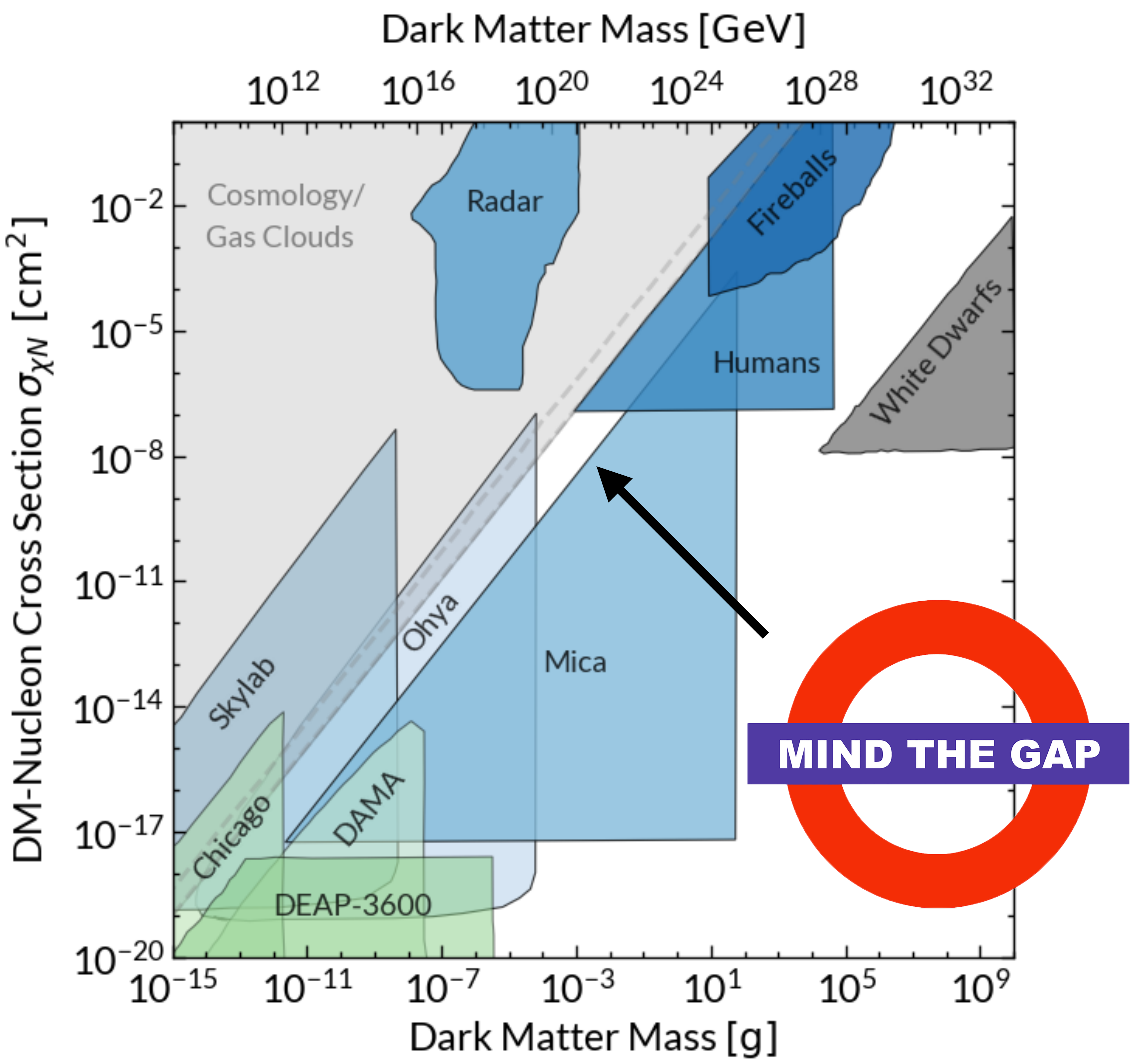

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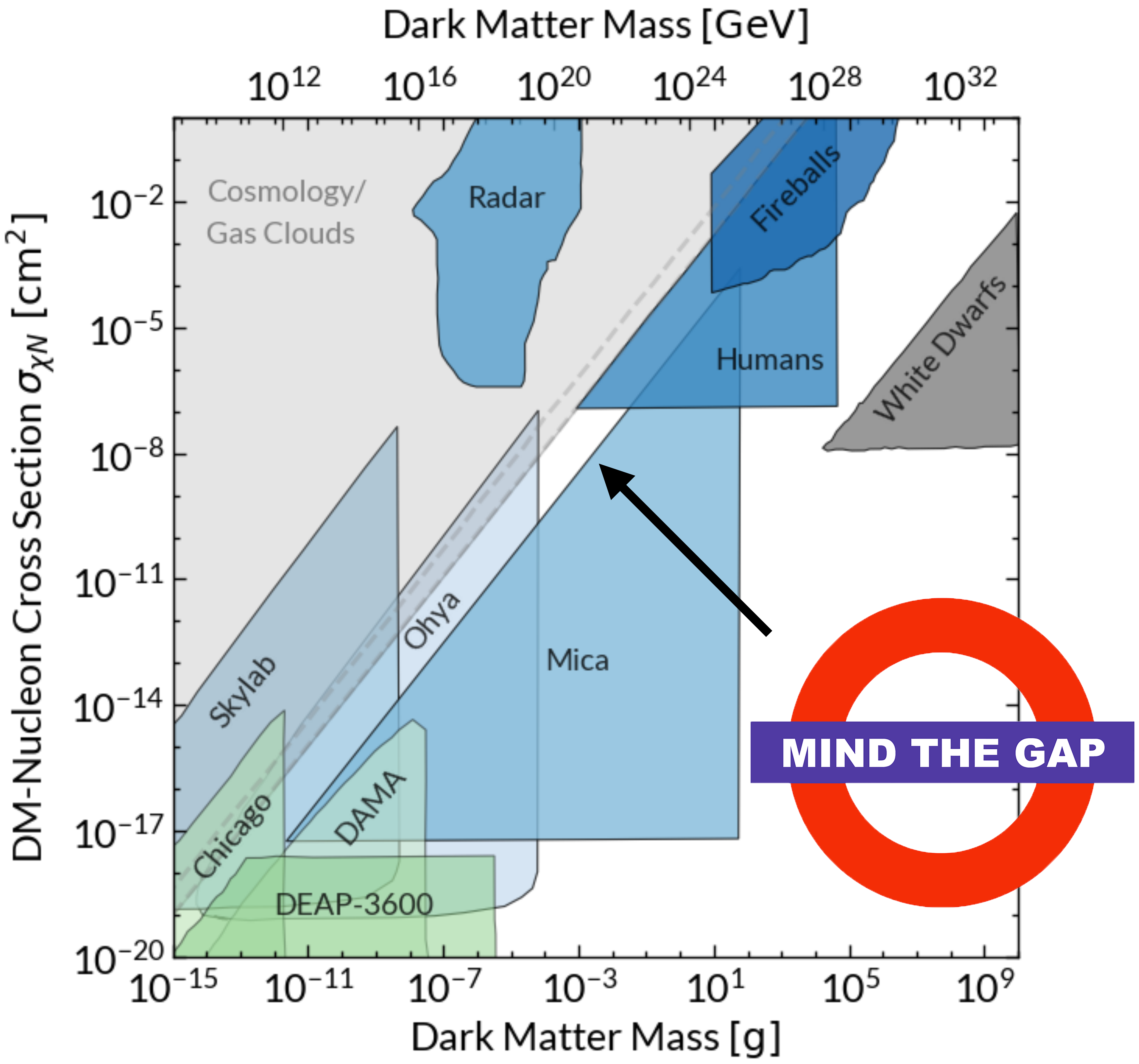

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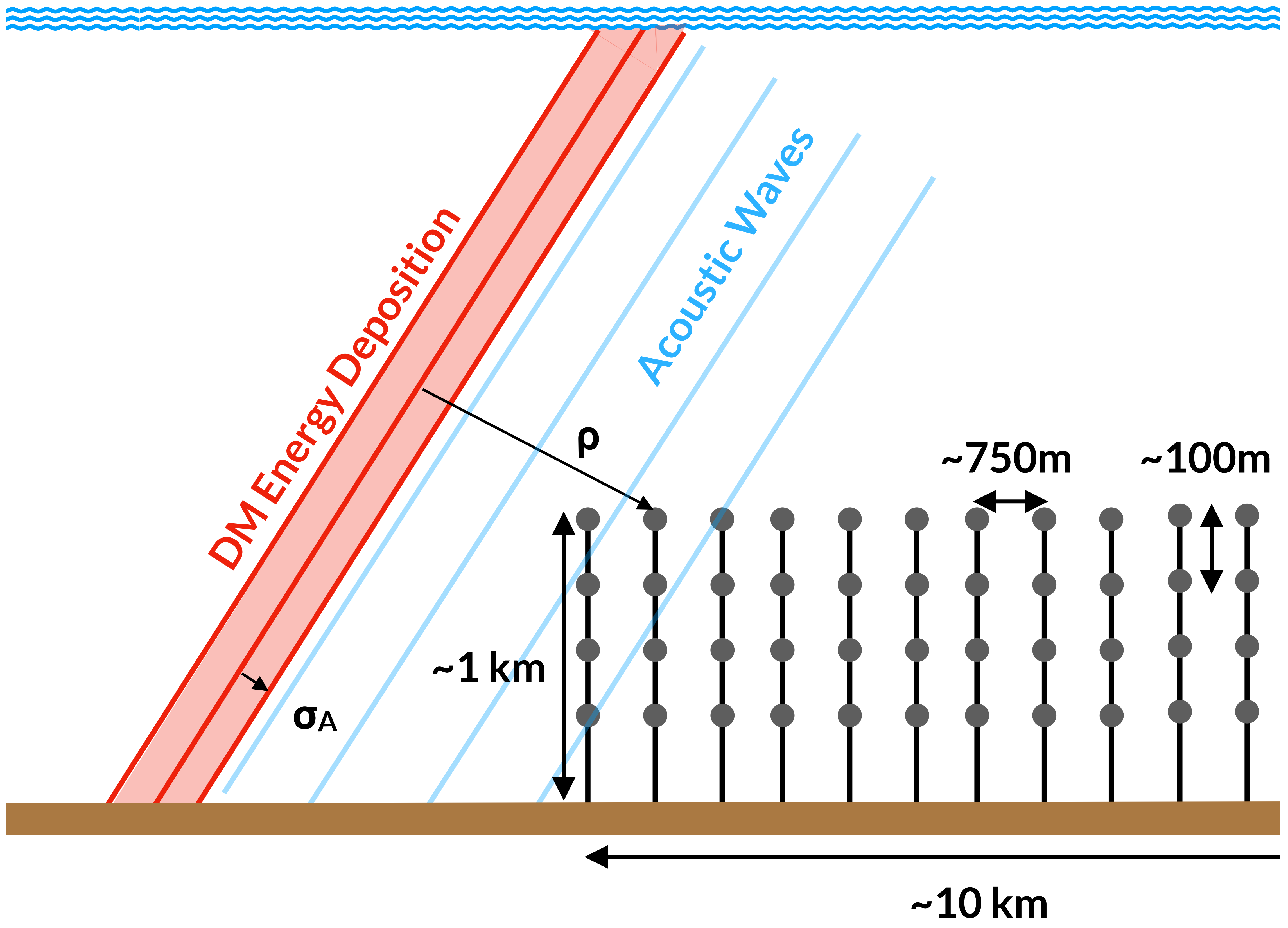
- **What phenomena could we use to constrain this region?**

Acoustic Detection



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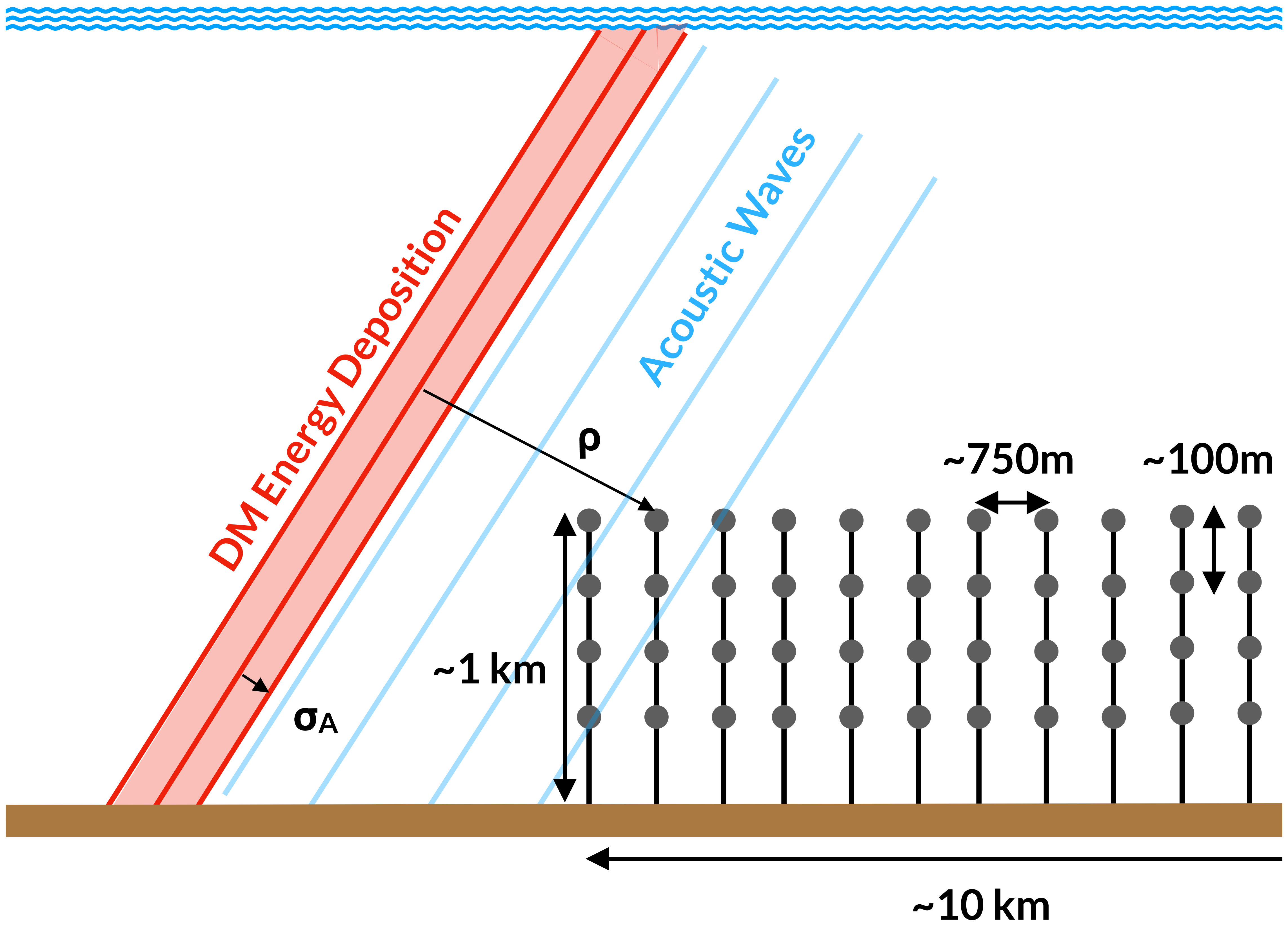

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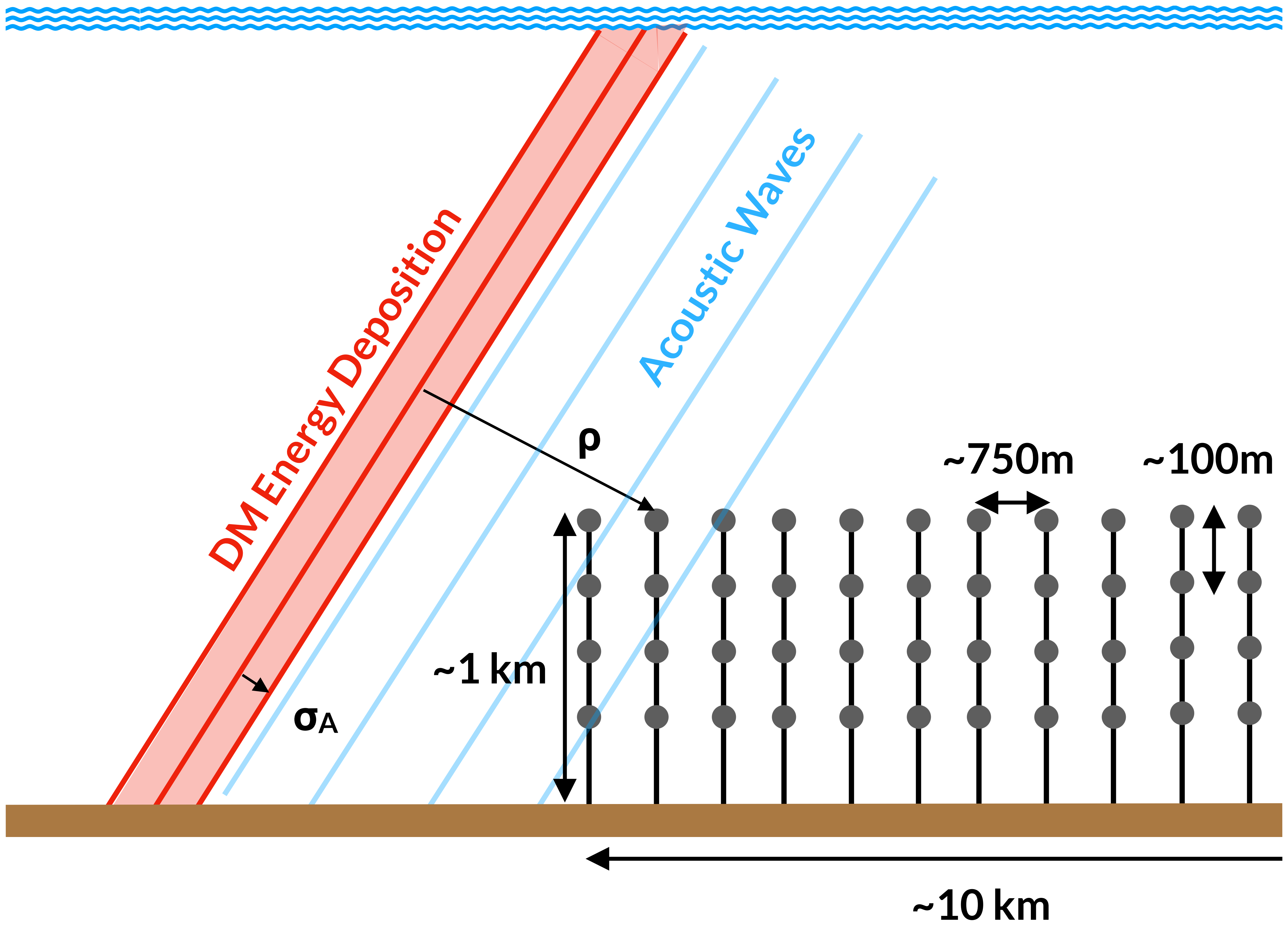

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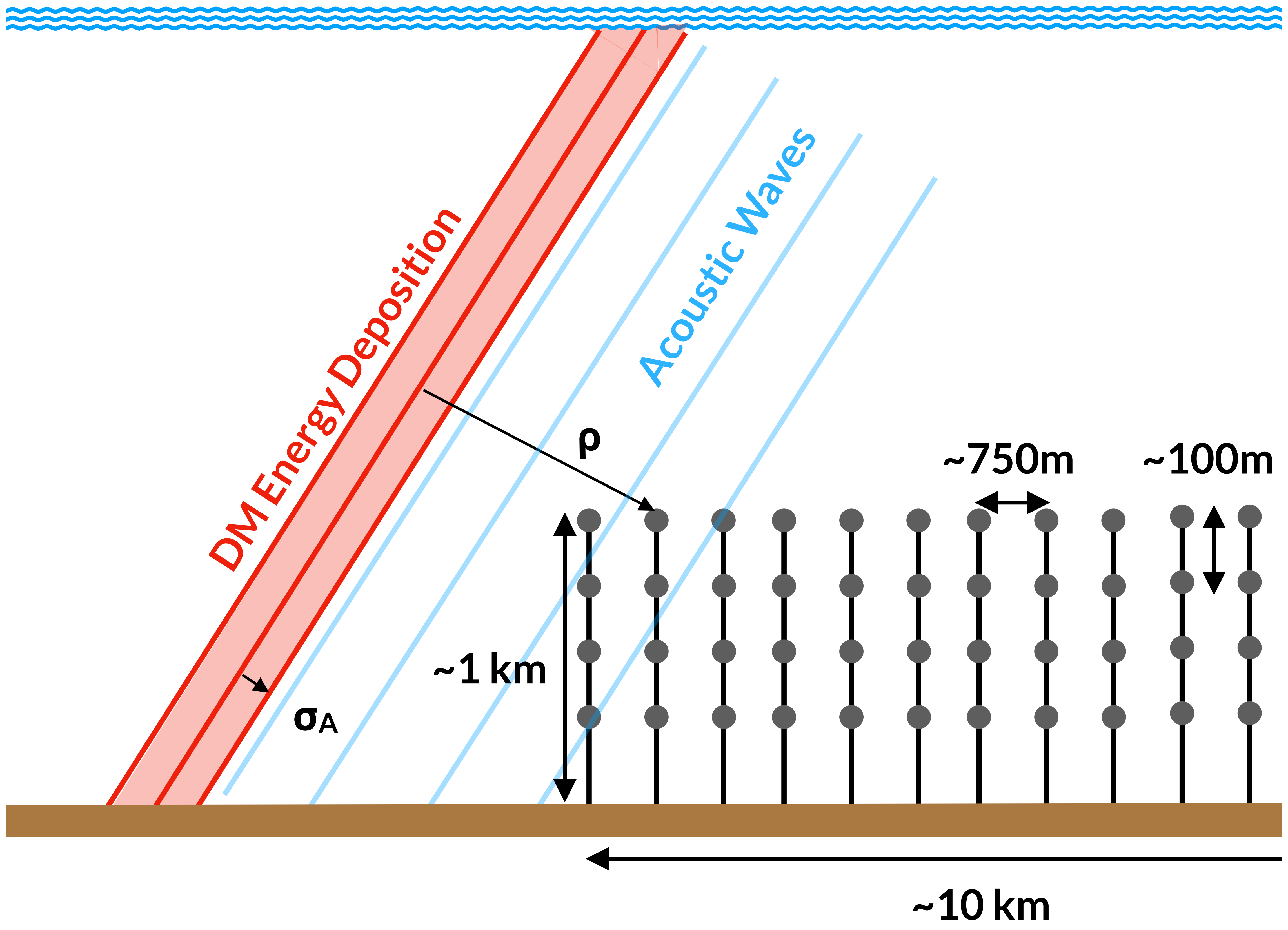

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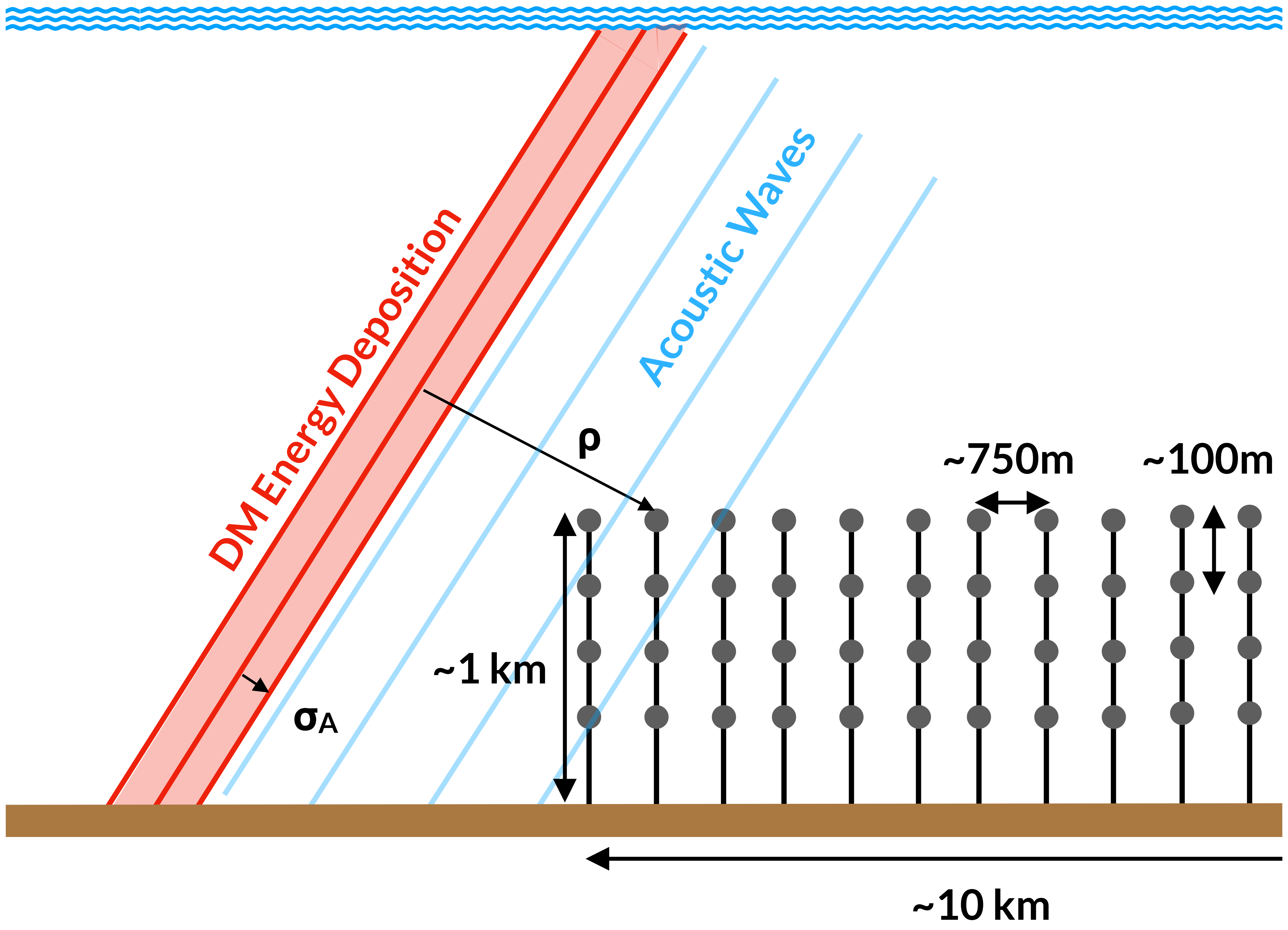

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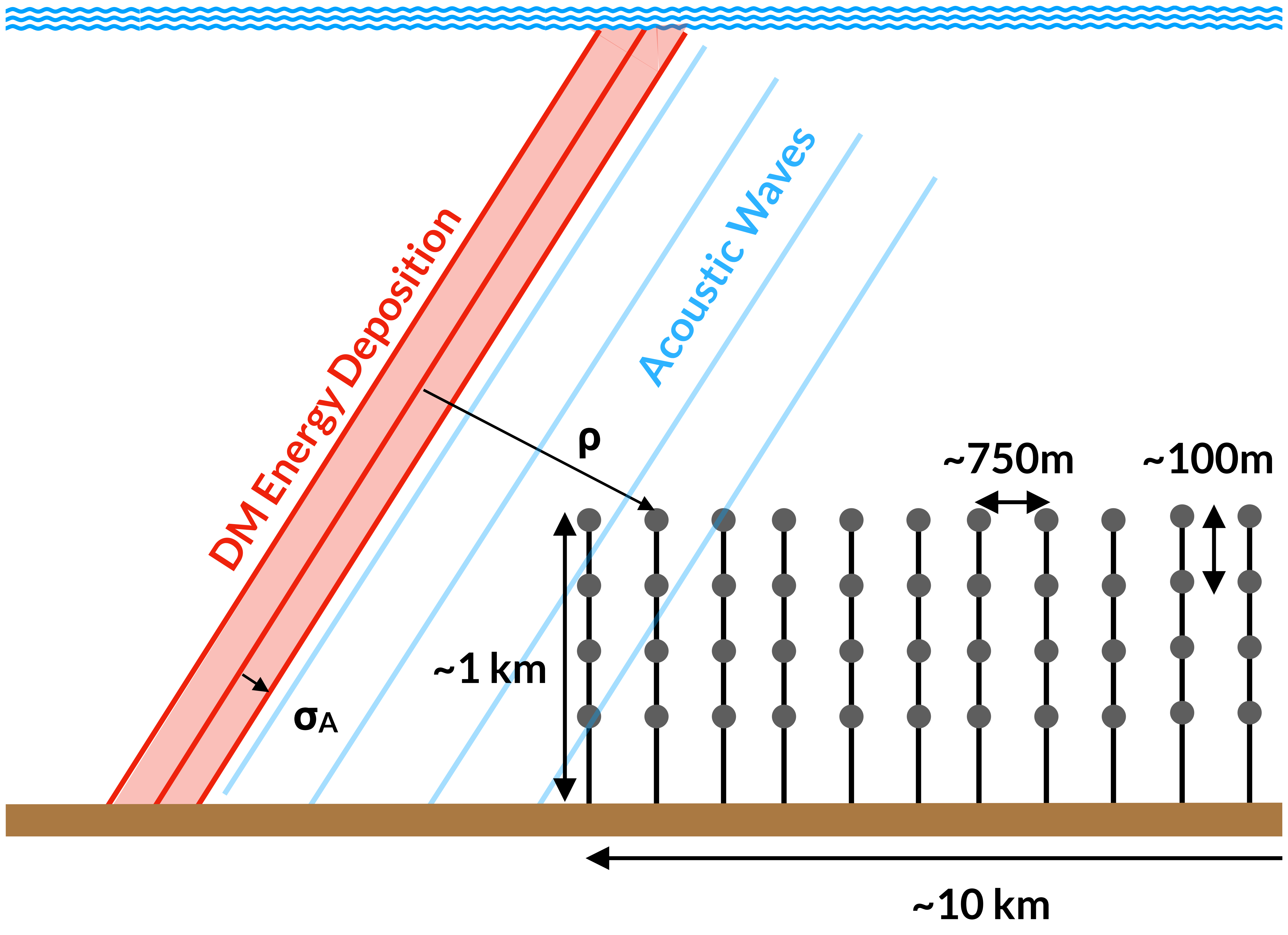

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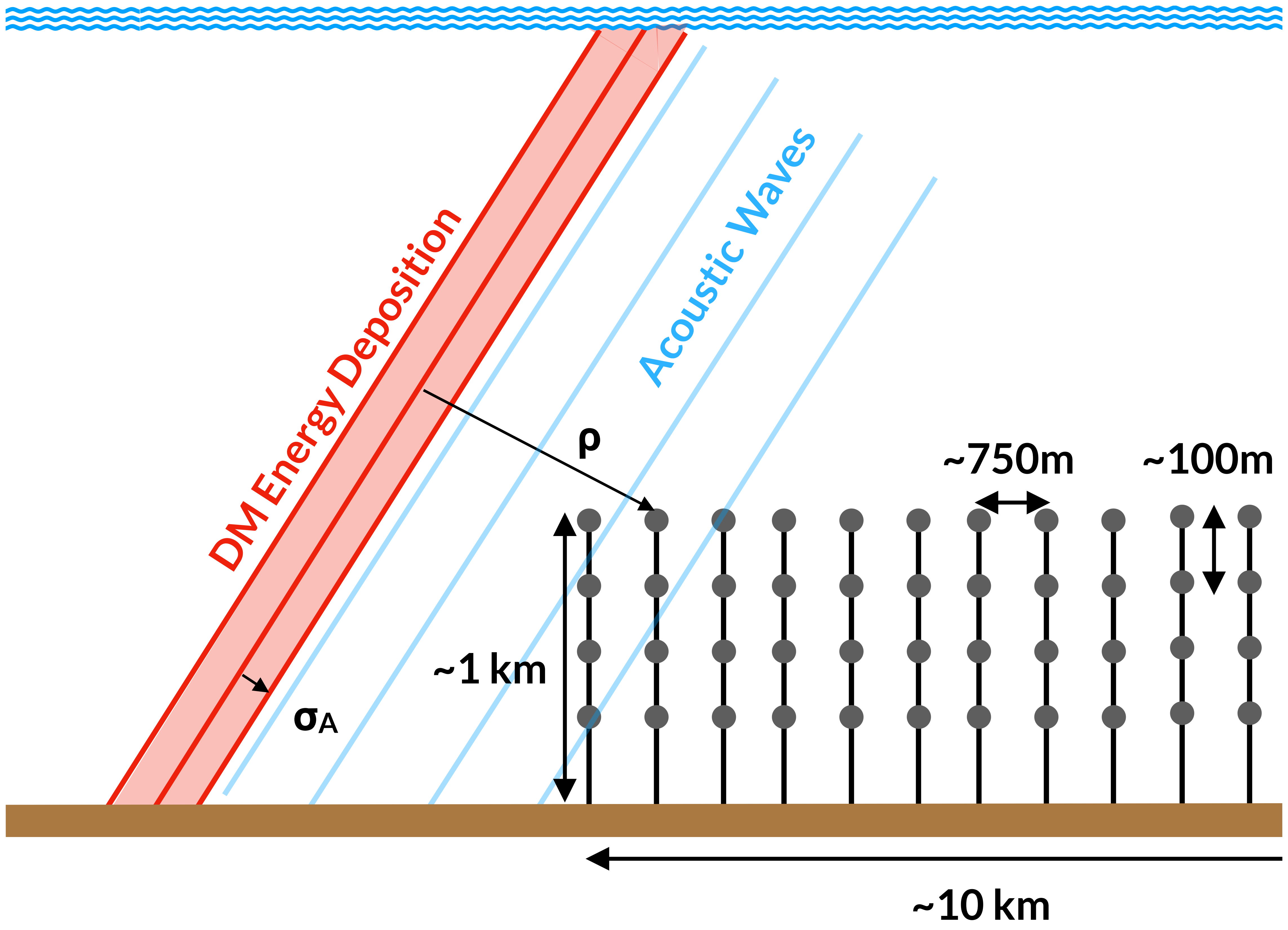

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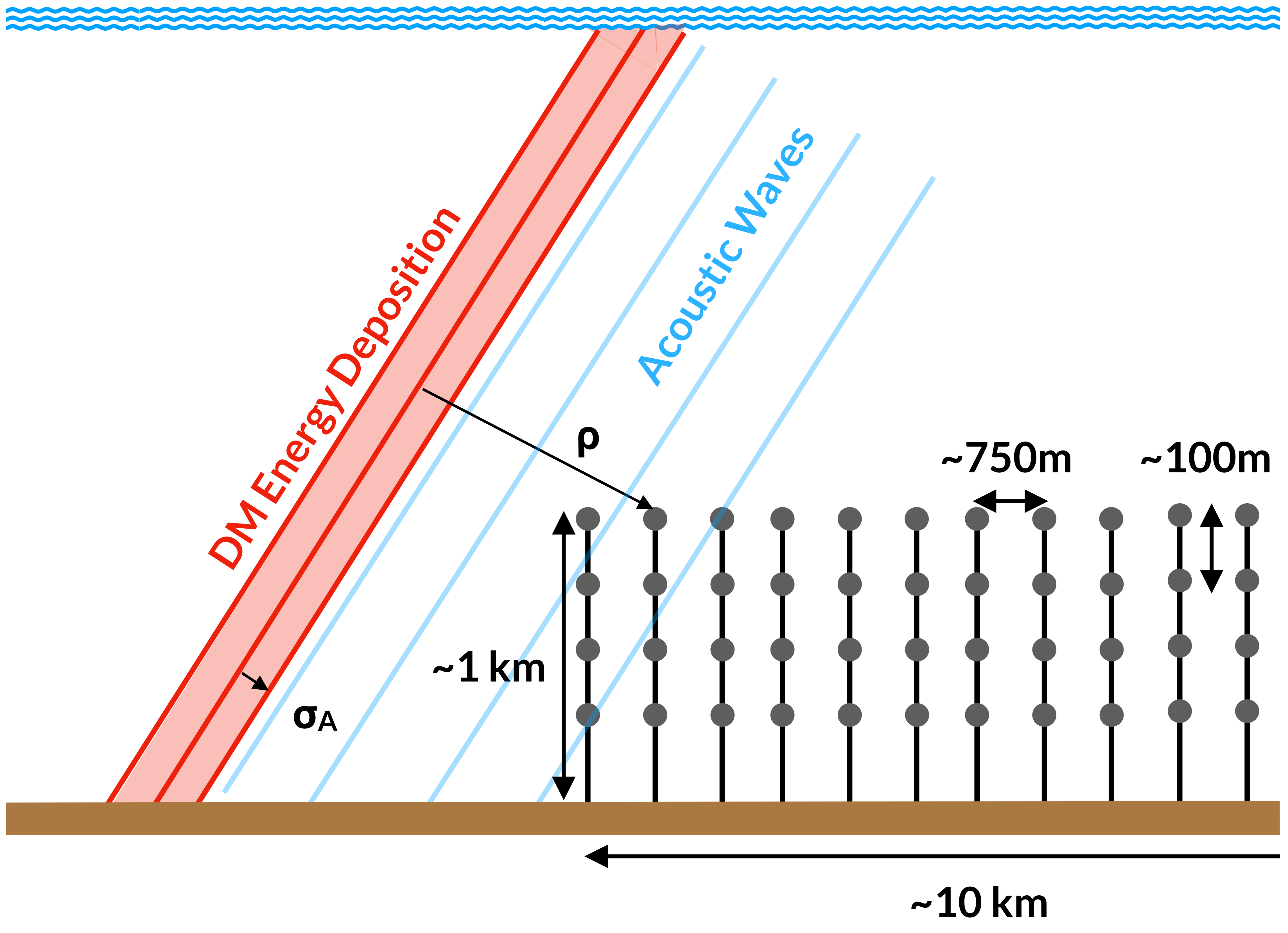

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General Solution:

$$p(r,t) = \frac{\alpha}{4\pi c_p}\int \frac{\mathrm{d}^3 r'}{|r - r'|}\frac{\partial^2 q(r',t')}{\partial t^2}$$

$$t' = t - |r - r'|/c_s$$

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Taking a geometric cross section only and taking the number of scatters to infinity:

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ℓ_{sea} can be very long, in this case: $\frac{\mathrm{d}E_\chi}{\mathrm{d}z} \simeq -\rho_{\mathrm{sea}}\sigma_\chi v_\chi^2 = \mathrm{const}$

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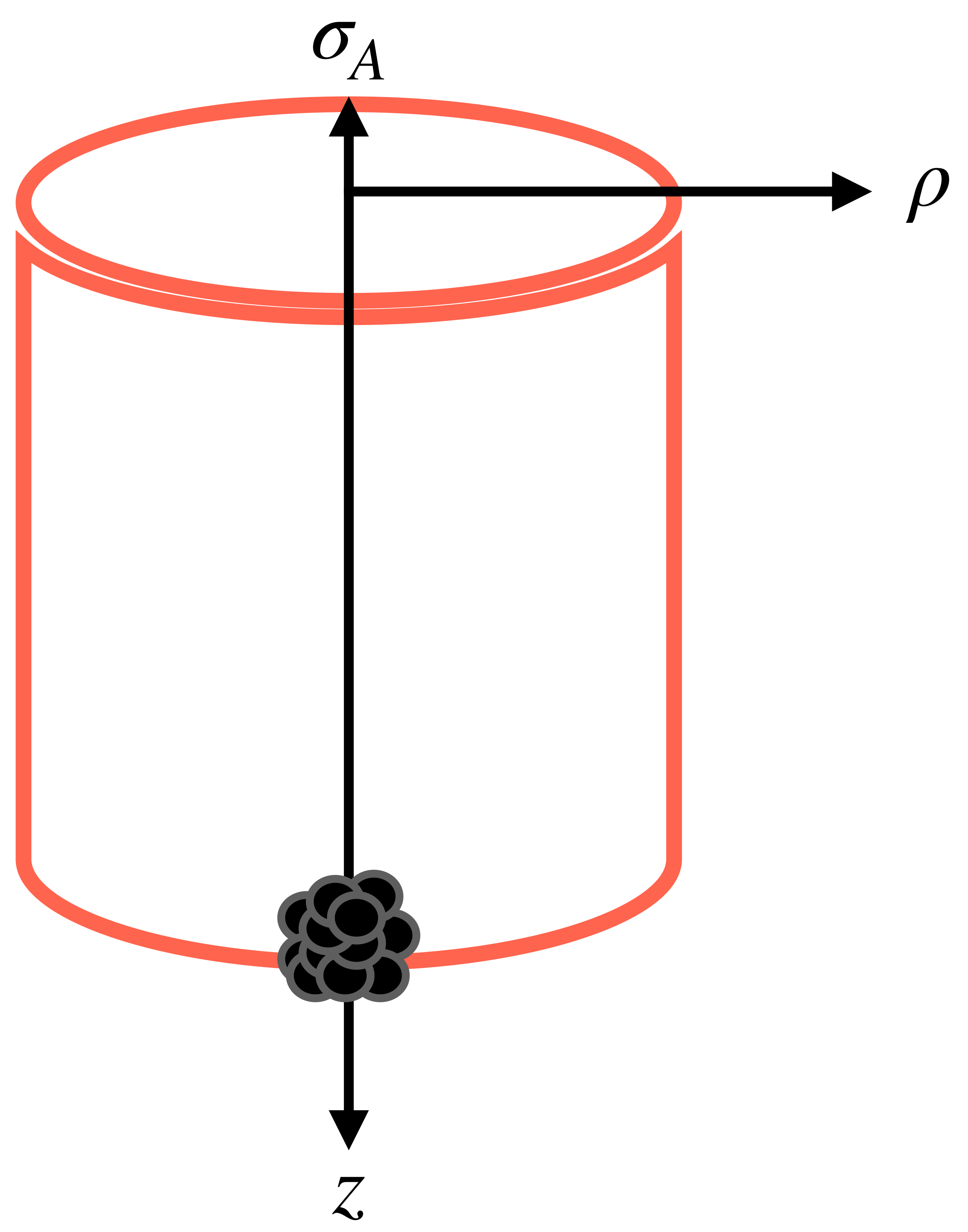

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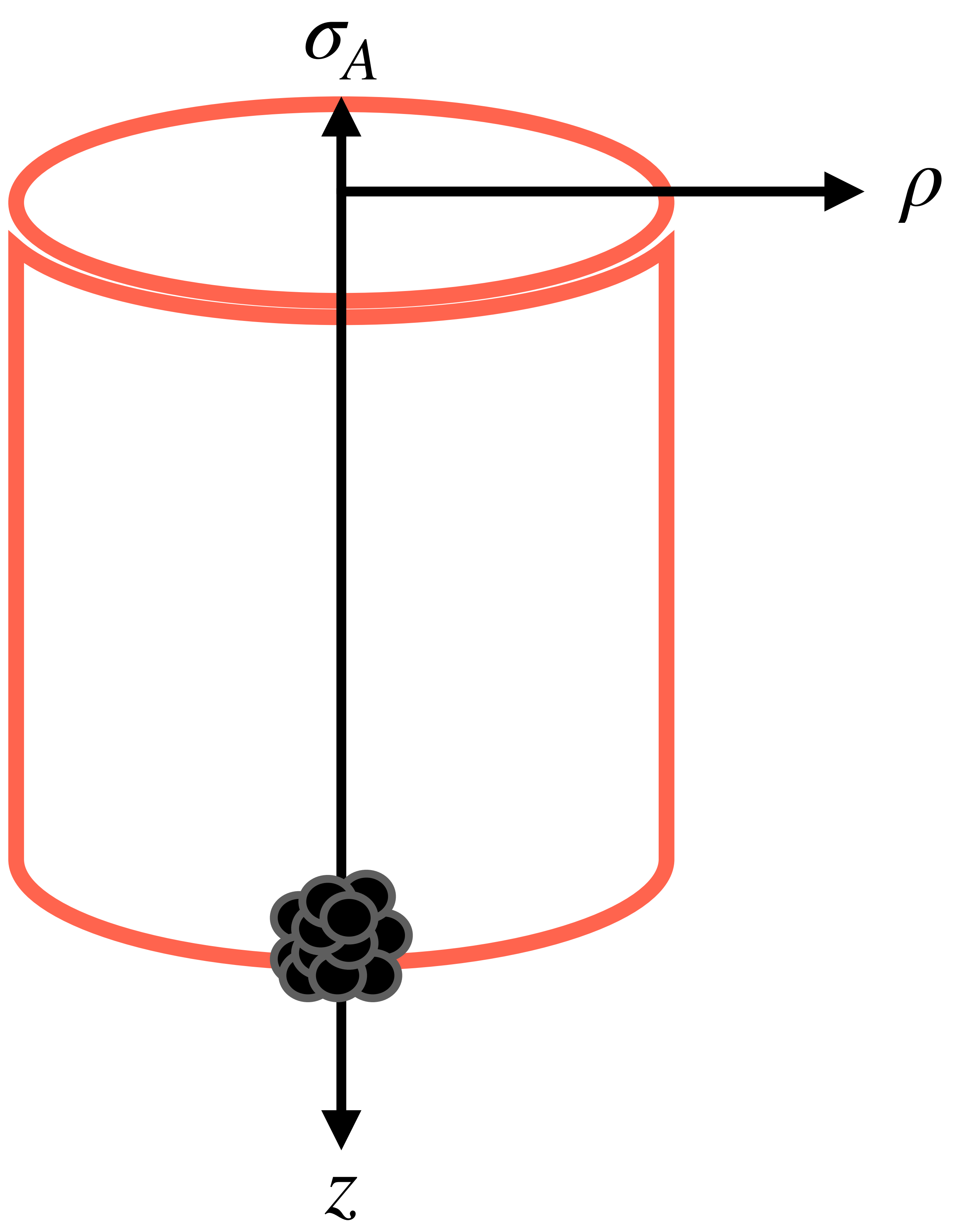

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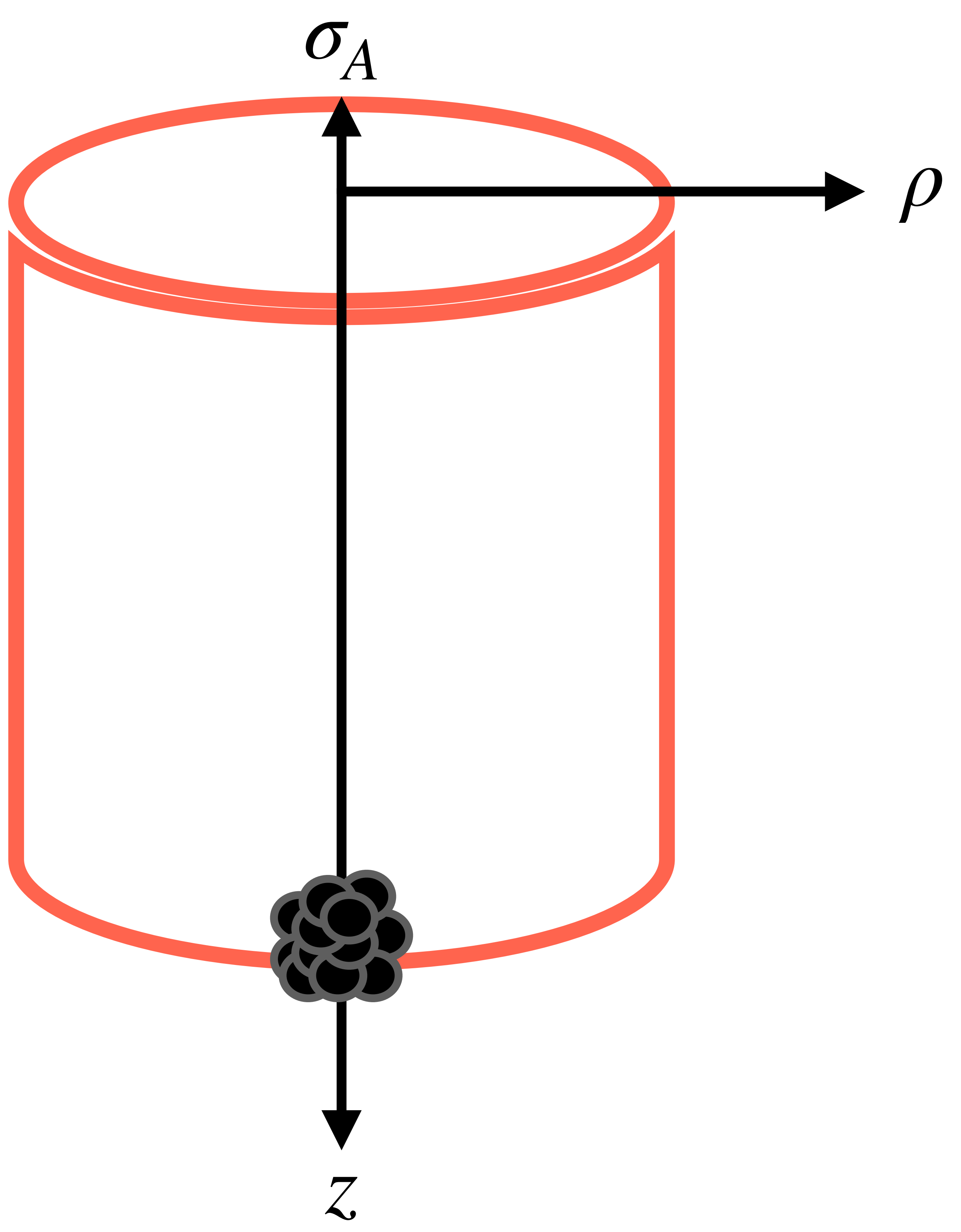

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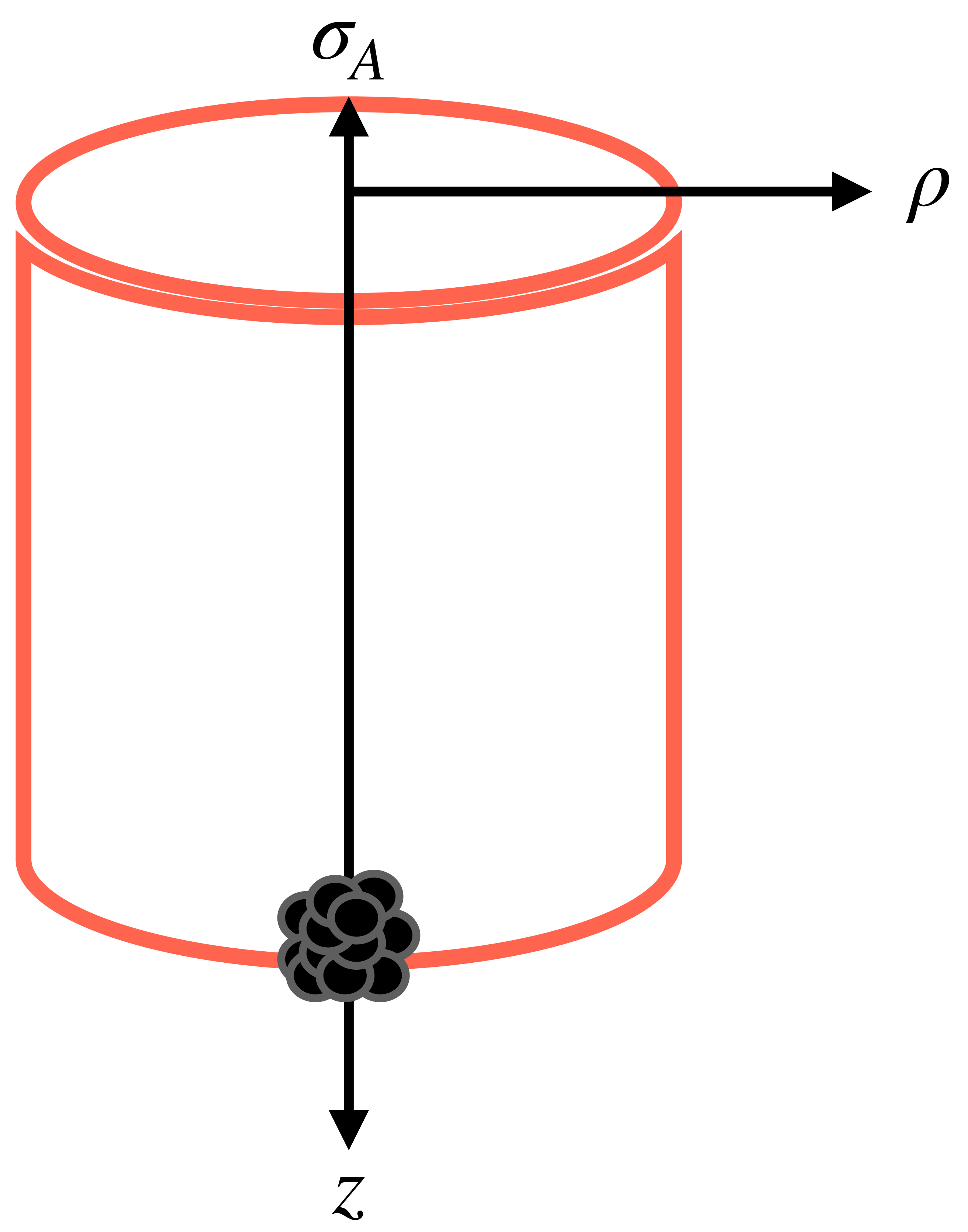
Gaussian allows us to find analytic solutions for the pressure - turns out to be enough to capture the physics



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$$p(r, t; \sigma \ll \rho) = \frac{\alpha}{2\pi c_p} \frac{dE}{dz} \frac{c_s^2}{\sqrt{2\pi\sigma^3}} \frac{1}{\sqrt{\rho}} I_p\left(\frac{t - \rho/c_s}{\sigma/c_s}\right)$$

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$$I_p(A) = \int_0^\infty dY\sqrt{Y}\exp\left(-\frac{Y^2}{2}\right)\cos\left(A\,Y + \frac{\pi}{4}\right)$$

$$= -\frac{\pi A}{4\sqrt{2}(A^2)^{1/4}}\exp\left(-\frac{A^2}{4}\right)\left[\left(A+\sqrt{A^2}\right)\left(I_{1/4}\left(\frac{A^2}{4}\right) - I_{3/4}\left(\frac{A^2}{4}\right)\right) + \frac{\sqrt{2}}{\pi}\left(\sqrt{A^2}K_{1/4}\left(\frac{A^2}{4}\right) - AK_{3/4}\left(\frac{A^2}{4}\right)\right)\right]$$

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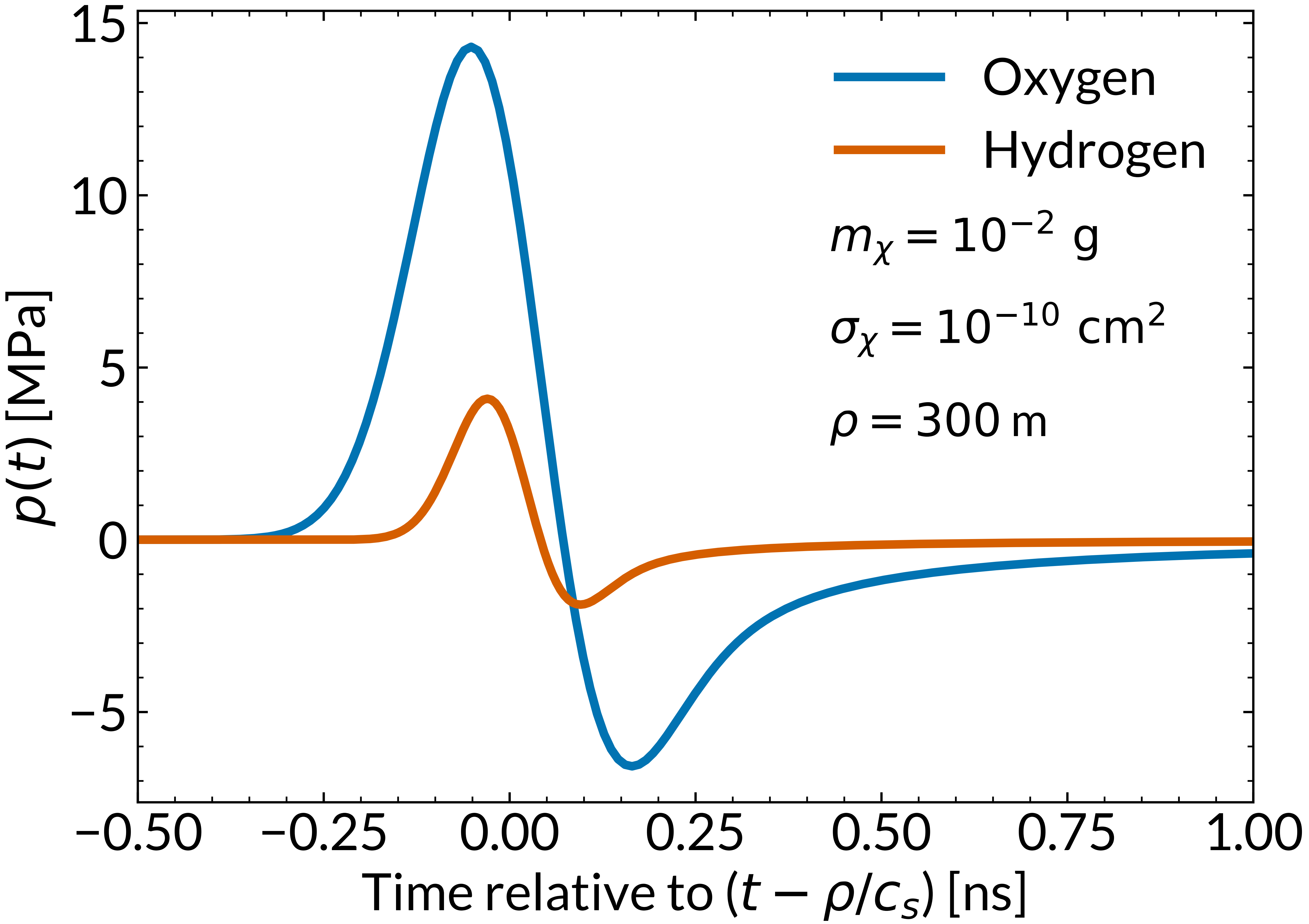

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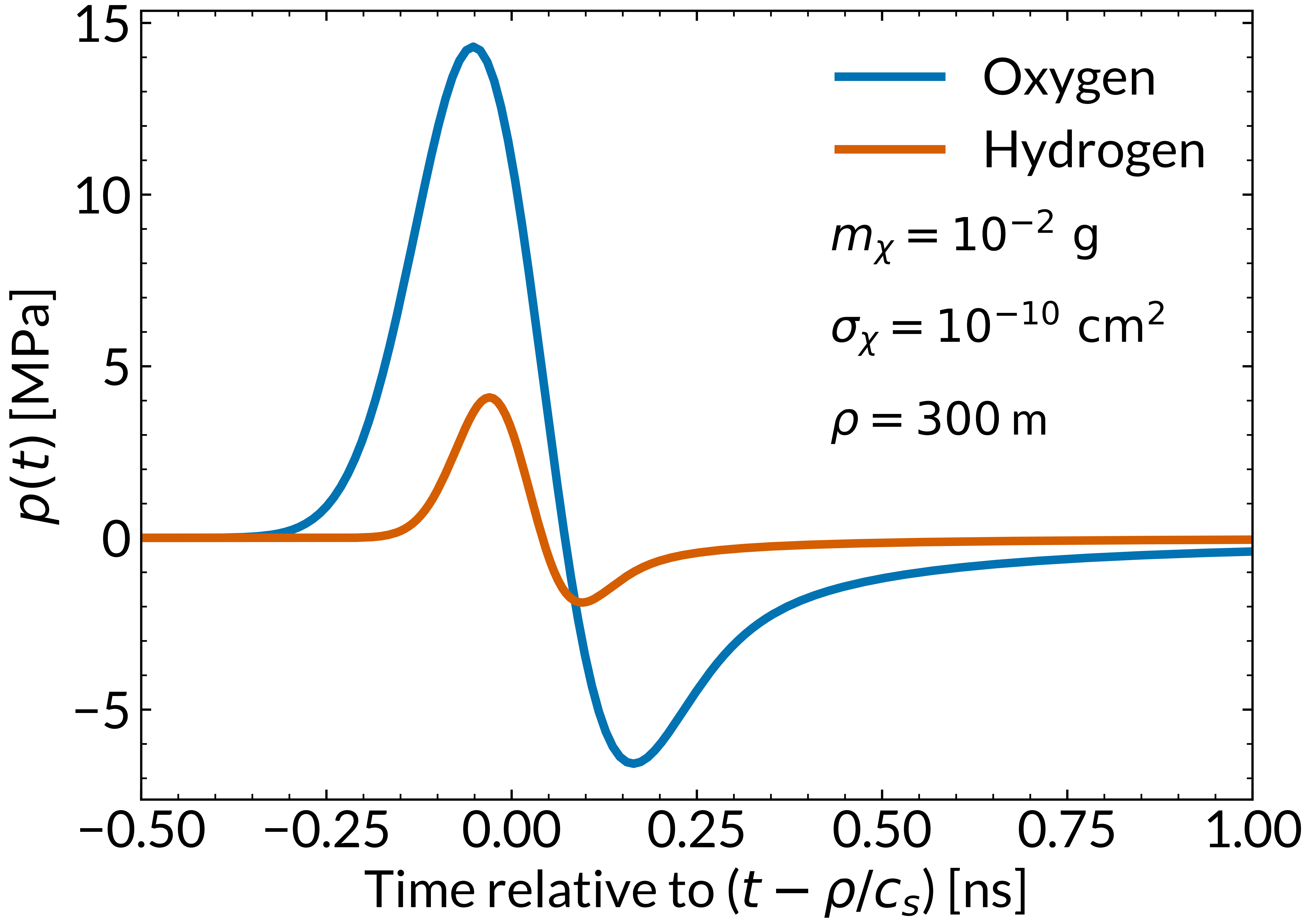

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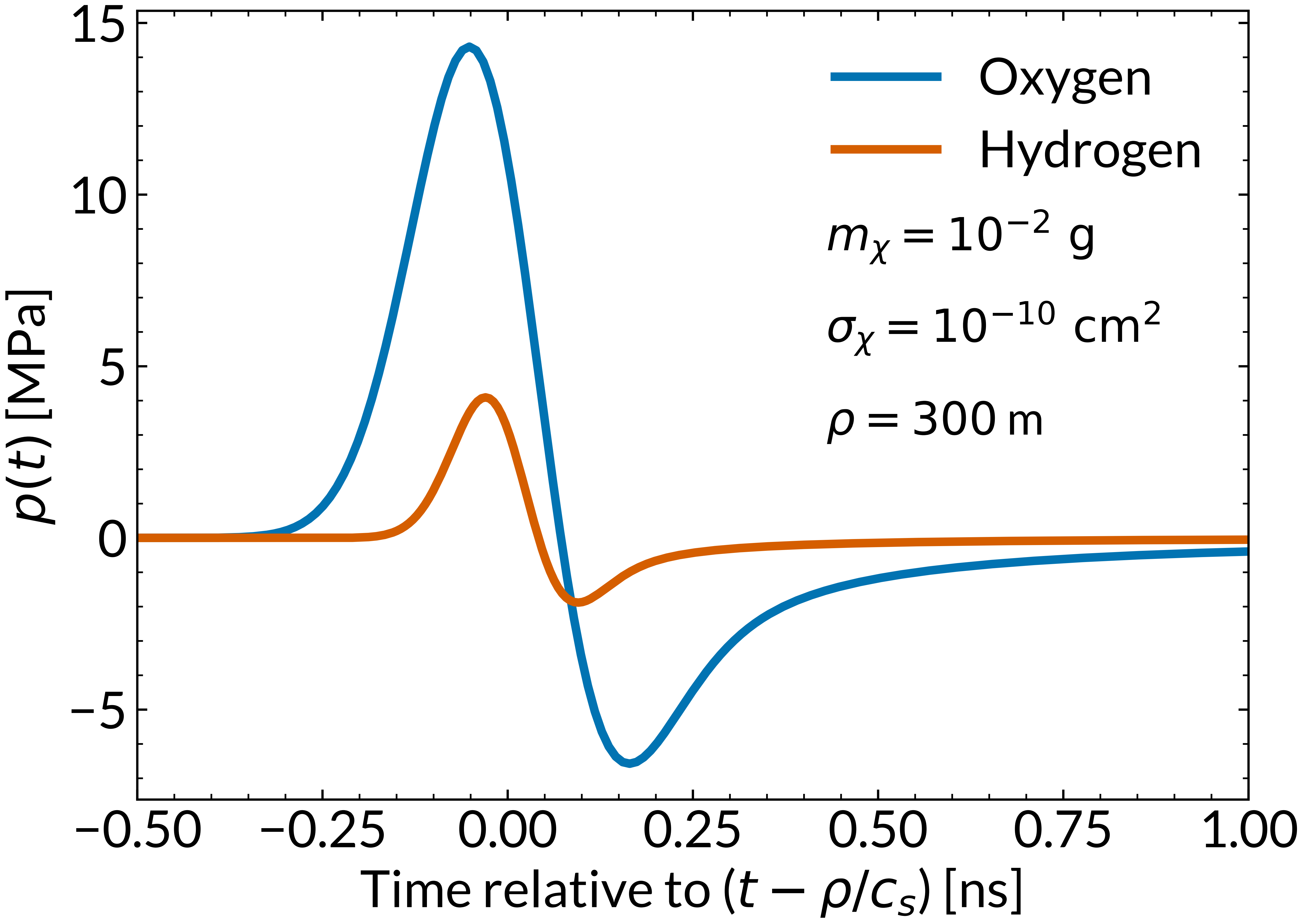

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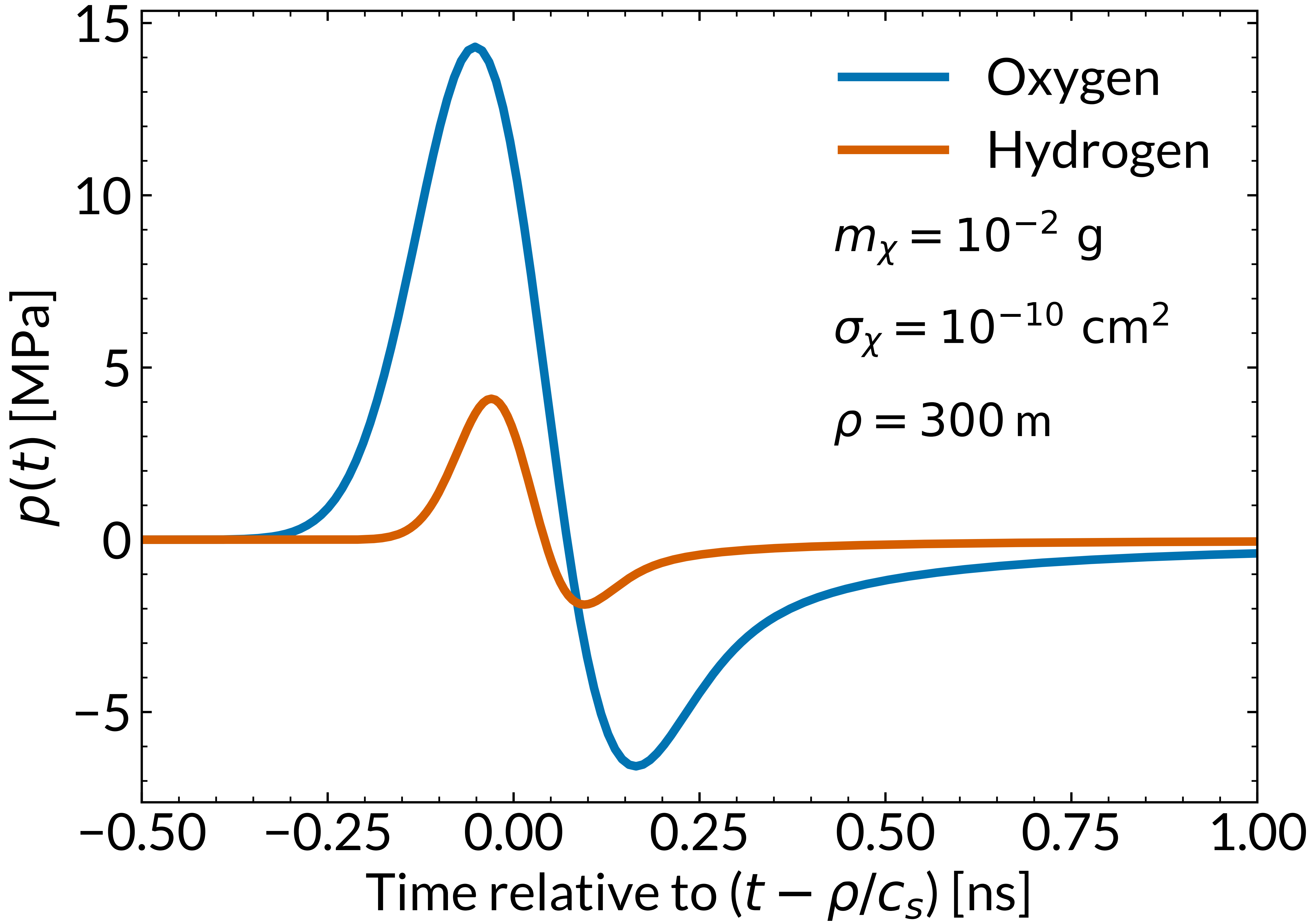
Full pressure solution is sum of O and H contributions.



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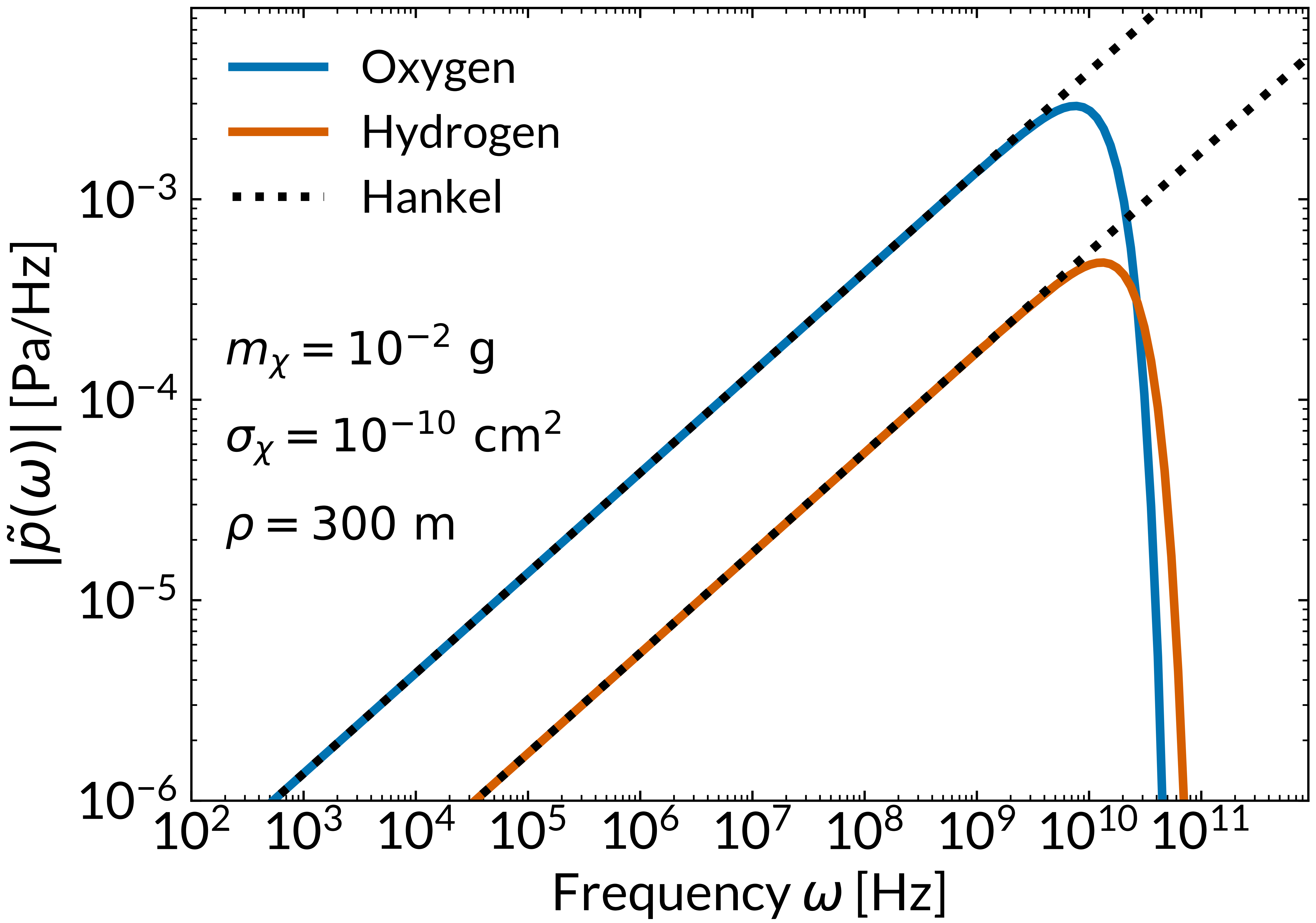

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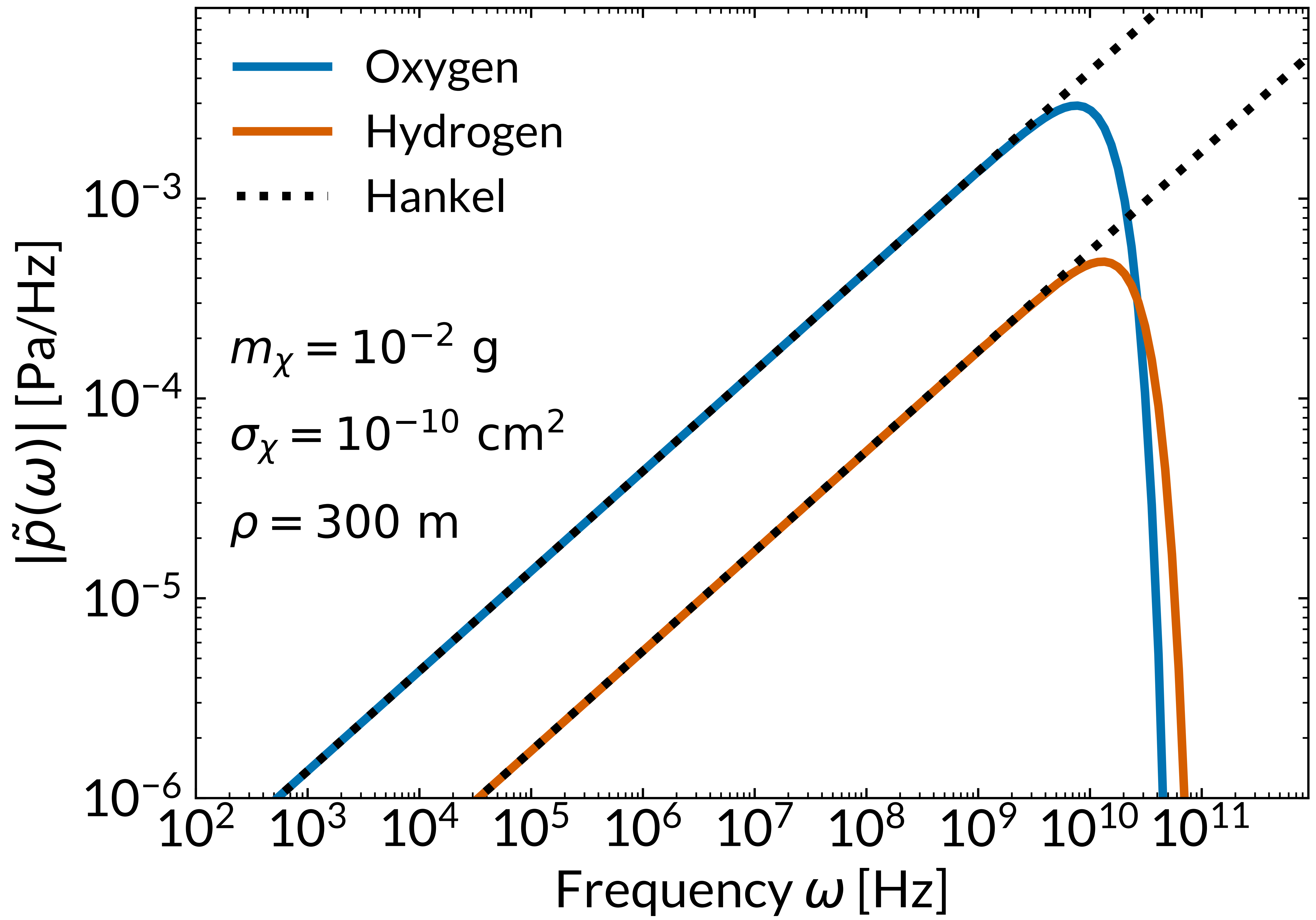

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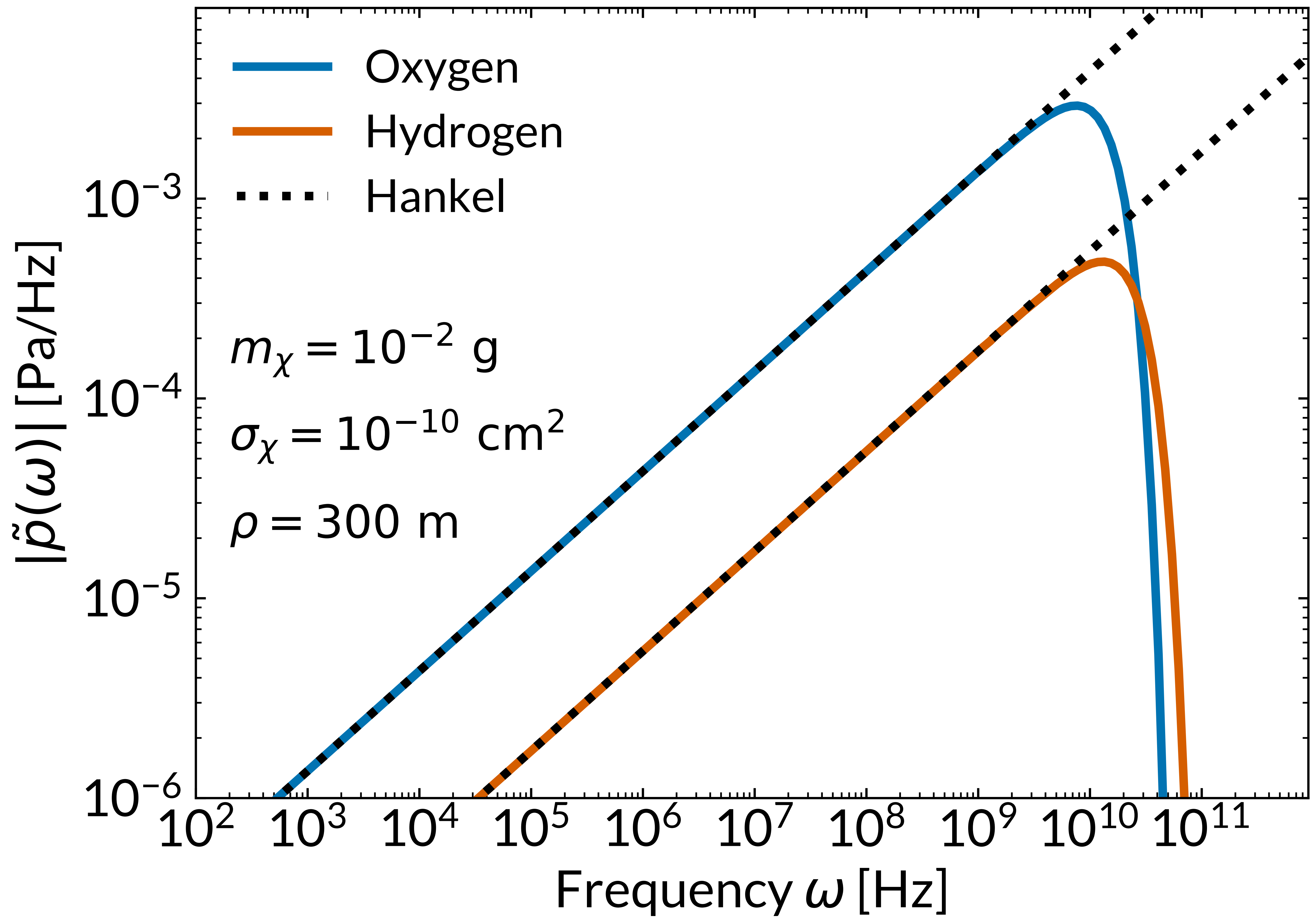

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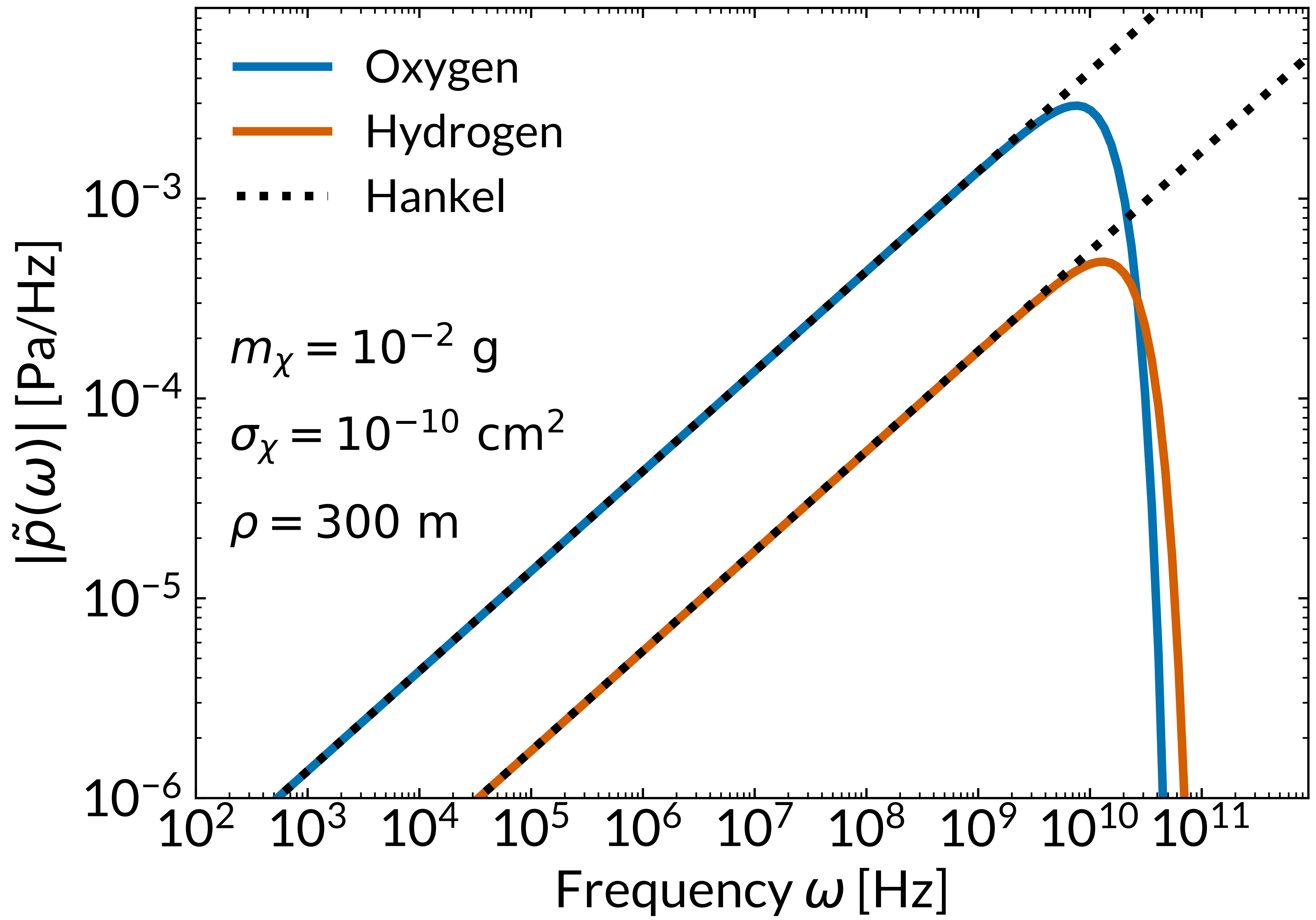

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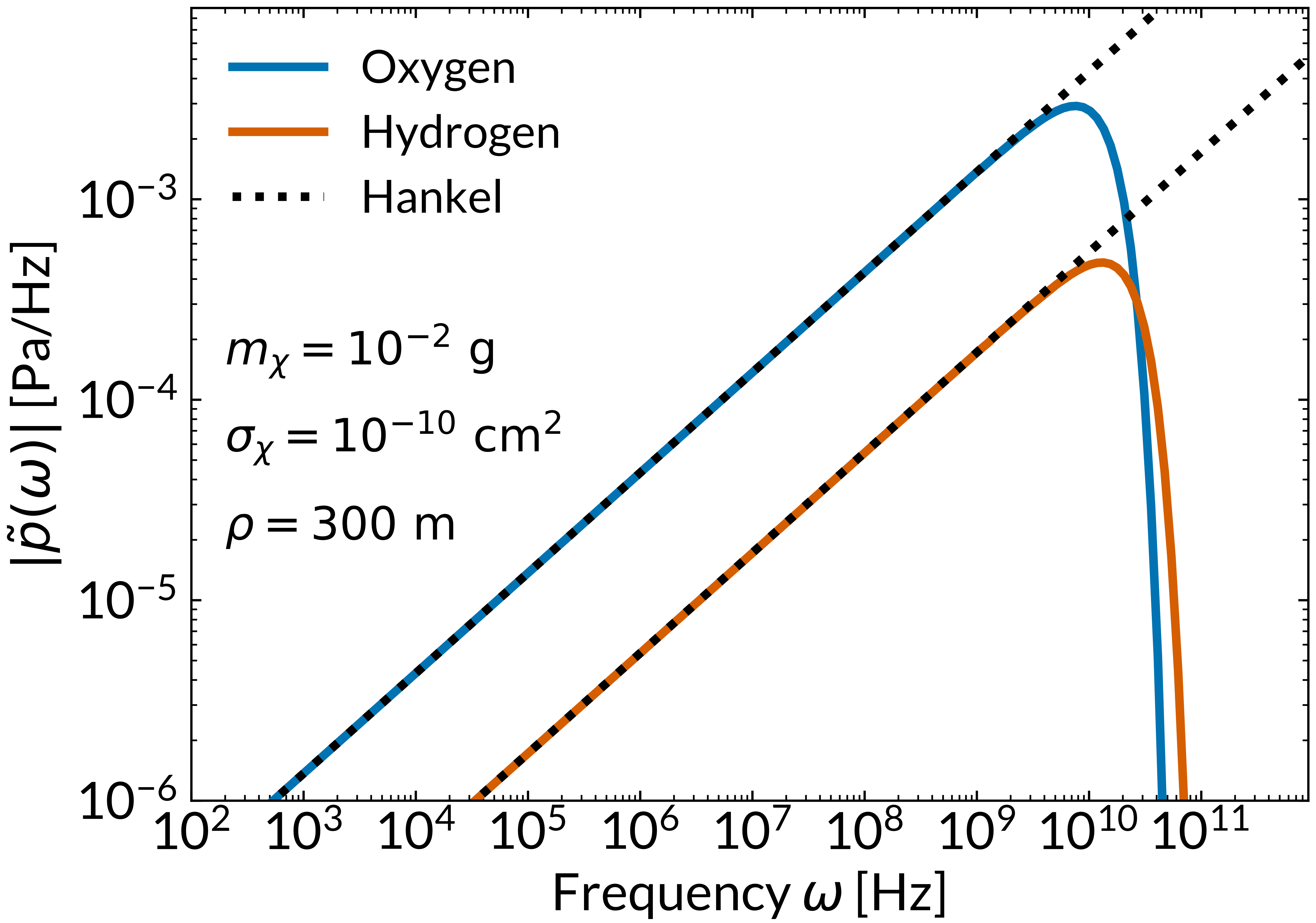

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$$\omega_0 = 5.32 \times 10^{11}\,\text{kHz}$$

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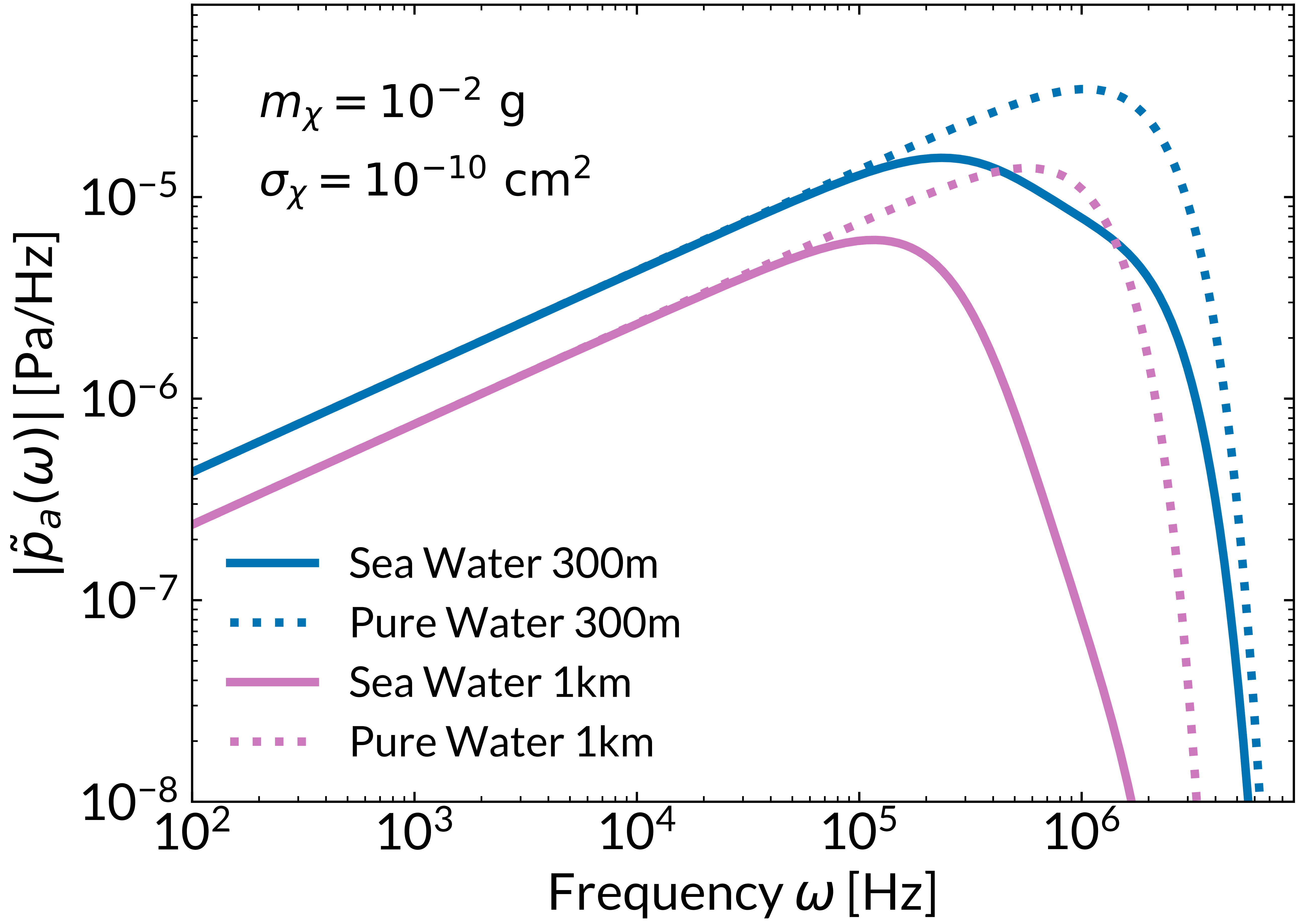

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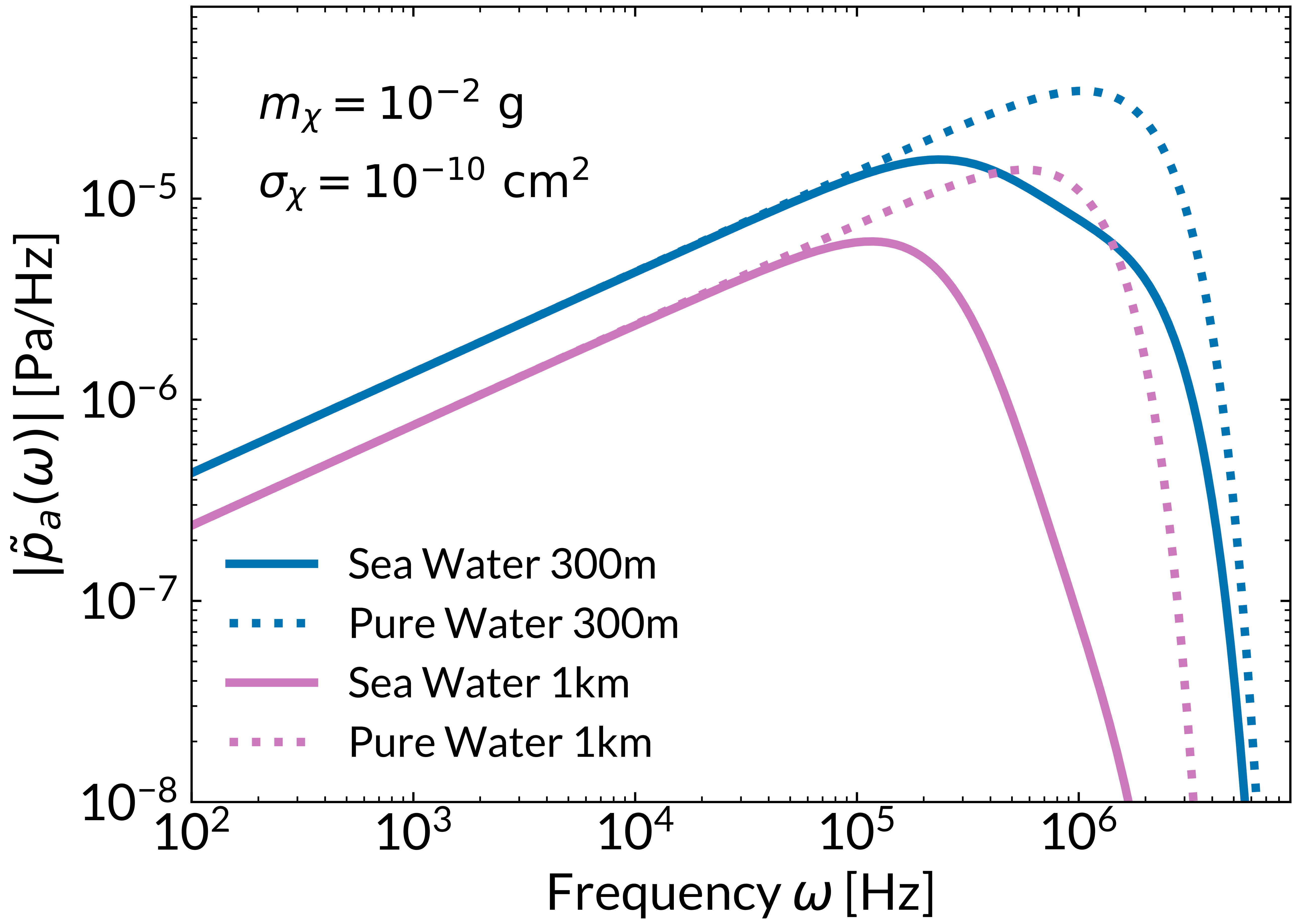

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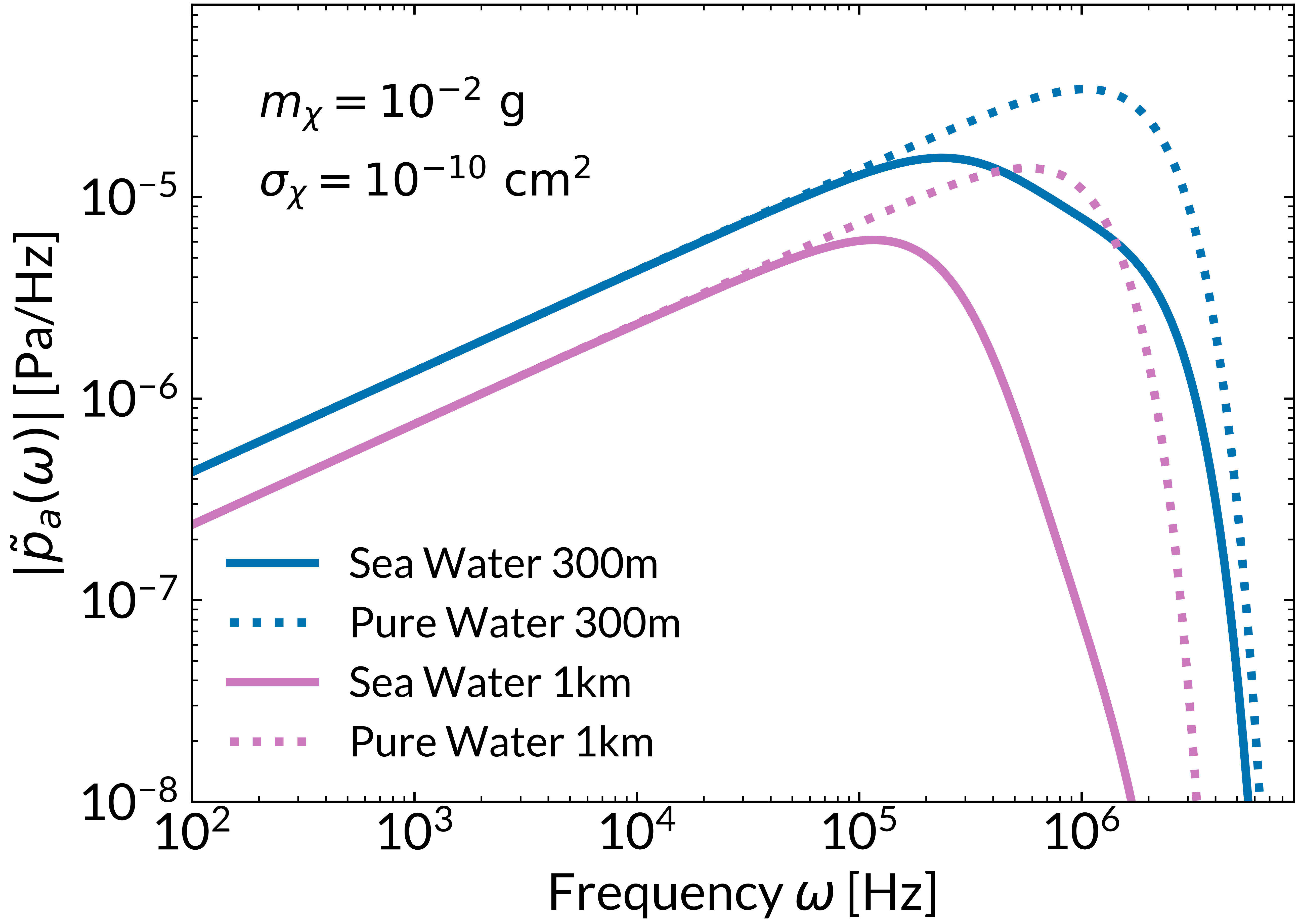

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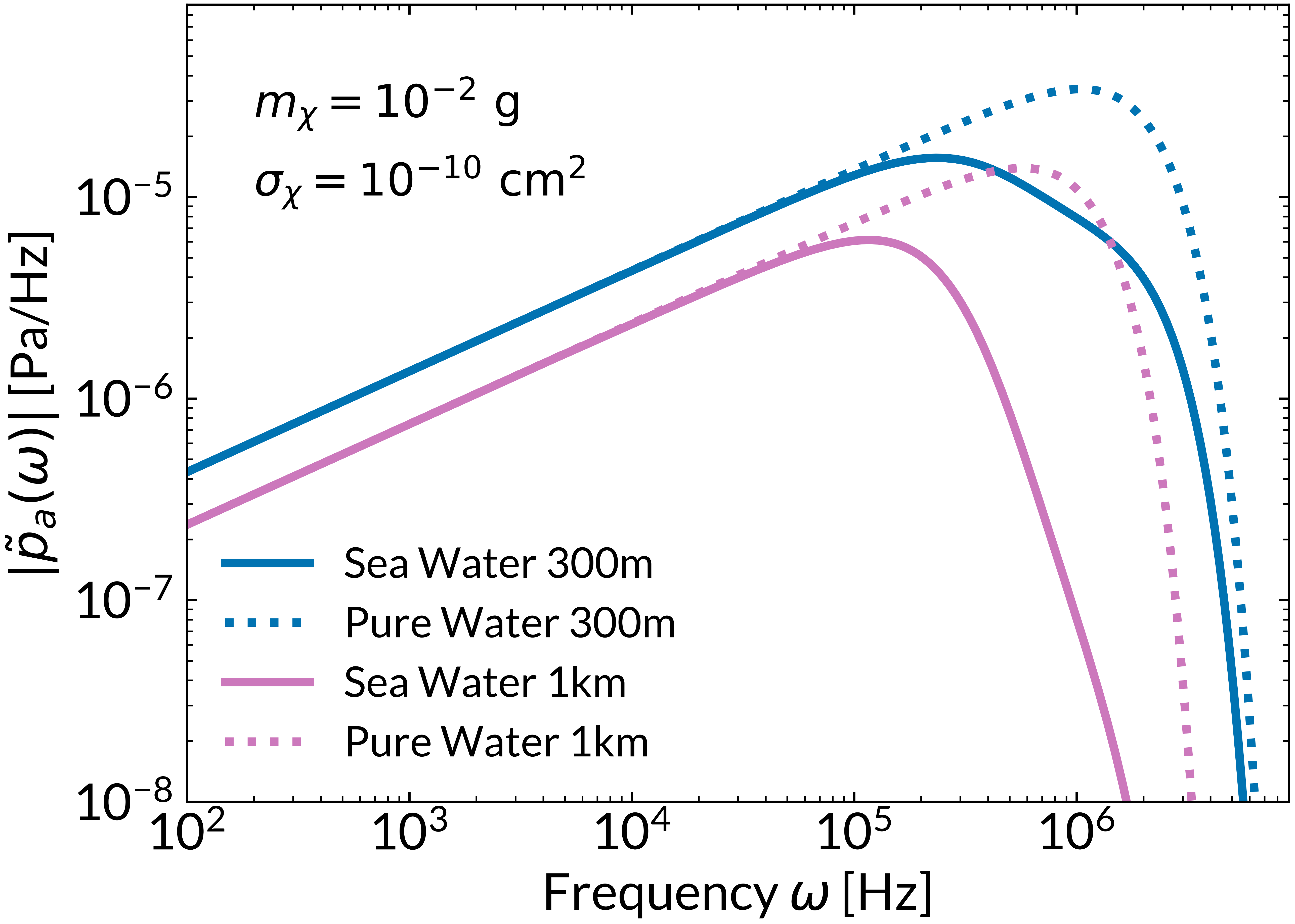
Cut-off profile is not Gaussian at certain characteristic distances



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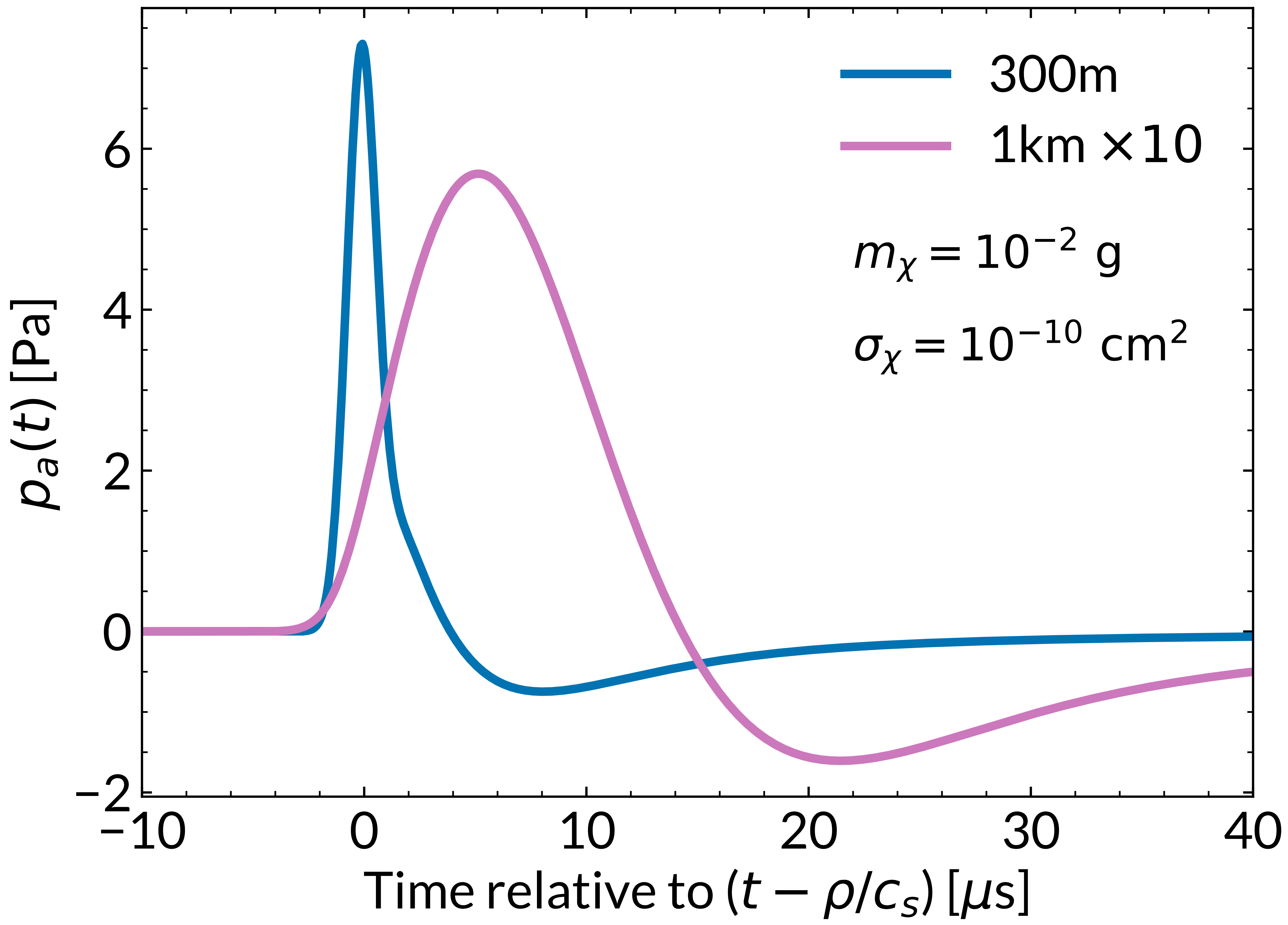

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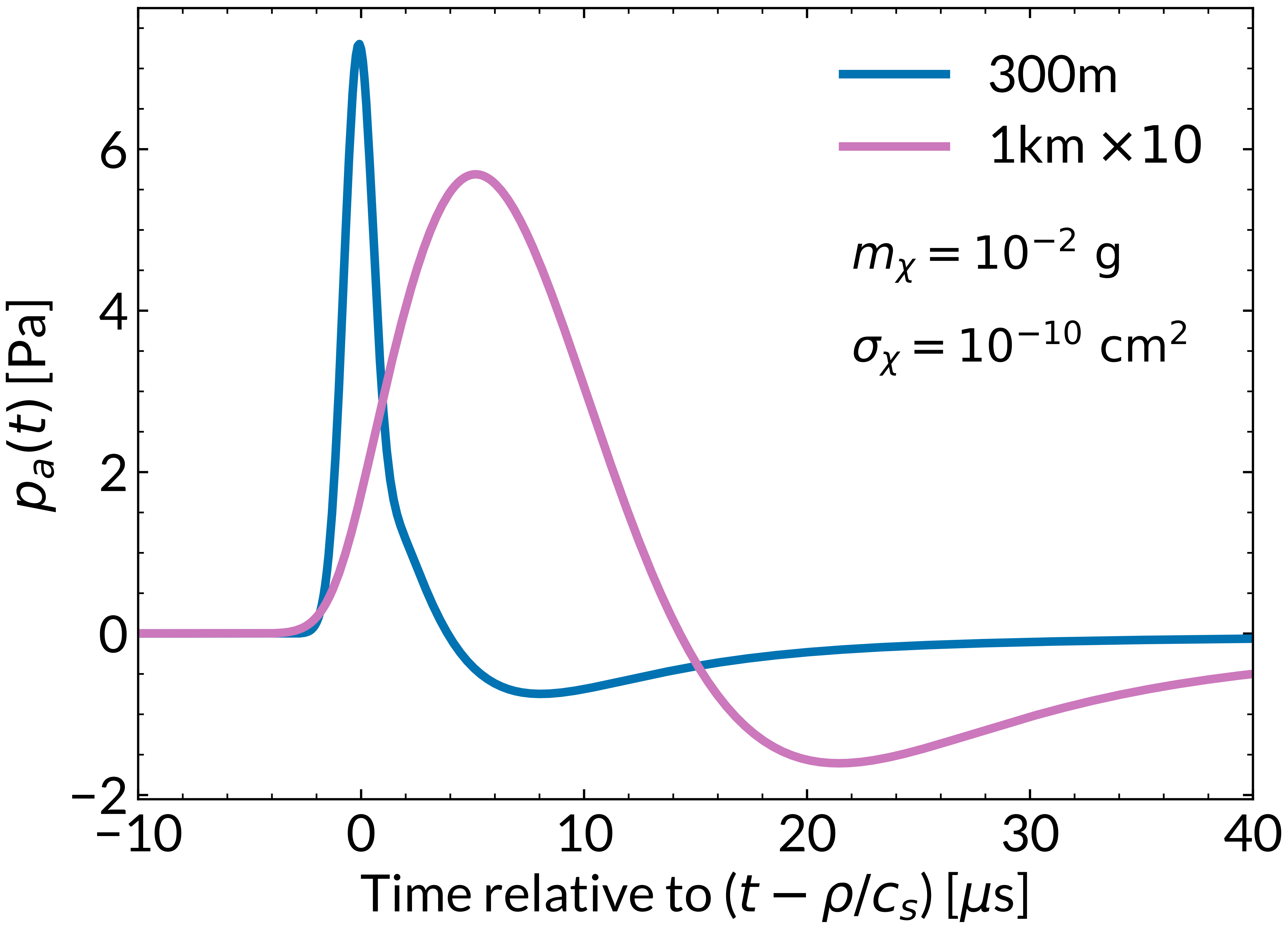

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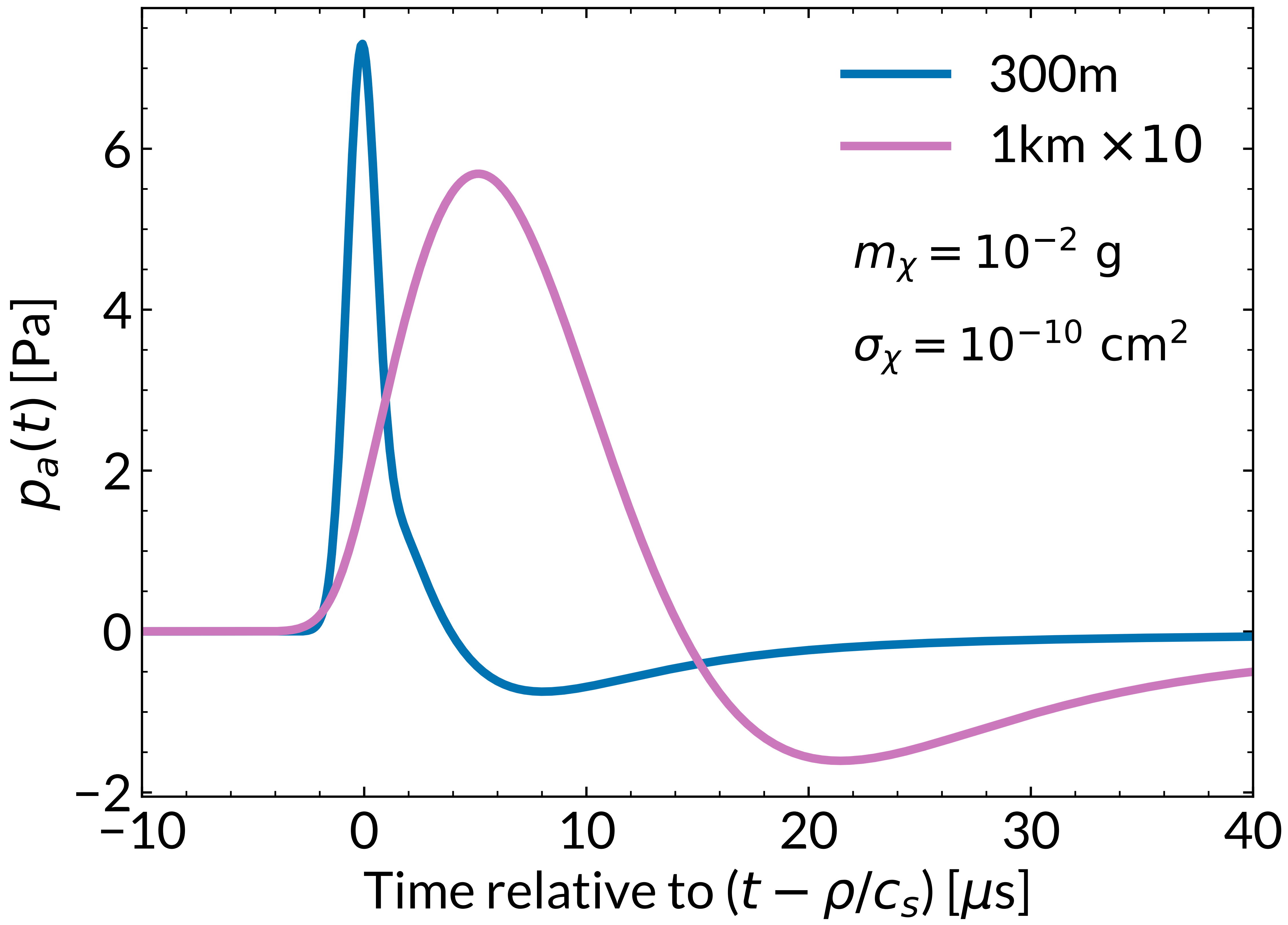

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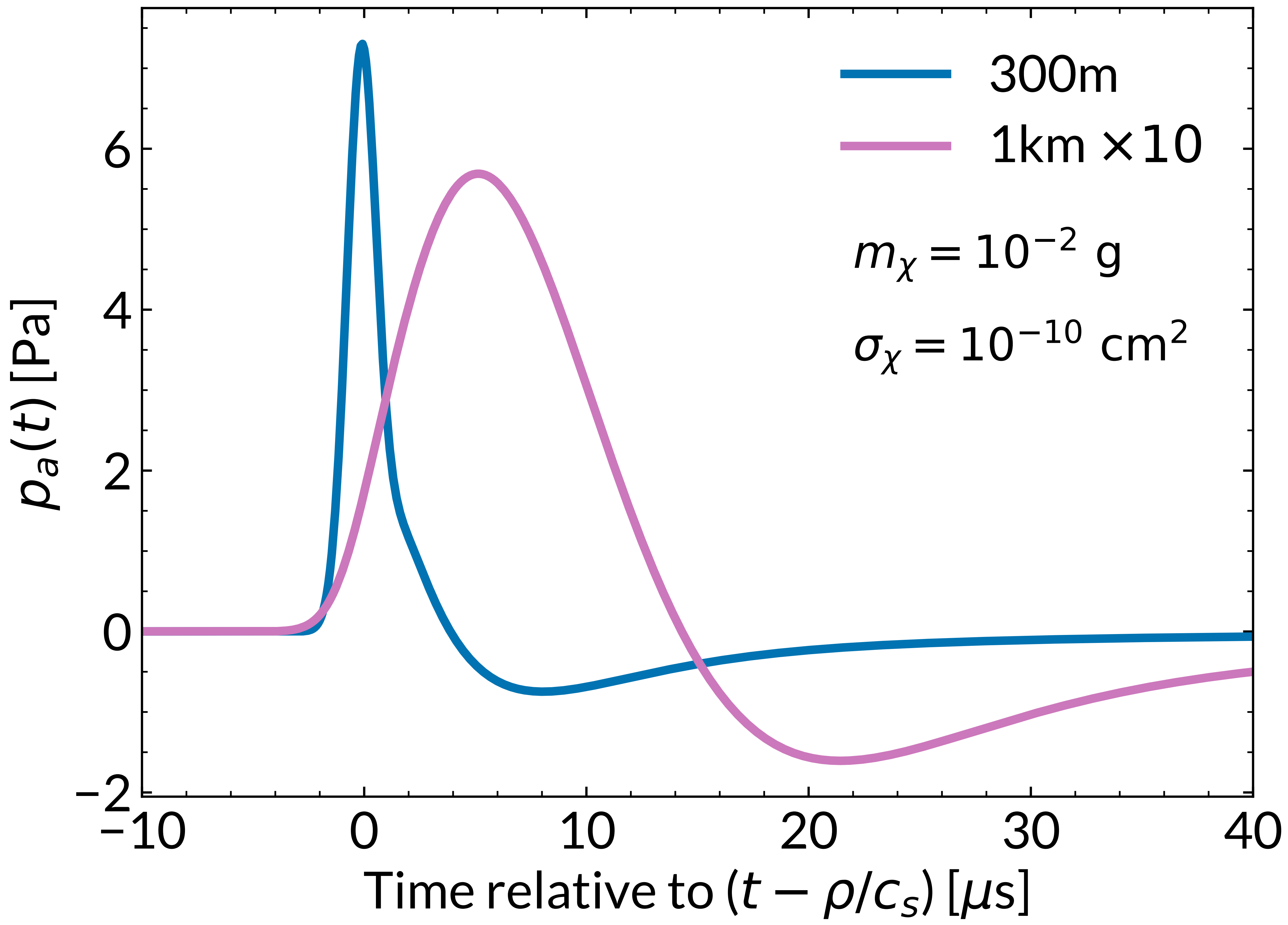

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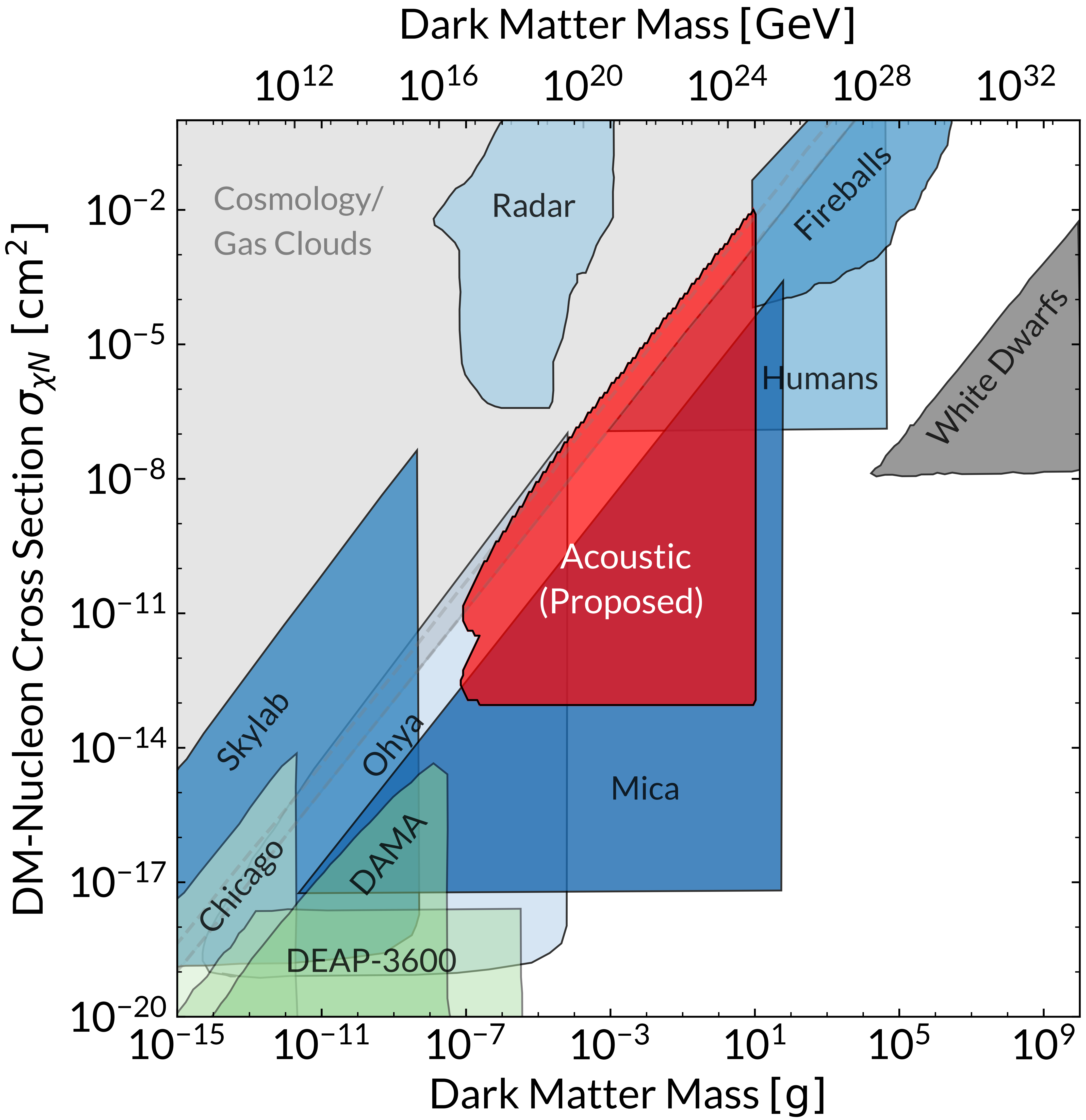
Preliminary Sensitivities



- Assuming proposed acoustic neutrino experiment parameters, **could constrain the gap!**
- Array Geometry: 10km x 10km x 1km with 13 x 13 x 10 hydrophone distribution. 2km depth.
- Requirements $p = 5$ mPa, $\rho = 300$m, $N_{\text{events}} \geq 100$/yr
- Complementary to Humans, Mica, Ohya and Cosmological Bounds

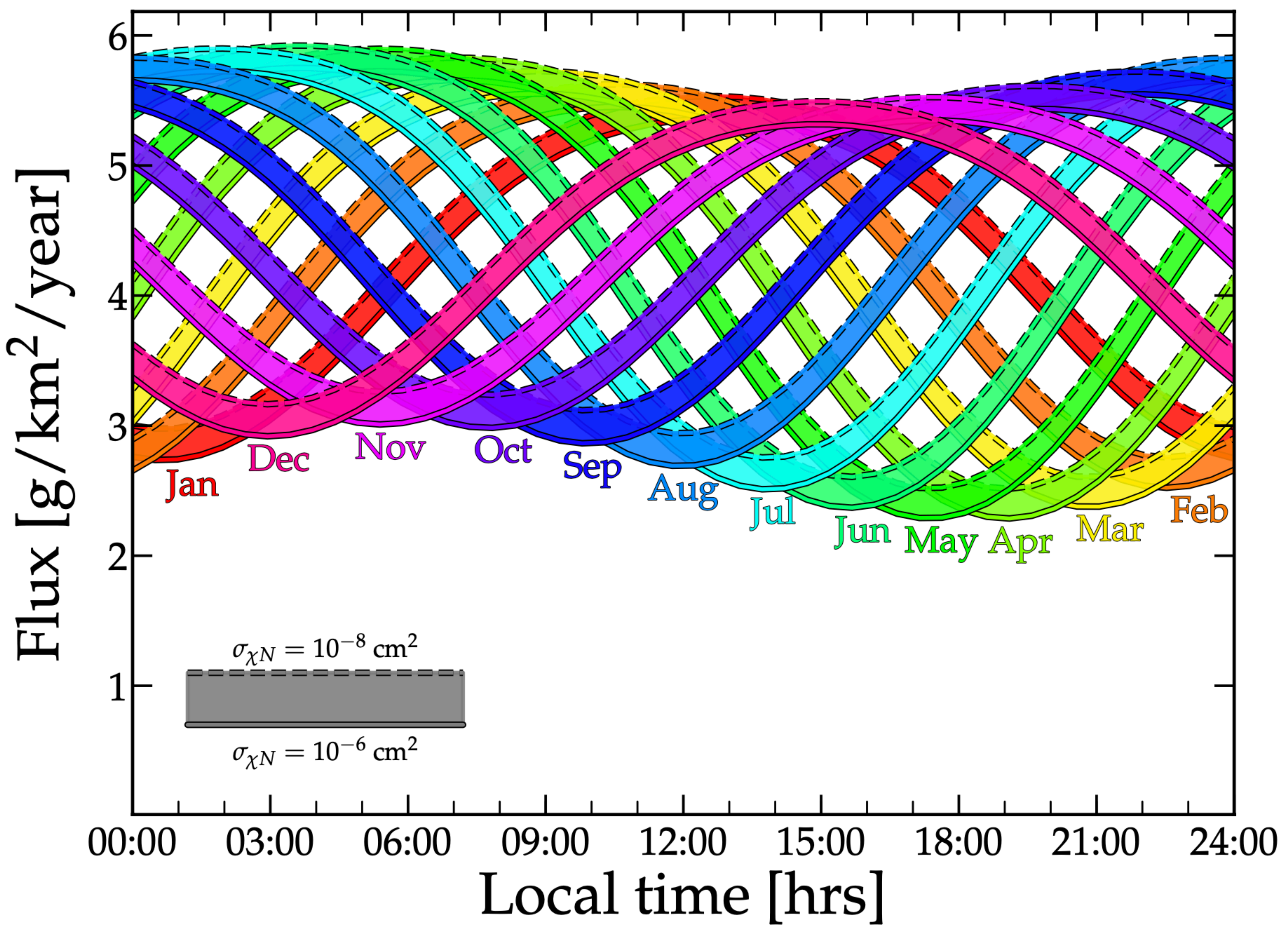
Punchline:

Future acoustic neutrino experiments could have the power to constrain UHDM candidates

Thank you for listening!
Any Questions?

Backup slides

Discerning Neutrinos from DM



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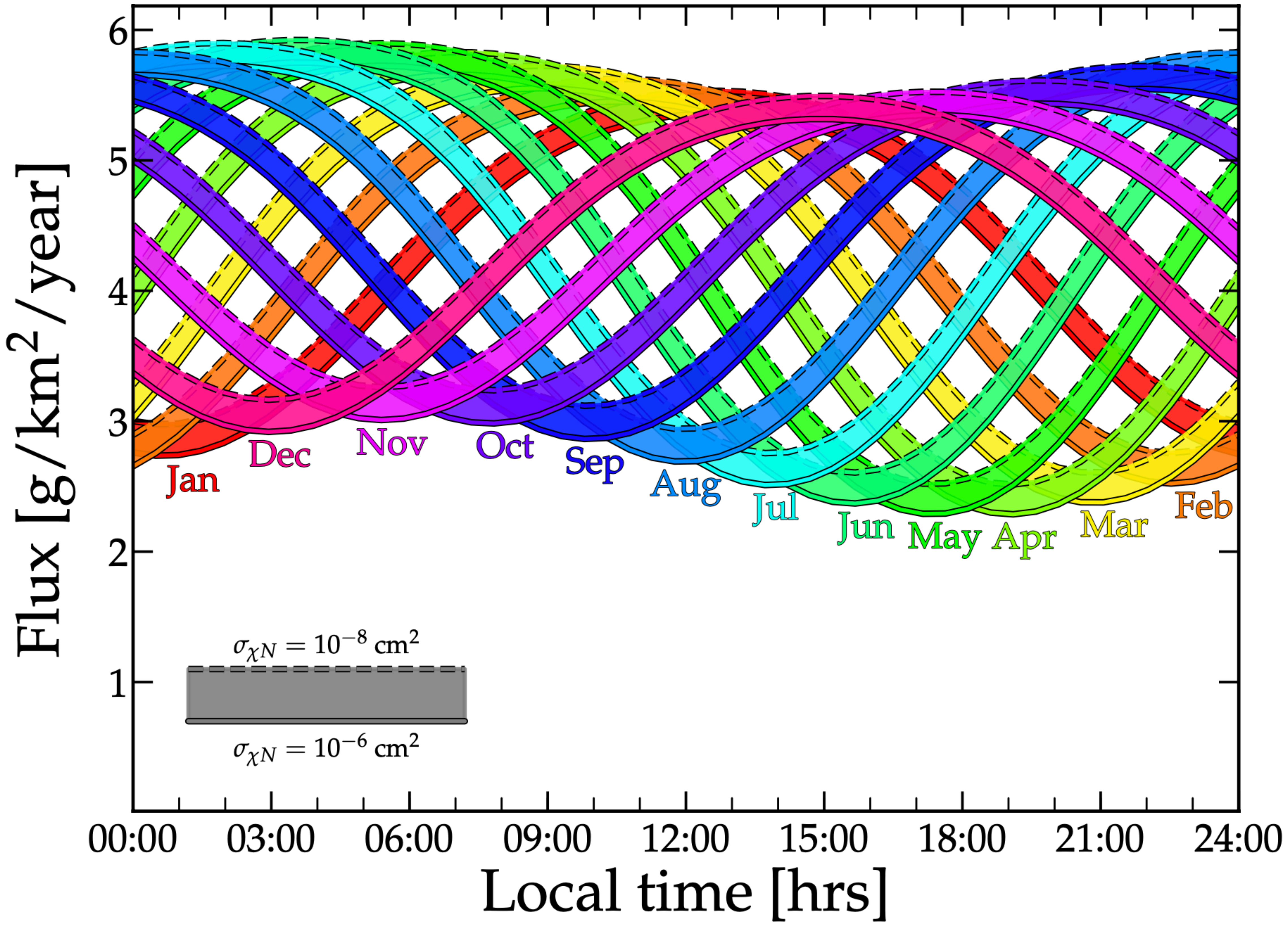

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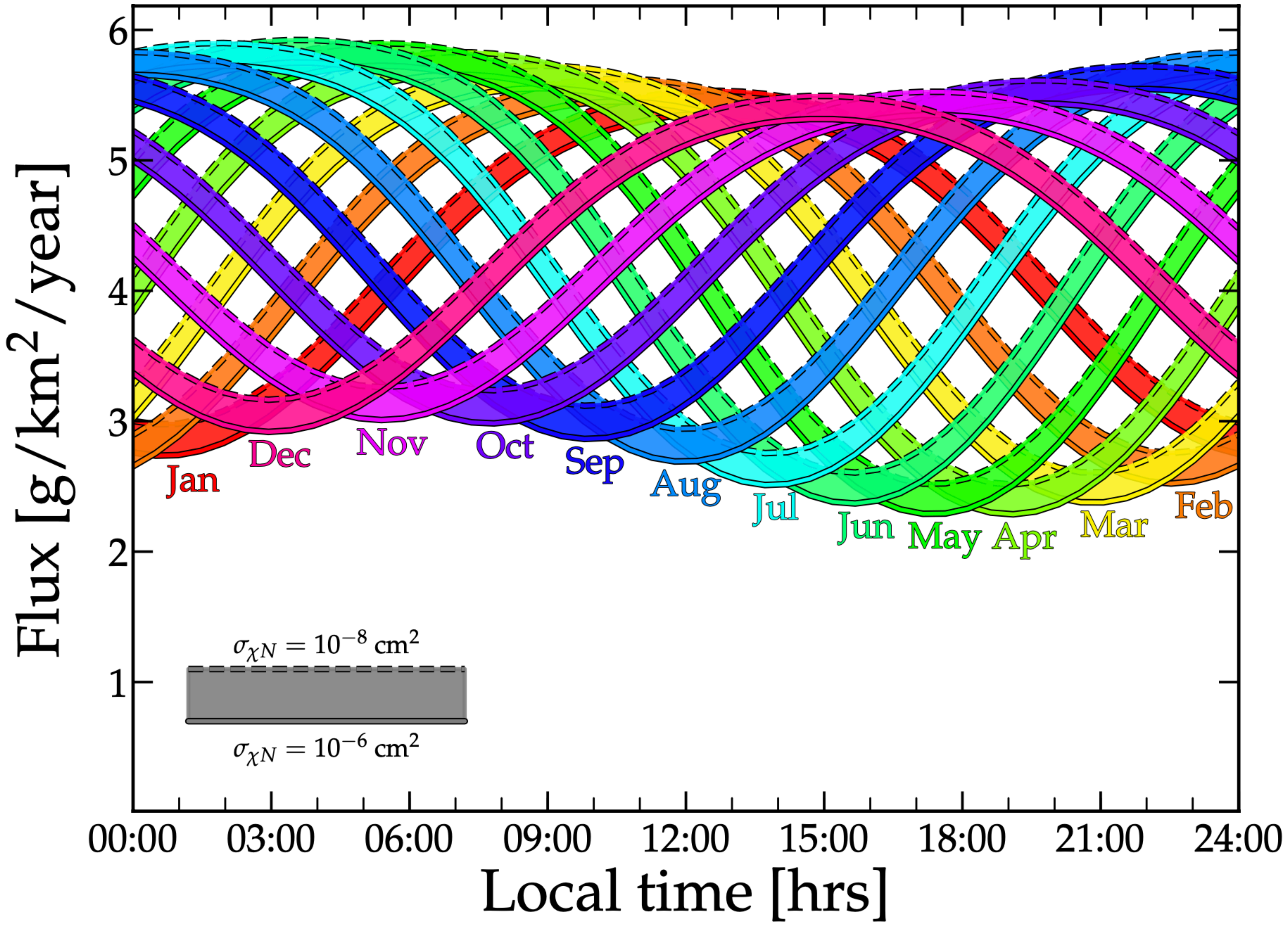

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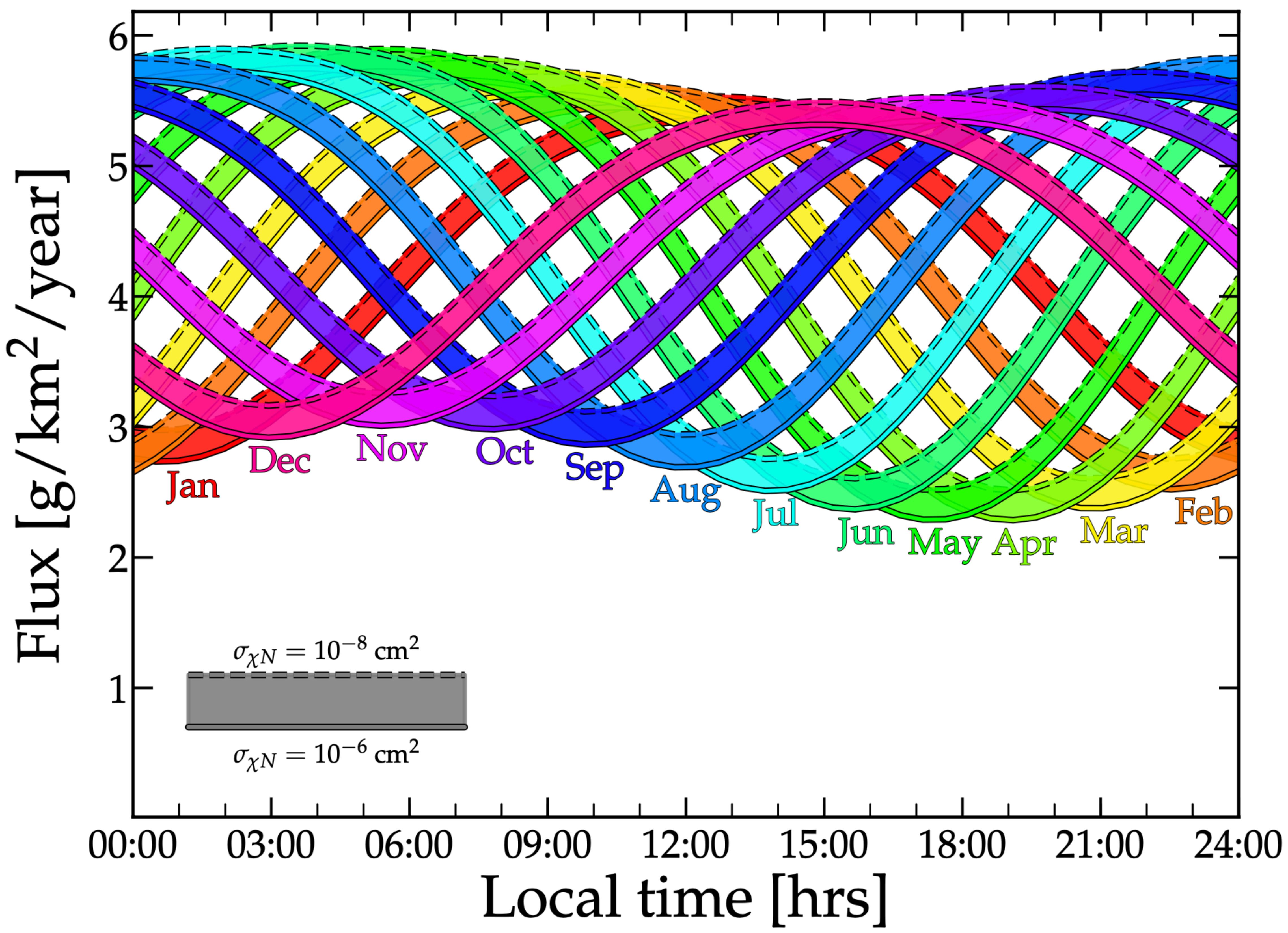

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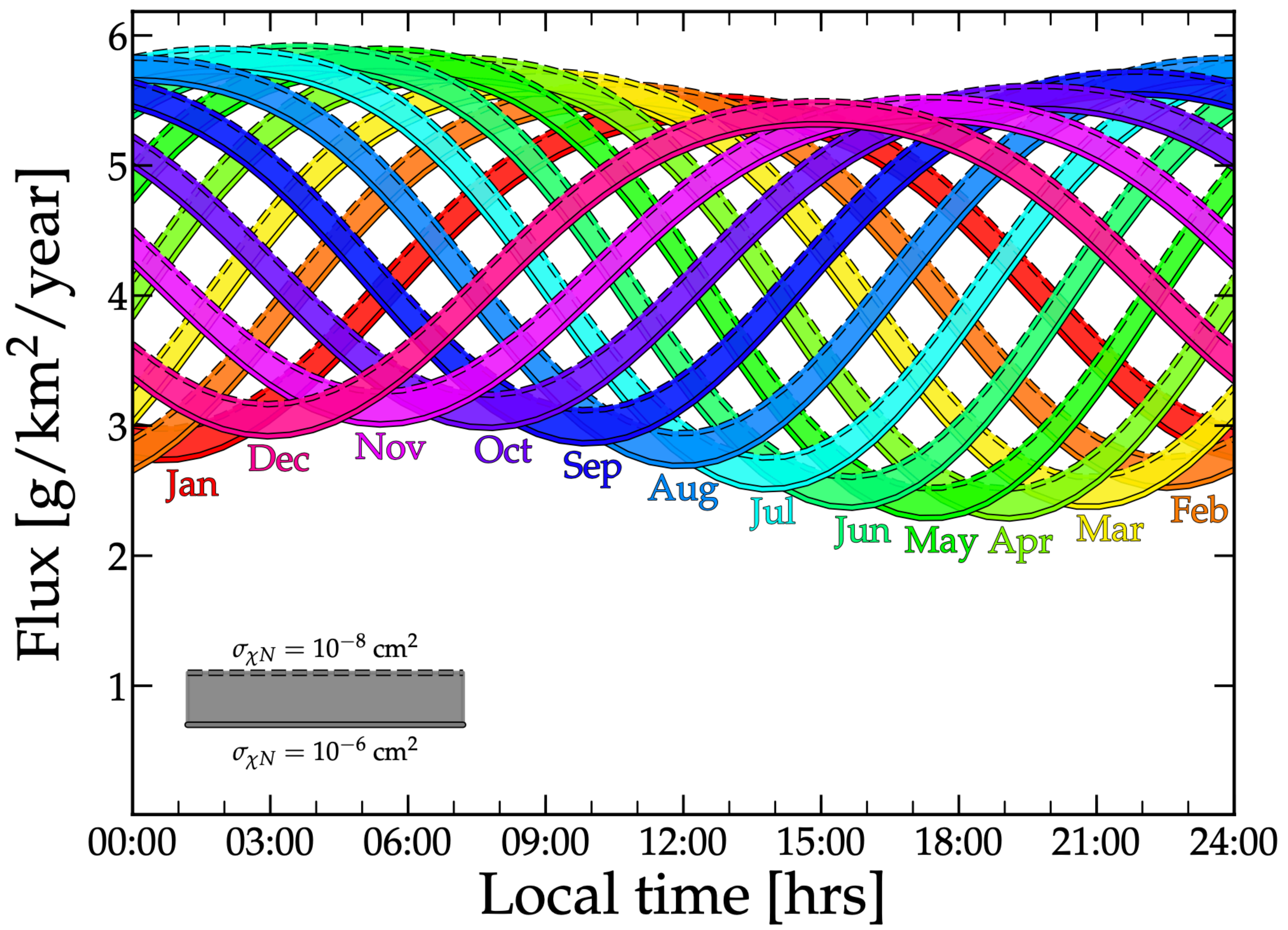

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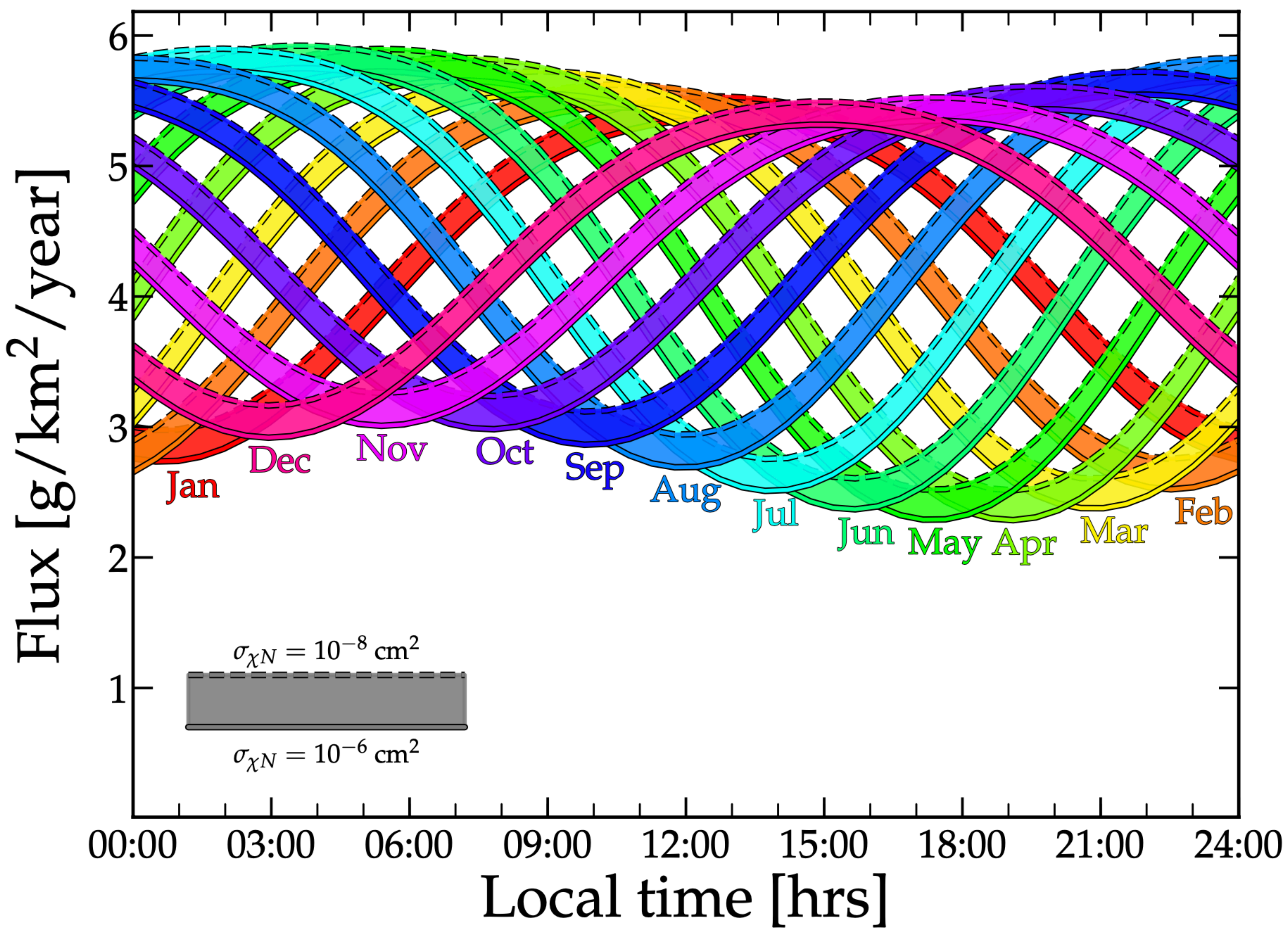

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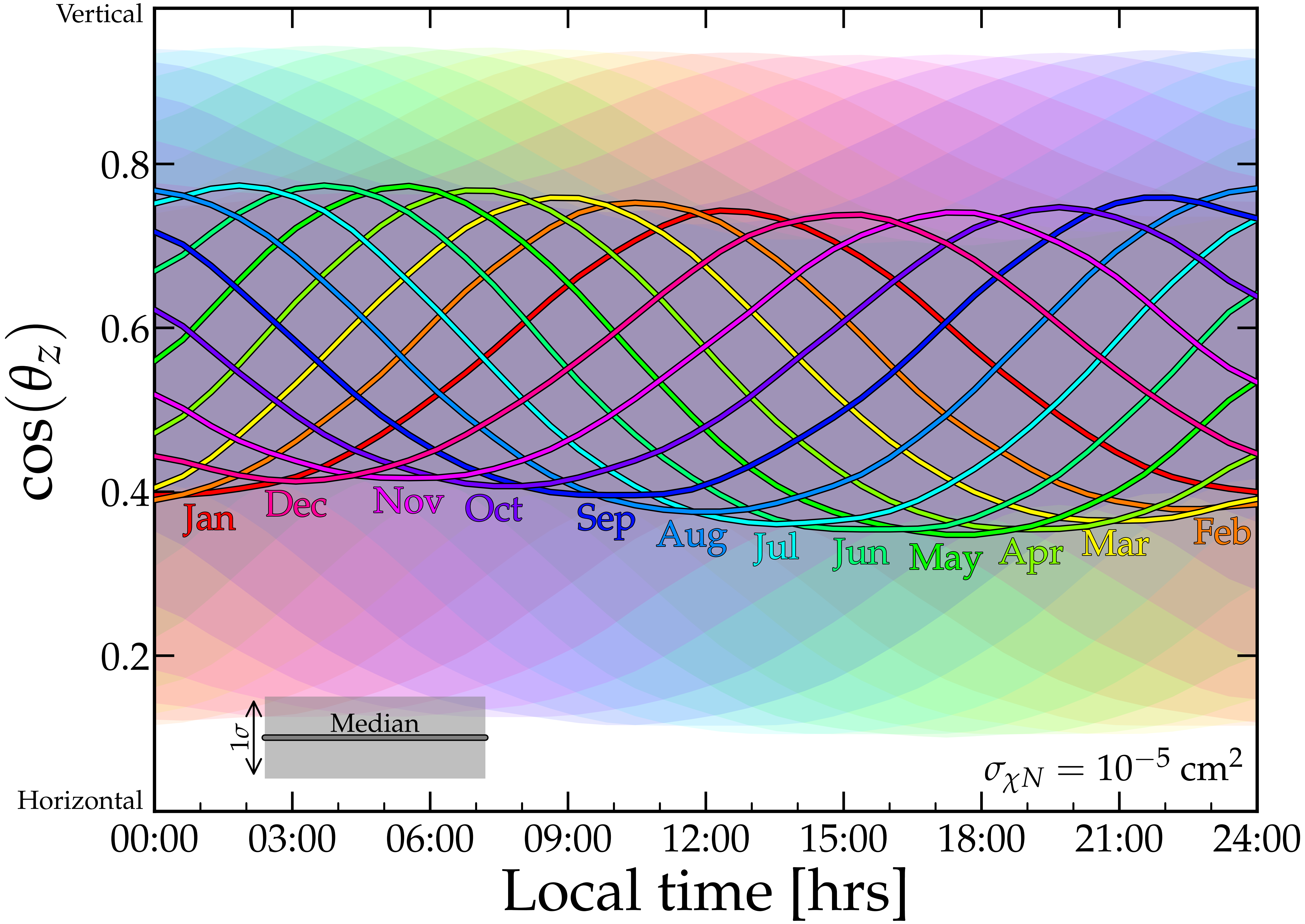
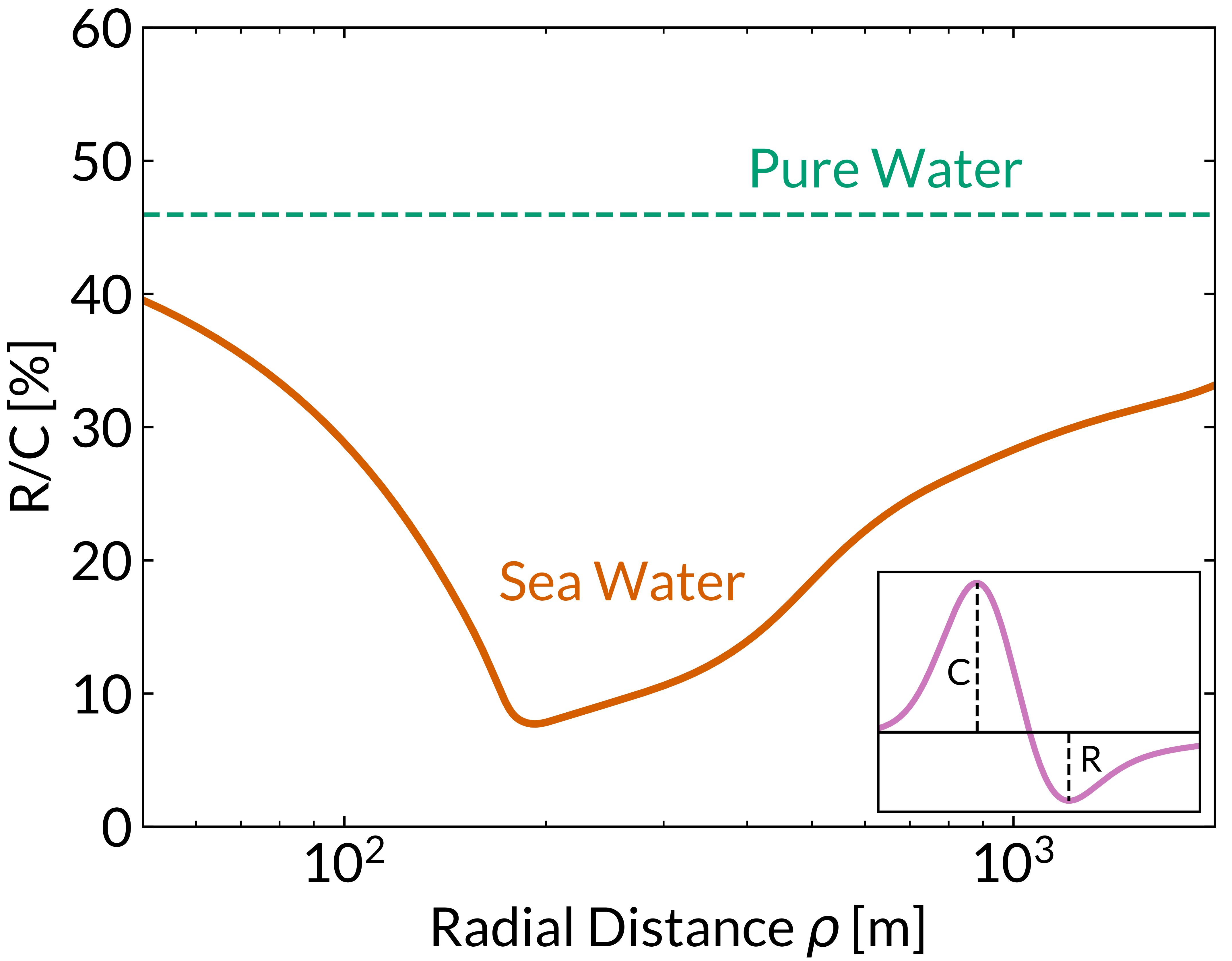
Angular Entry to Array



Pulse Asymmetry



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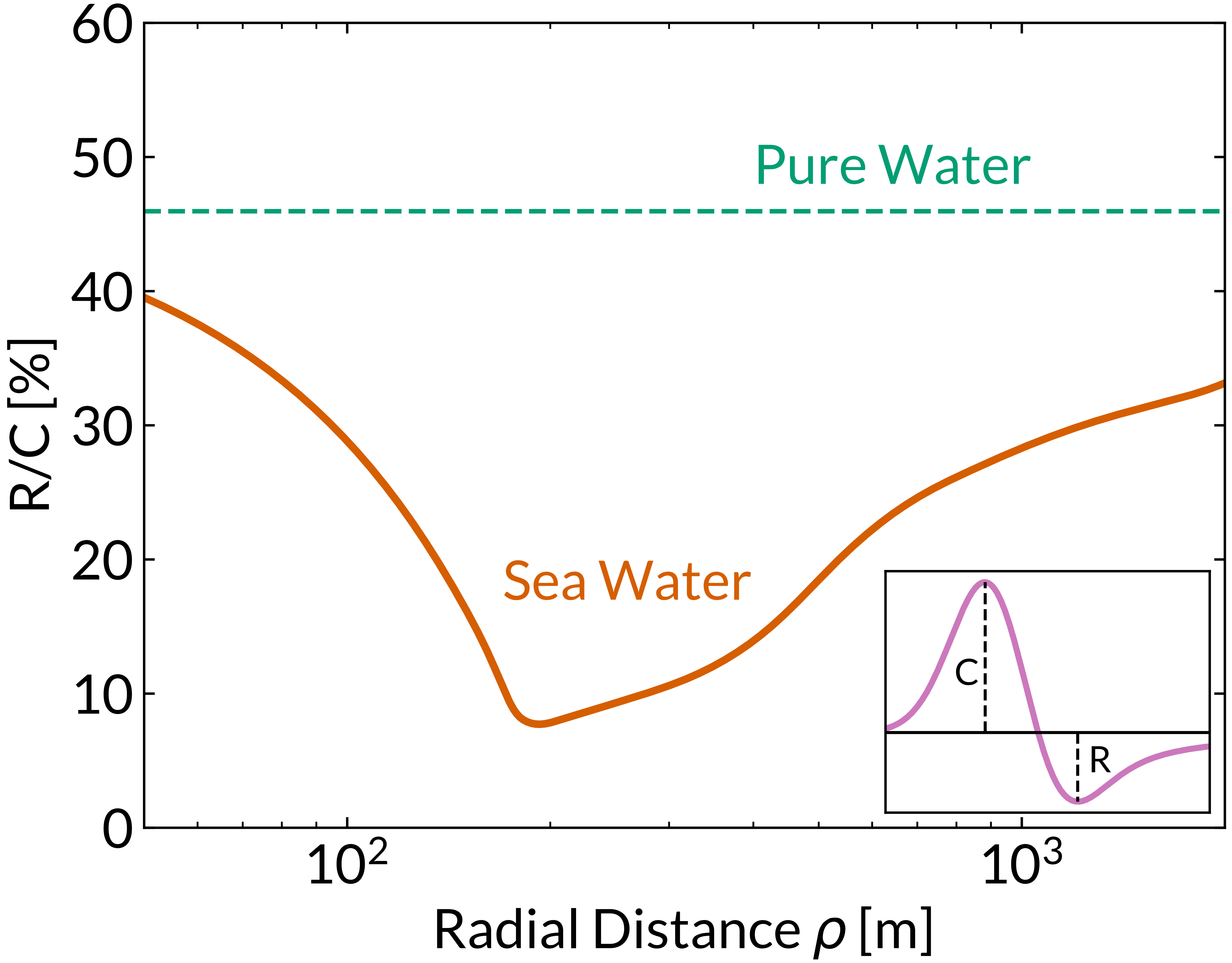

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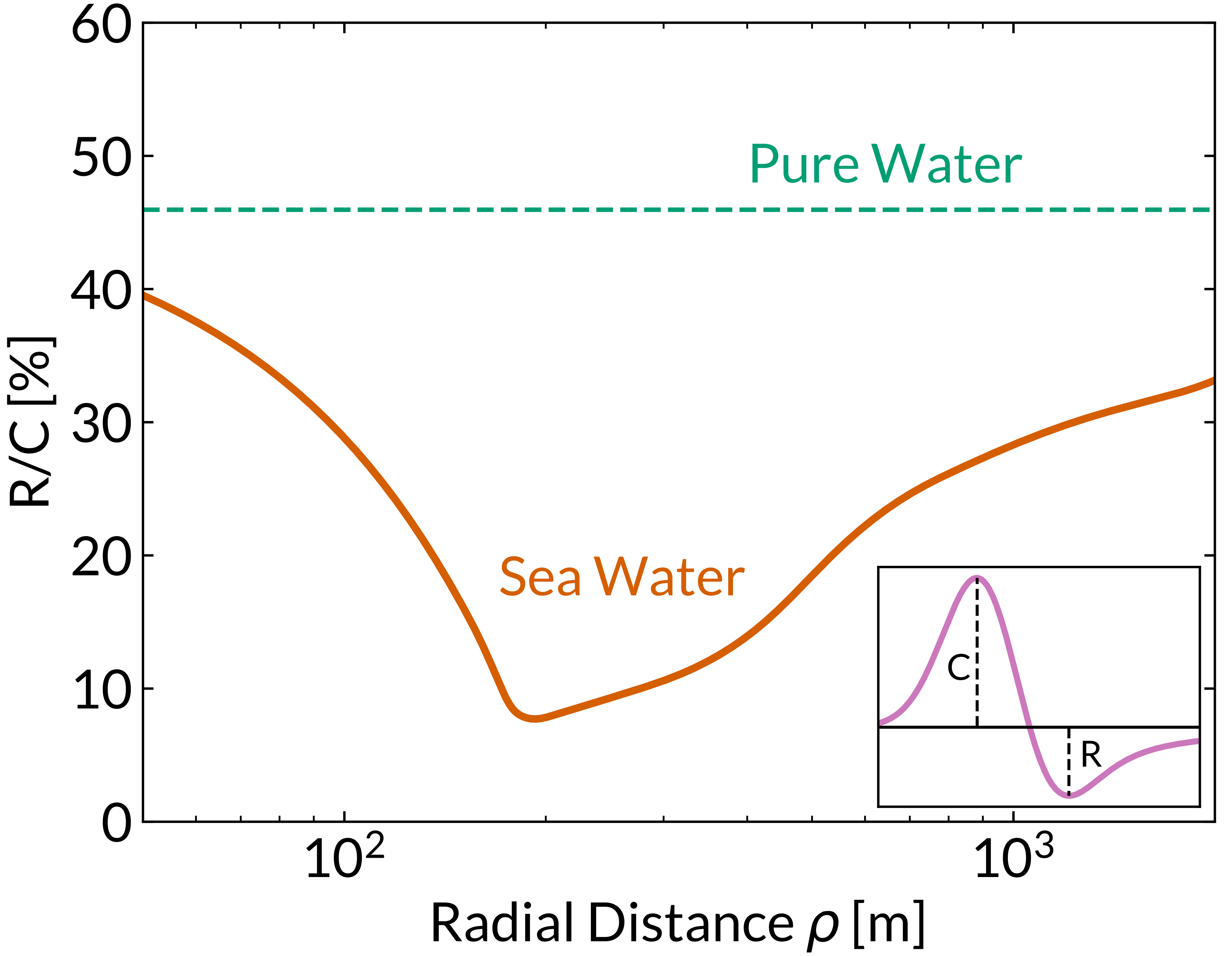

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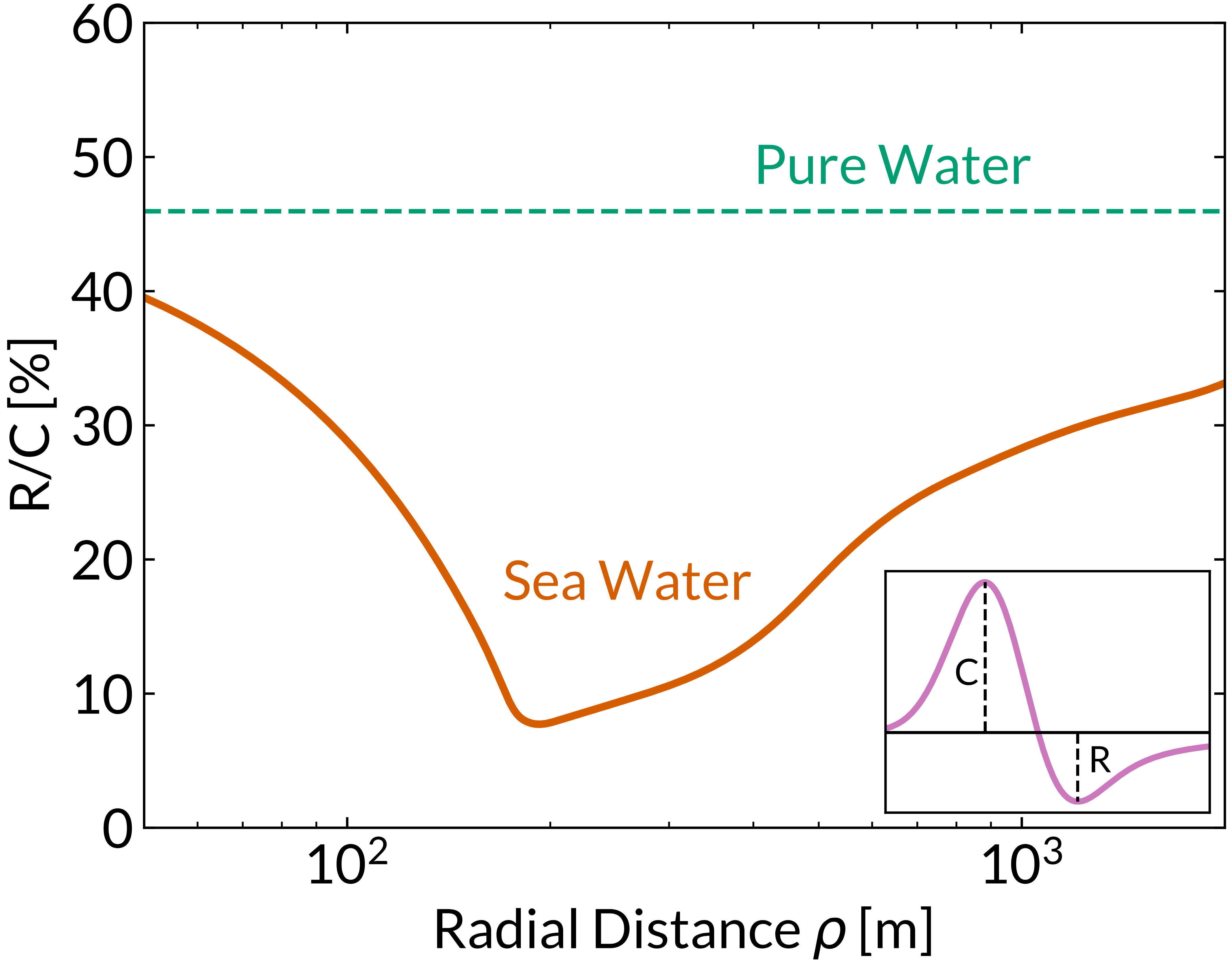

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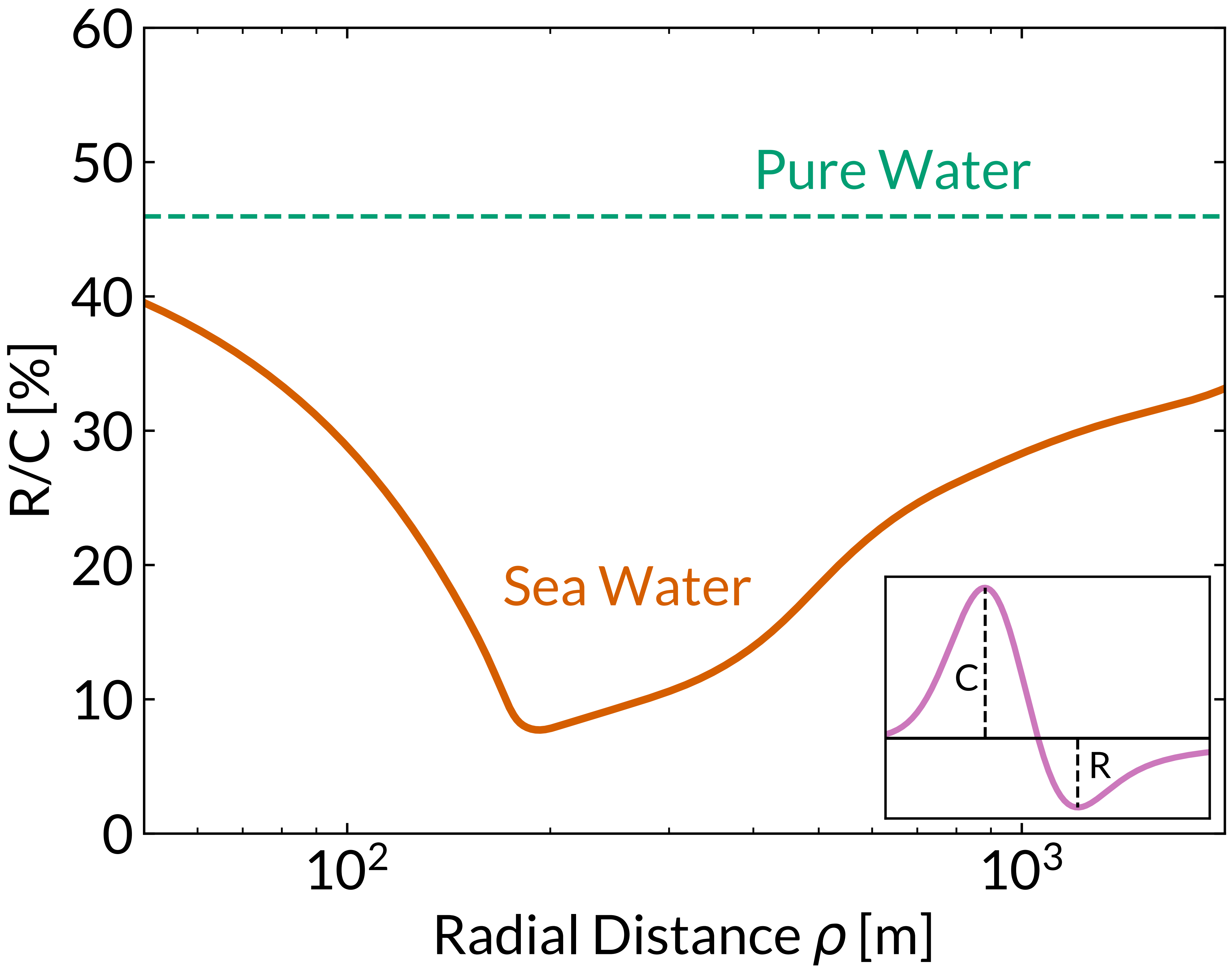

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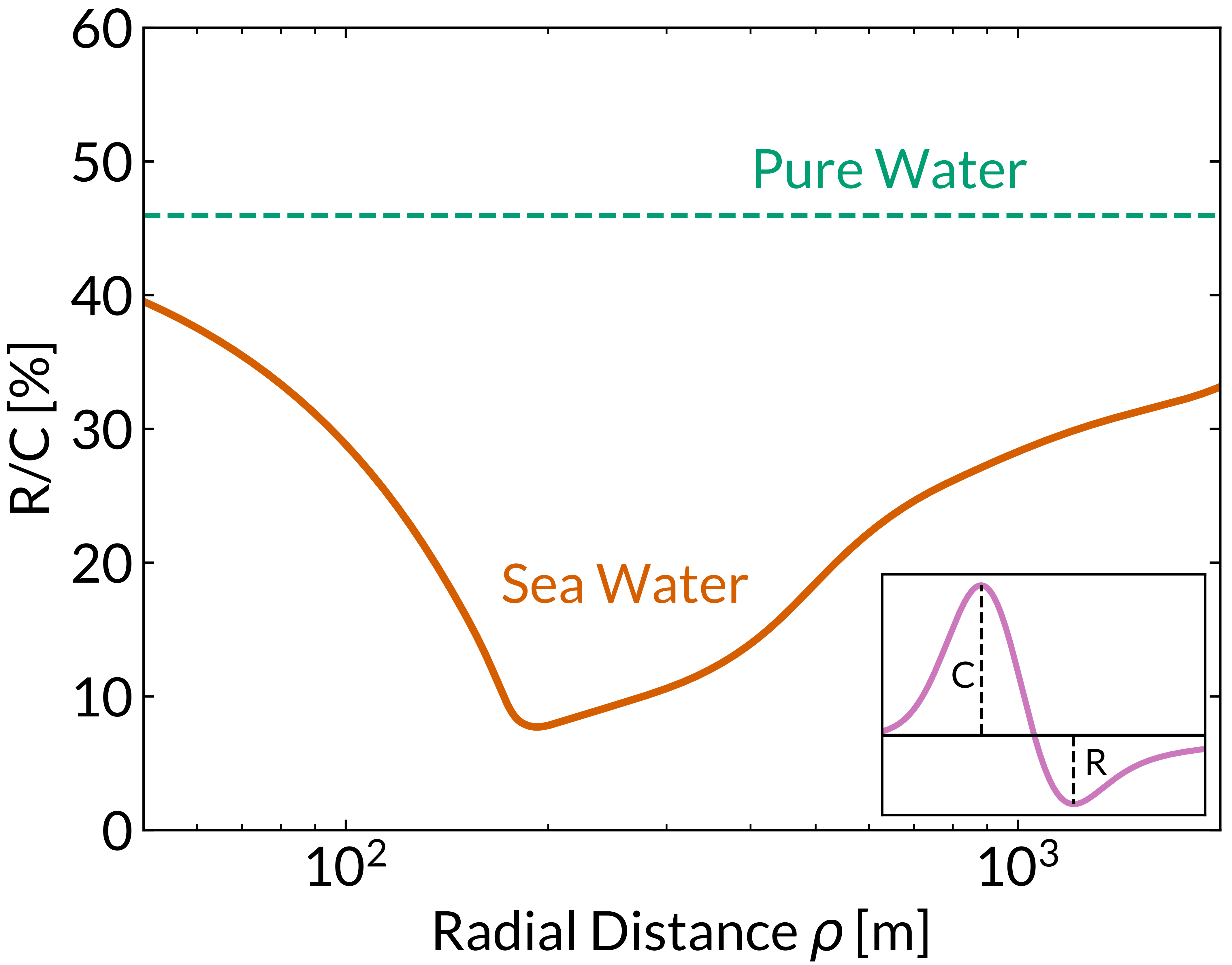

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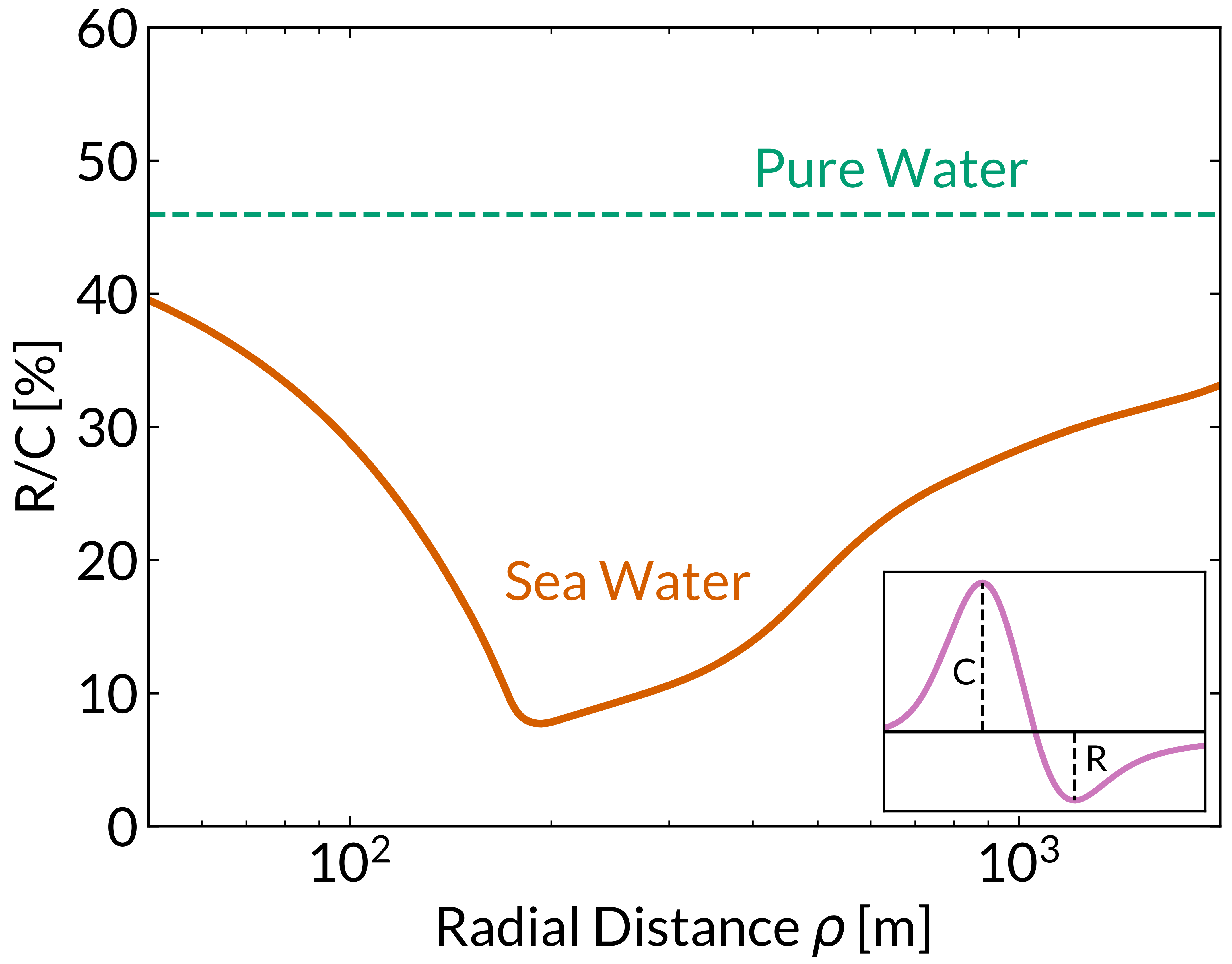
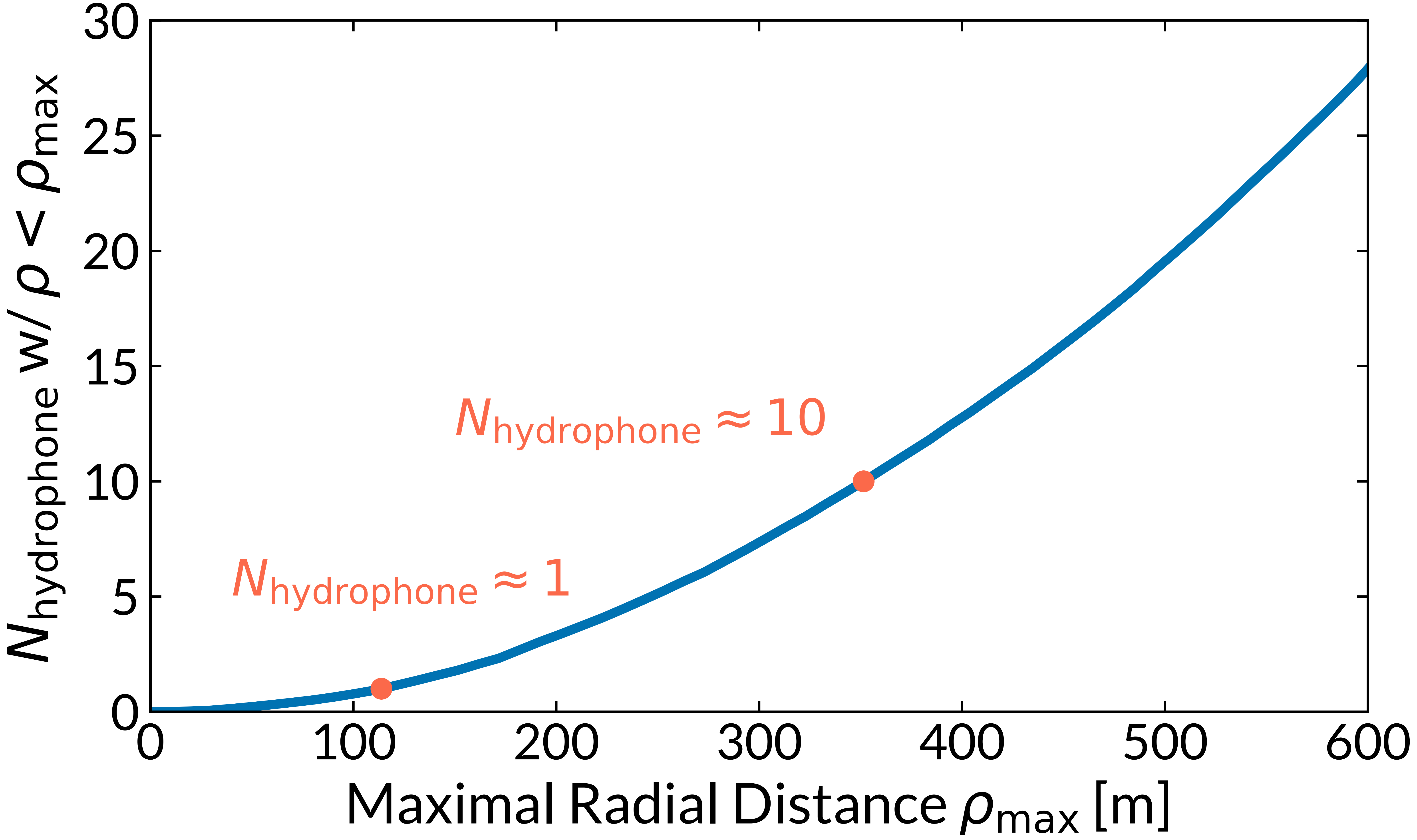
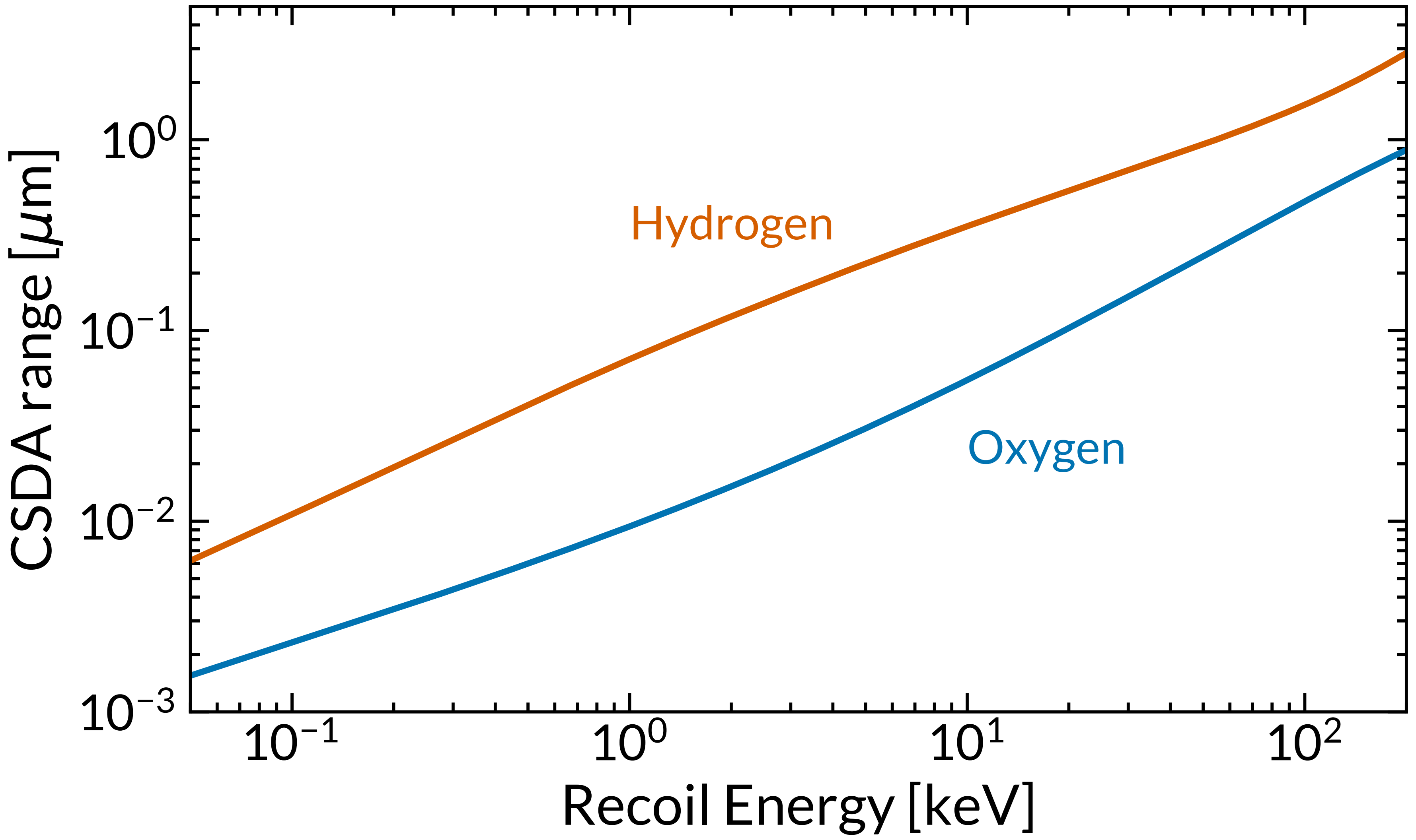
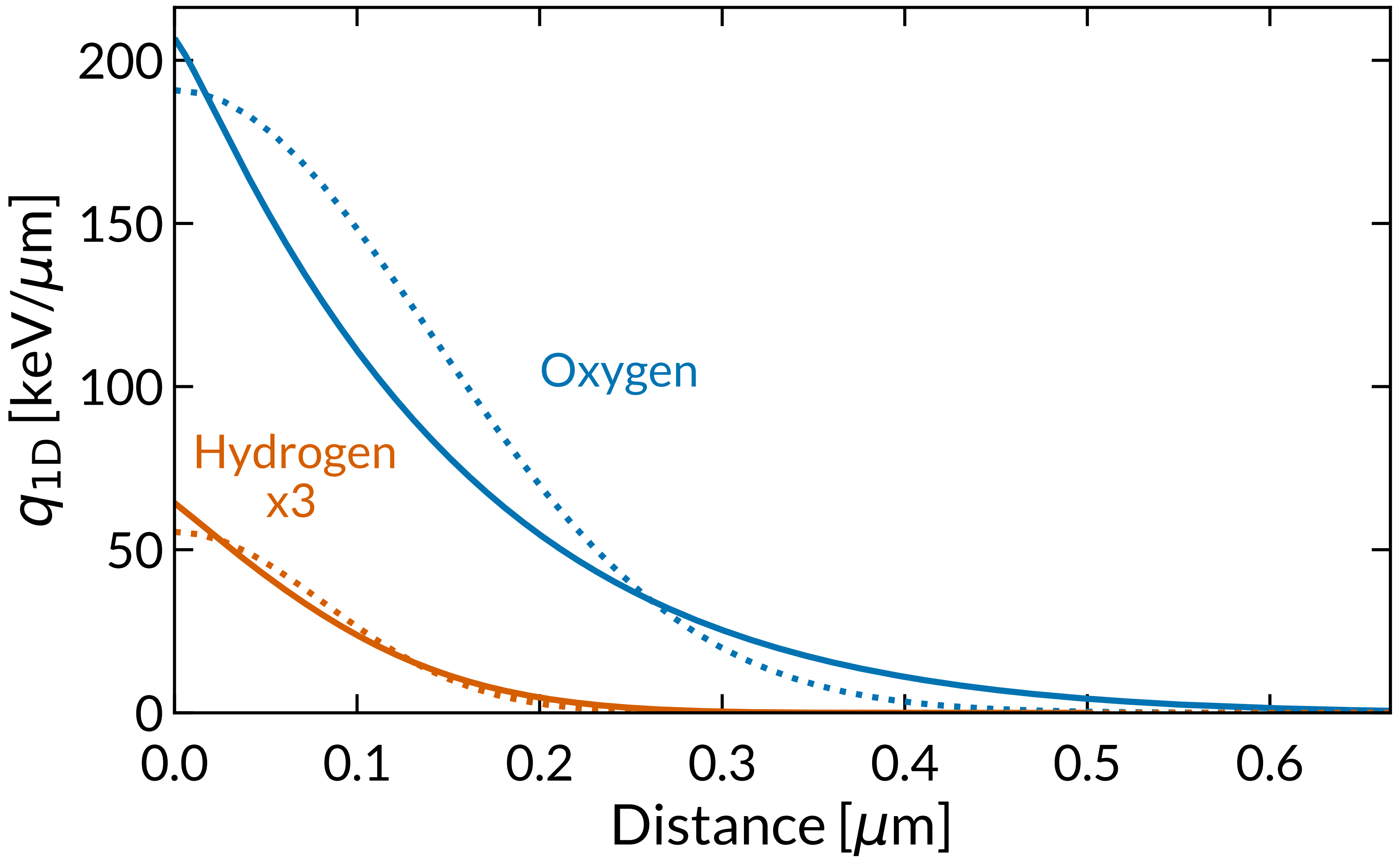


Finding a good hydrophone distance



Track Width + Gaussian Approx





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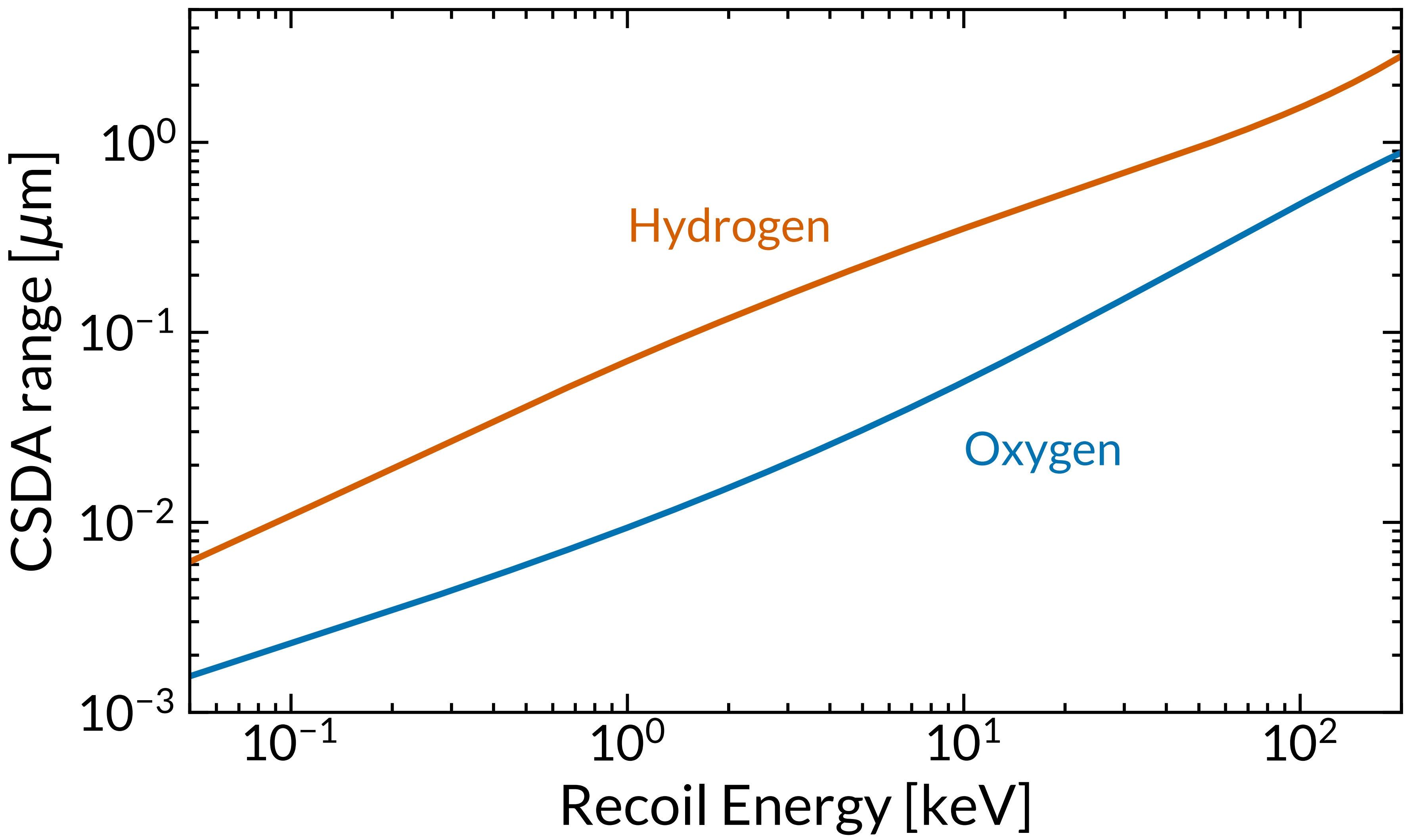

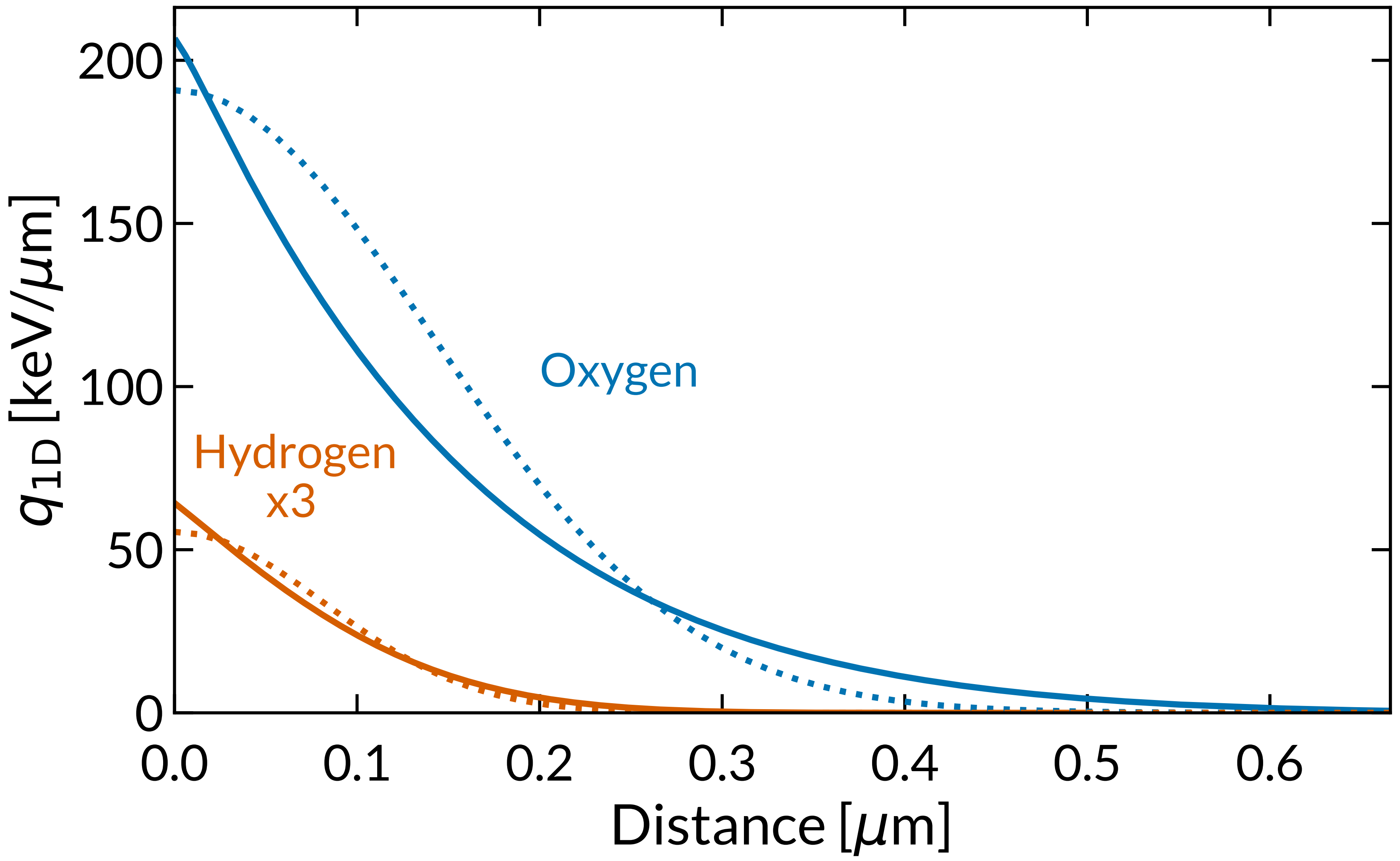

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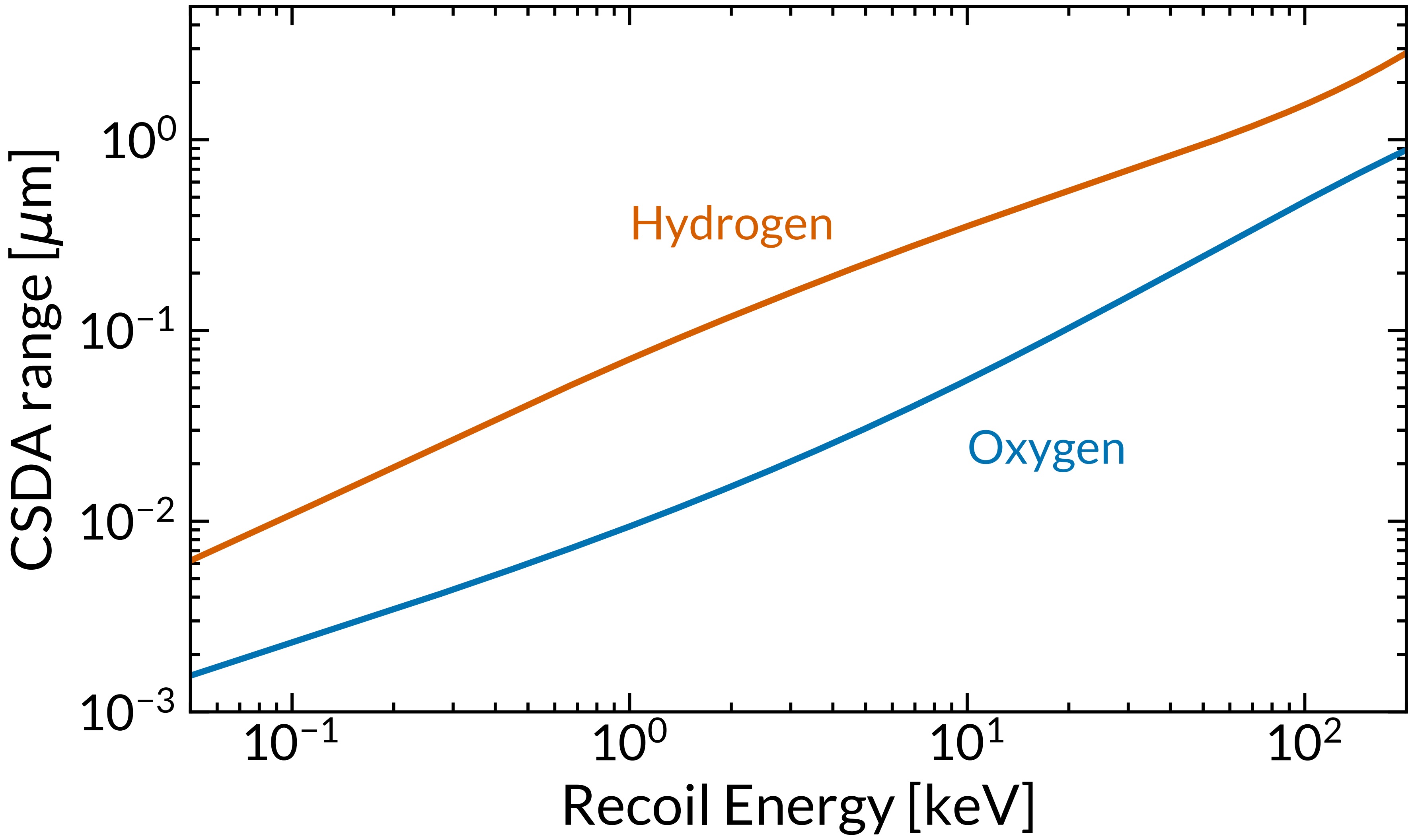

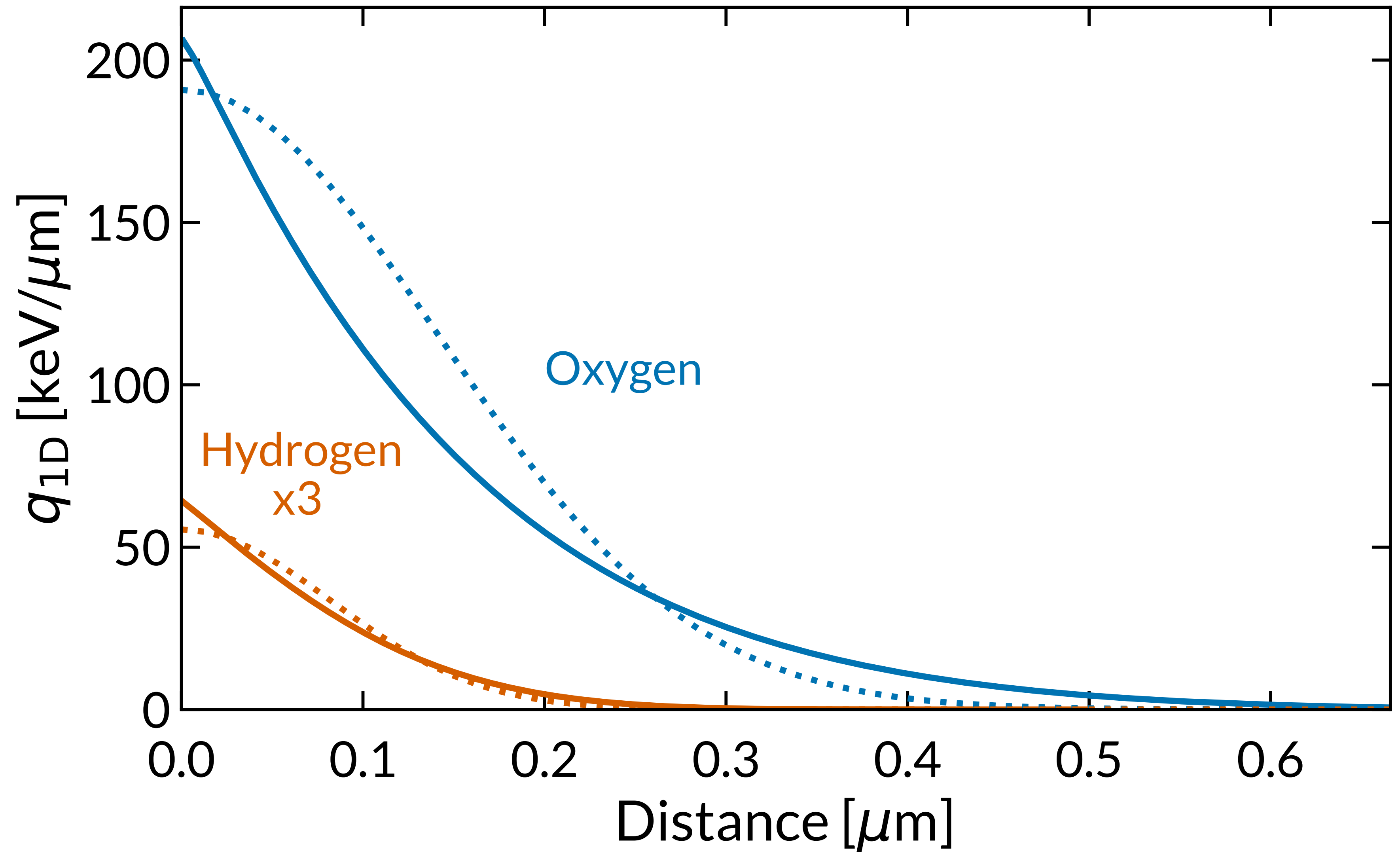

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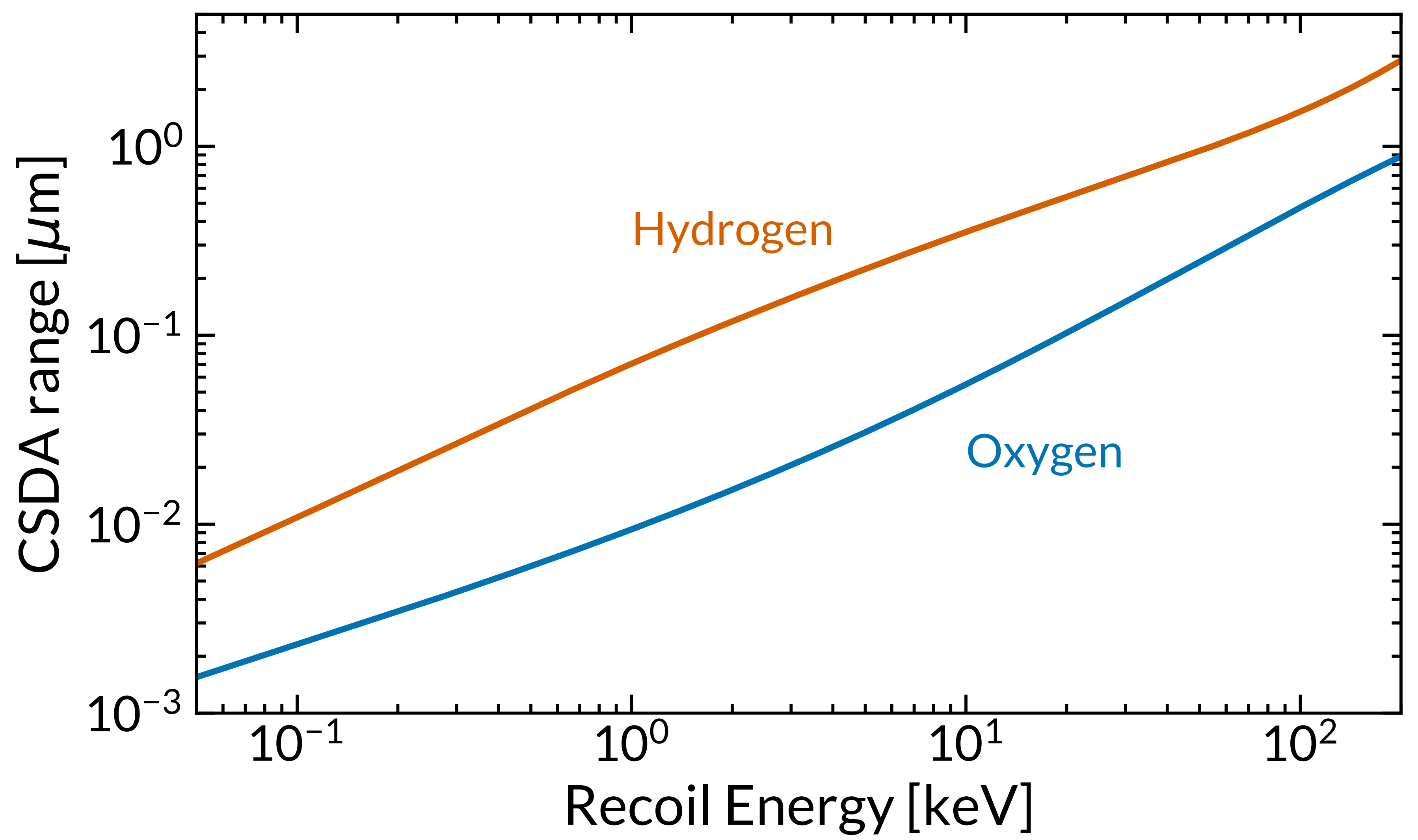

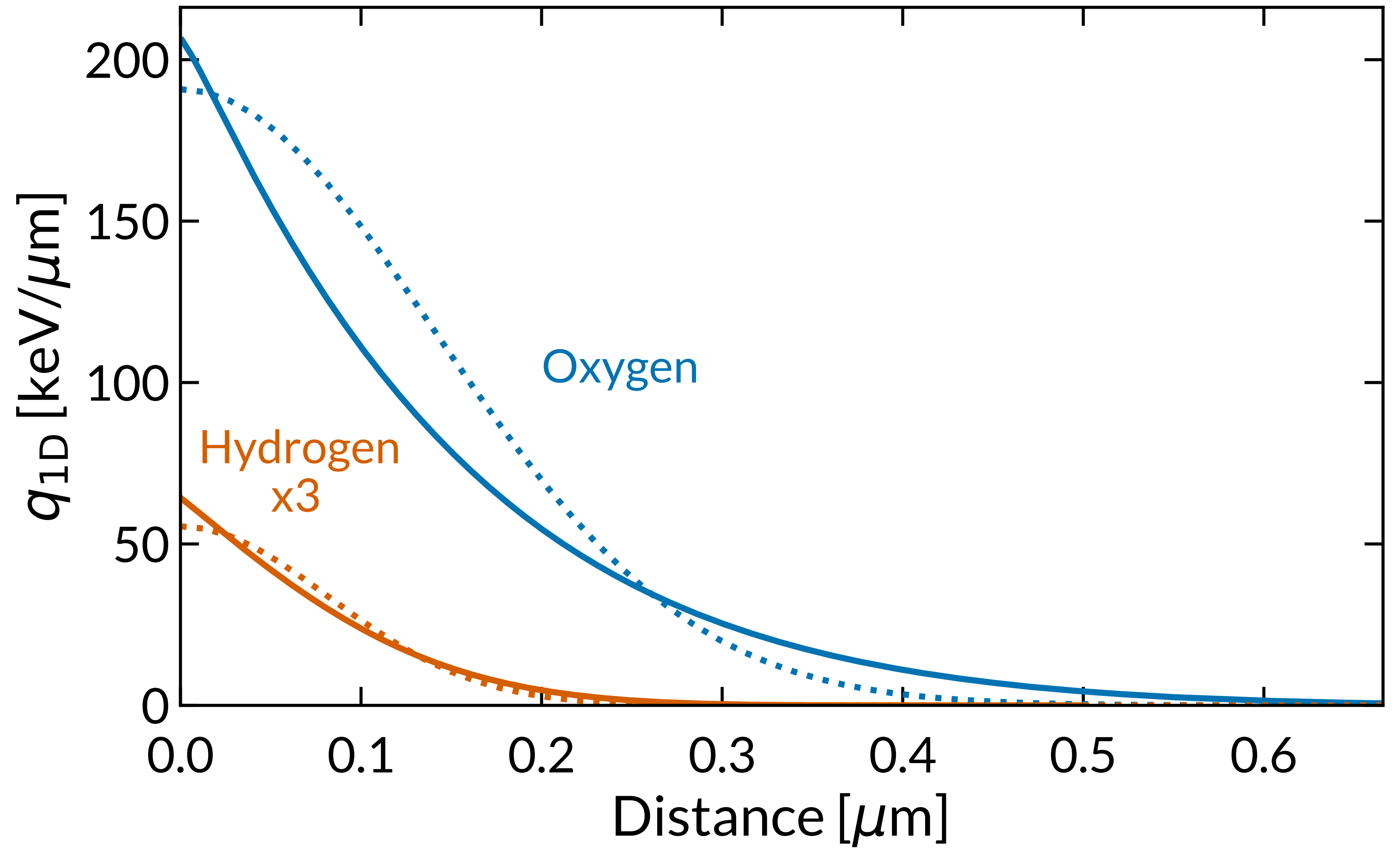

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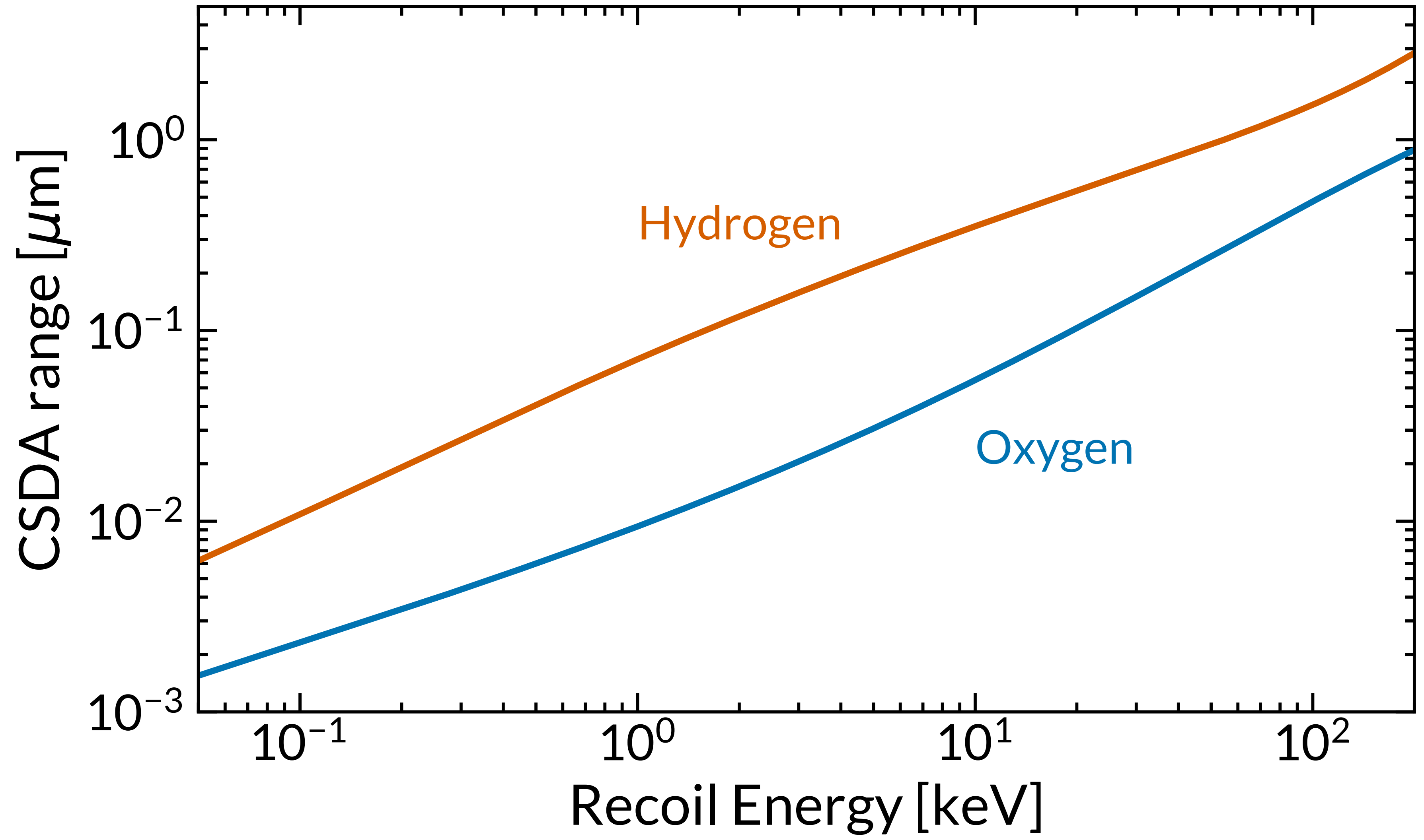

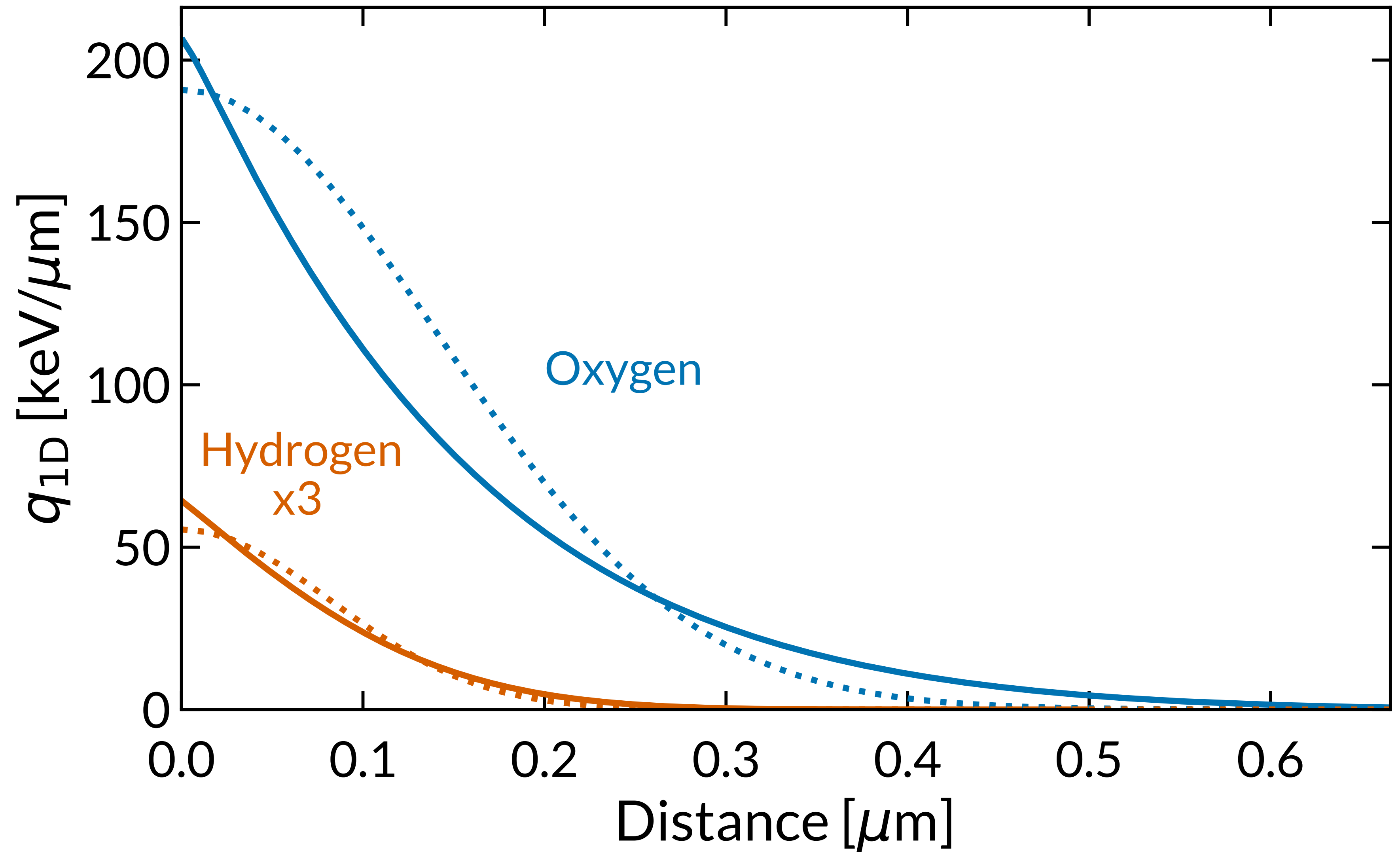

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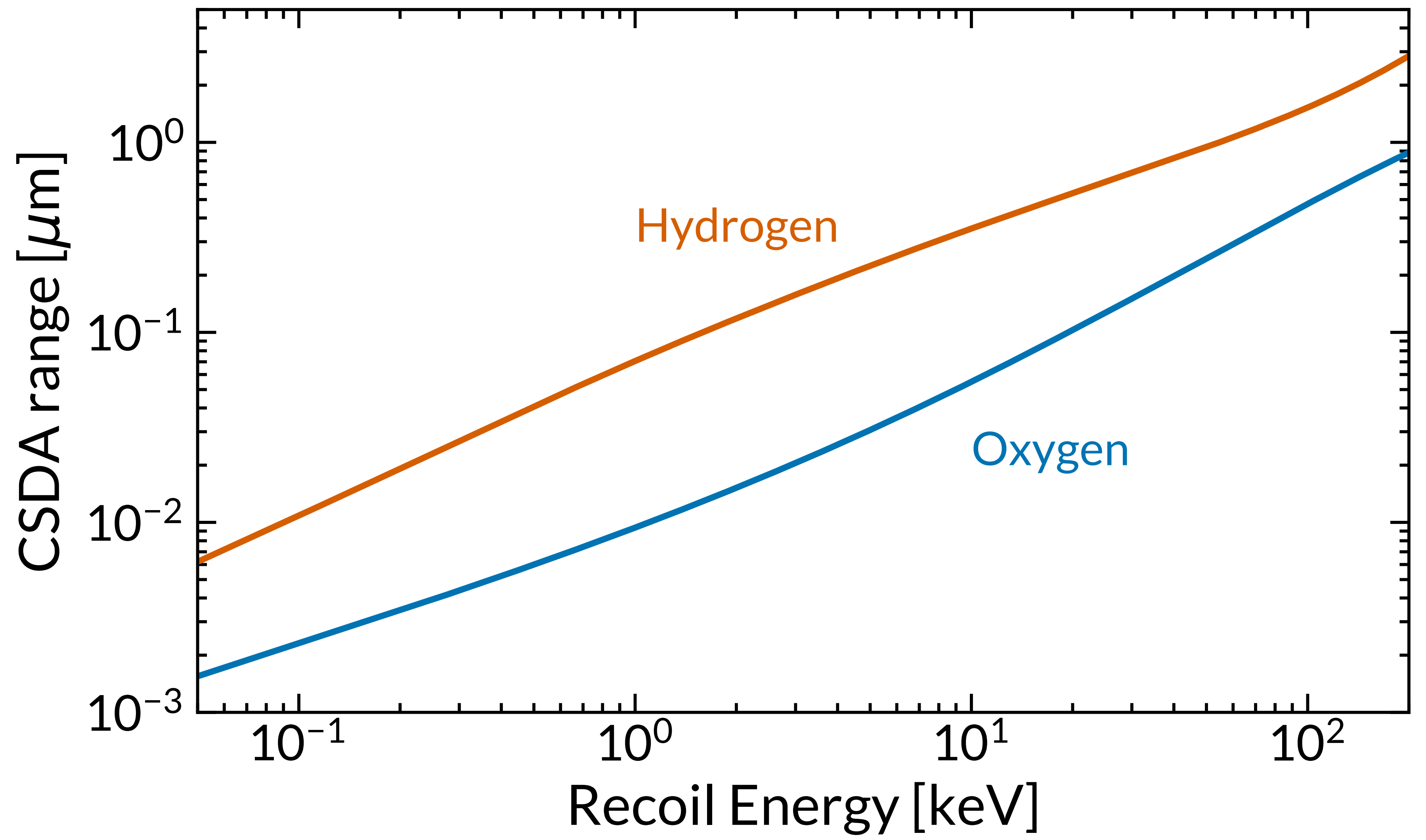

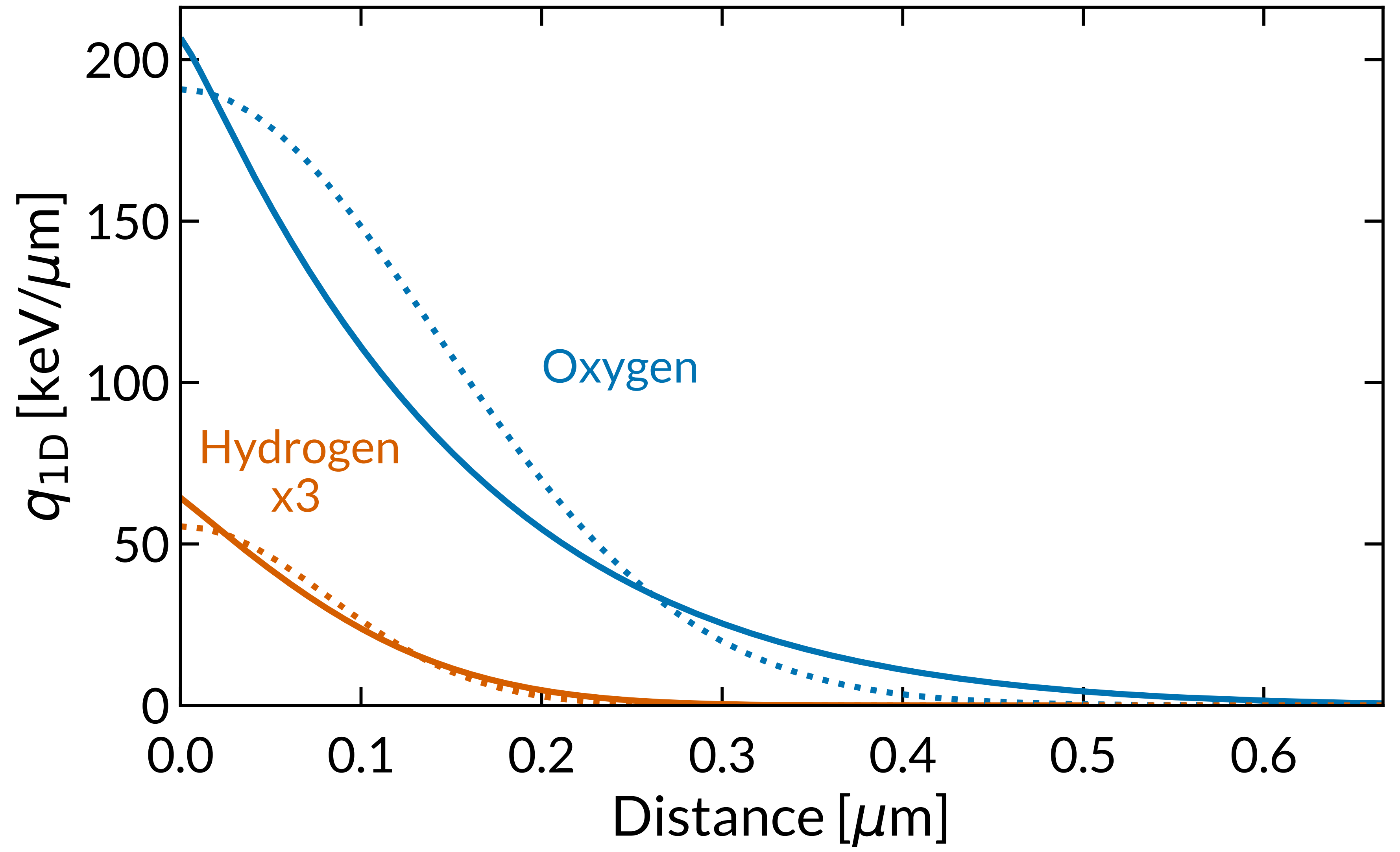

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$$p(\rho, z, t) = \frac{\alpha}{4\pi c_p} \frac{dE}{dz'}\bigg|_{z'=z} \frac{\partial}{\partial t} \left(\frac{e^{a(c_s\sqrt{t^2 - t_0^2})}}{\sqrt{t^2 - t_0^2}} \Theta(t - t_0) \right).$$

Short Track Case

If we let the DM energy evolve but with no track width:

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