Dissipative Losses in Self-Interacting Dark Matter Collisions

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(in preparation)

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Probing properties of dark matter

Direct detection	Indirect detection	Production
Shake it!	Break it!	Make it!

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Shake it!	**Break it!**	**Make it!**

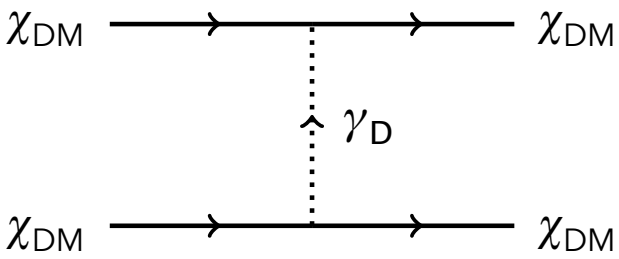
Astrophysical probes:
Structure formation

Bake it!

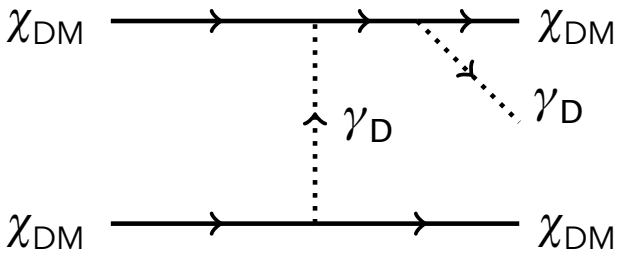
https://www.pinterest.com/explore/planet-cake

What is self-interacting dark matter and how does dissipation matter?

Dark matter self-interaction



Dissipation of energy in form of bremsstrahlung



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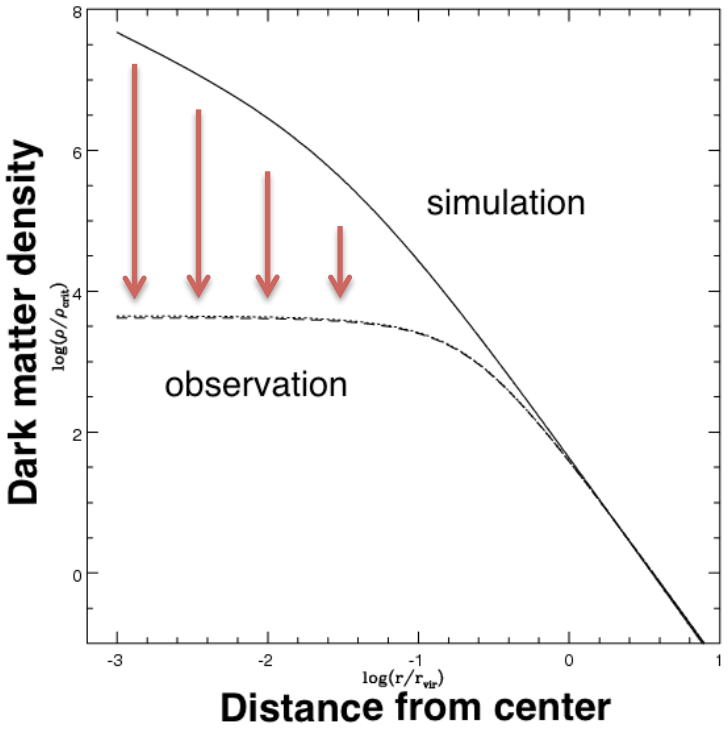
Self-interactions introduced to solve small structure problems



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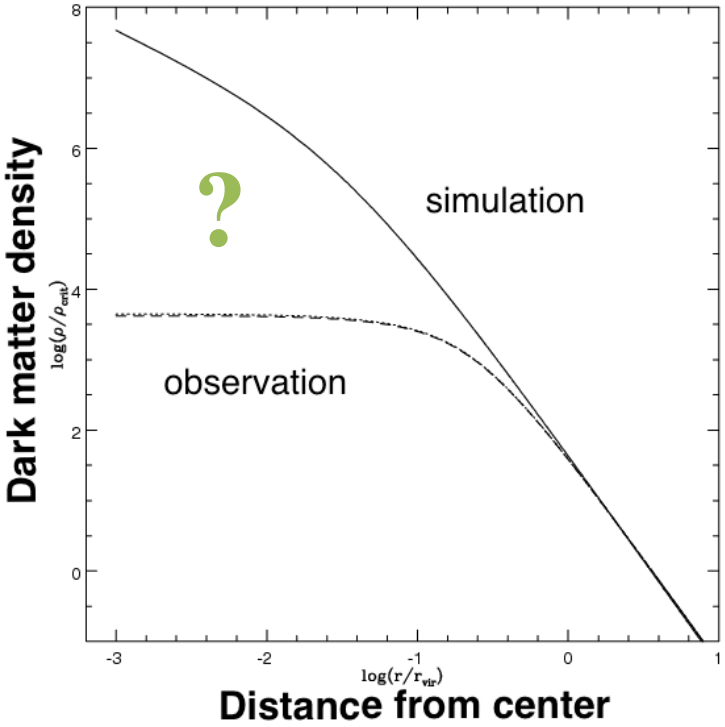

Self-interactions naturally come with bremsstrahlung:

- suppressed for heavy mediators
- non-negligible for light mediators

DISSIPATION ALTERS DENSITY PROFILE

↓

Influence on structure formation

Can dissipation in dark matter collsions influence structure formation?

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Compare relevant time scales for structure formation in the universe to estimate importance of bremsstrahlung

Cooling time	Hubble time	Gravitational time
$t_{\rm cool} = \frac{3 n_\chi T}{\dot{\epsilon}}$	$t_0 = H_0^{-1}$	$t_{\rm grav} = \sqrt{\frac{3\pi}{8 m_\chi n_\chi G}}$

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Parameter space with three regions

$t_{\mathrm{cool}} > t_0$	$t_{\mathrm{cool}} < t_0$	$t_{\mathrm{cool}} < t_{\mathrm{grav}}$
No inelastic scattering event within the age of the universe	Inelastic scattering can influence structure formation	Inelastic scattering is a dominant process

Dark matter toy models

Free parameters:

interaction strength	α_{D}
dark matter mass	m_{DM}
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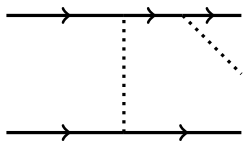
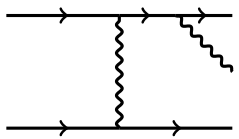
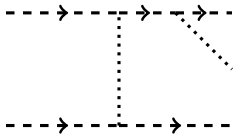
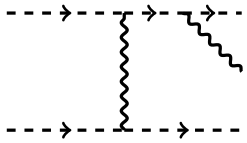
Dark matter: **Fermion**		
Dark Matter: **Scalar boson**		

Dark matter toy models

Leading order process in multipole expansion
(one particle dark matter)

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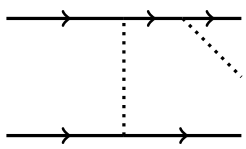
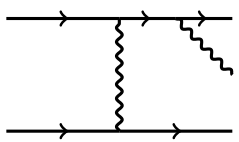
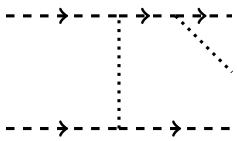
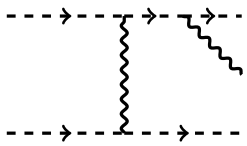
Dark matter: **Fermion**		
Dark Matter: **Scalar boson**		

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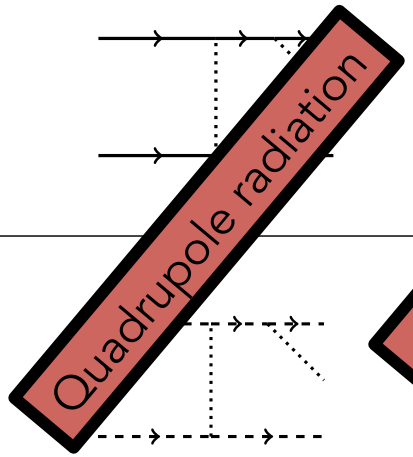
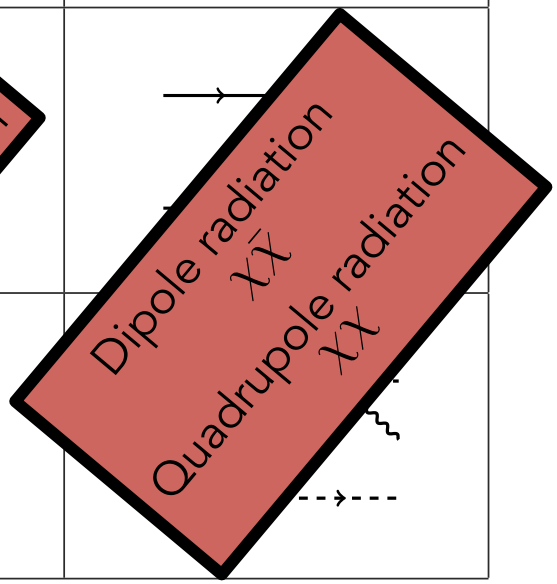
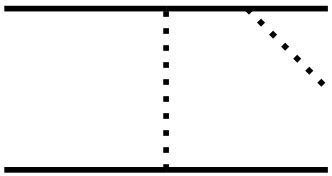
Dark matter: **Fermion**		
Dark Matter: **Scalar boson**		

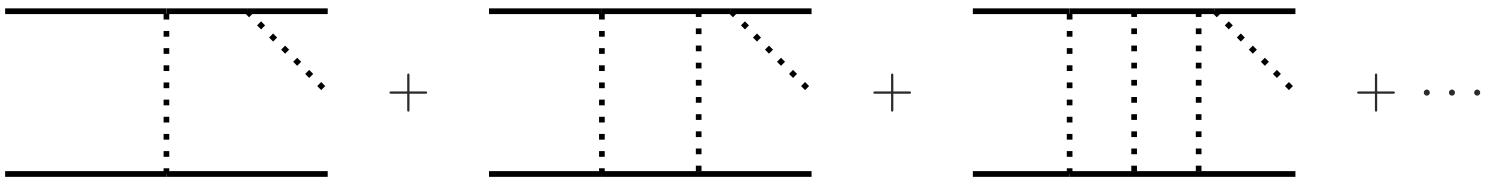
Perturbative vs. Non-perturbative

Perturbative calculations



valid for $\frac{\alpha}{v} \ll 1$ or $\frac{\alpha\, m_{\mathrm{DM}}}{m_{\mathrm{med}}} \ll 1$

Increase domain of validity by taking non-perturbative effects into account



Non-relativistic quantum mechanics

$$\mathcal{V}_{fi}^{(1)} = \left\langle \psi_f^{(1)} \right| \hat{O}_{\mathrm{rad}} \left| \psi_i^{(1)} \right\rangle$$

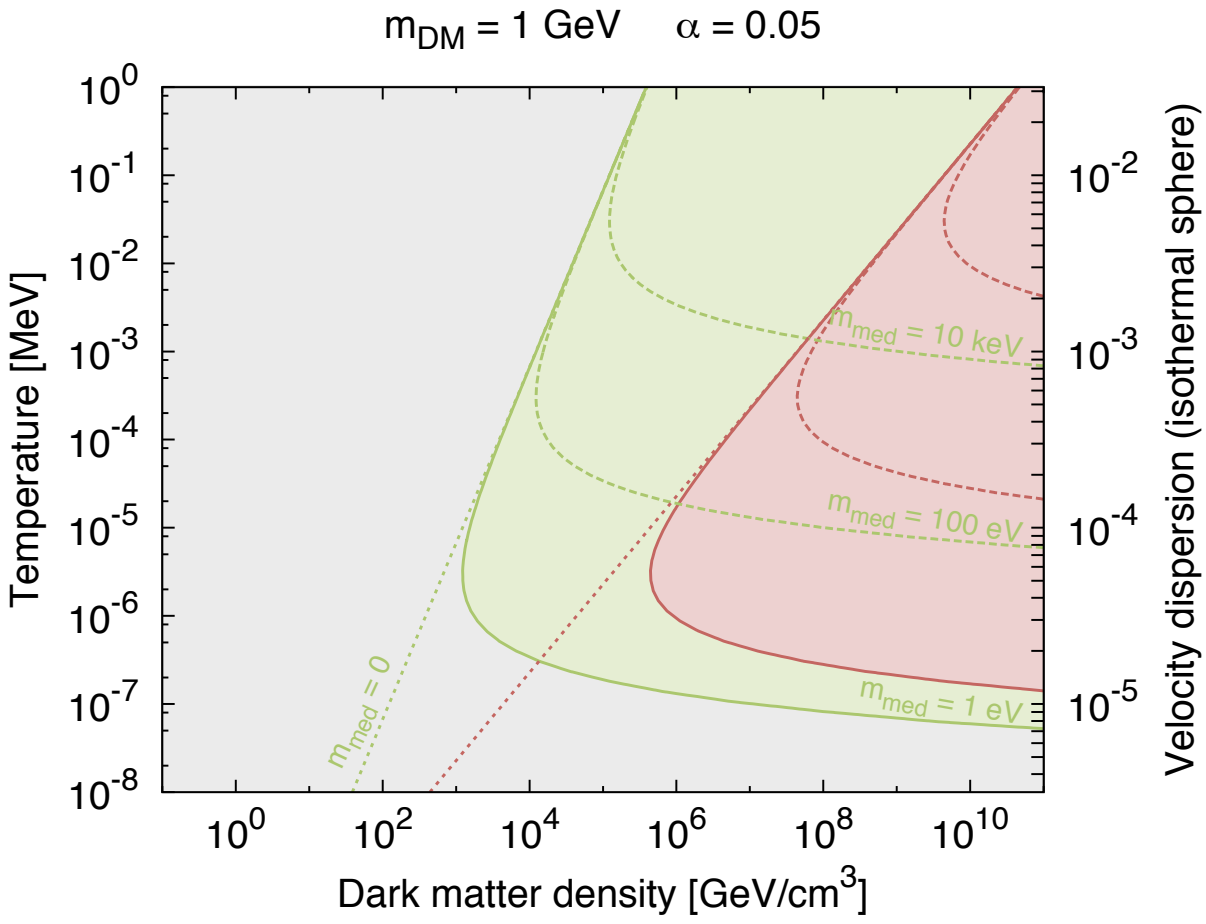
1st order Born wave function

$$\mathcal{V}_{fi} = \left\langle \psi_f \right| \hat{O}_{\mathrm{rad}} \left| \psi_i \right\rangle$$

Coulomb wave function

Preliminary Results

Fermionic dark matter dipole radiation



$t_{cool} > t_0$

No inelastic scattering event within the age of the universe

$t_{cool} < t_0$

Inelastic scattering can influence structure formation

$t_{cool} < t_{grav}$

Inelastic scattering is a dominant process

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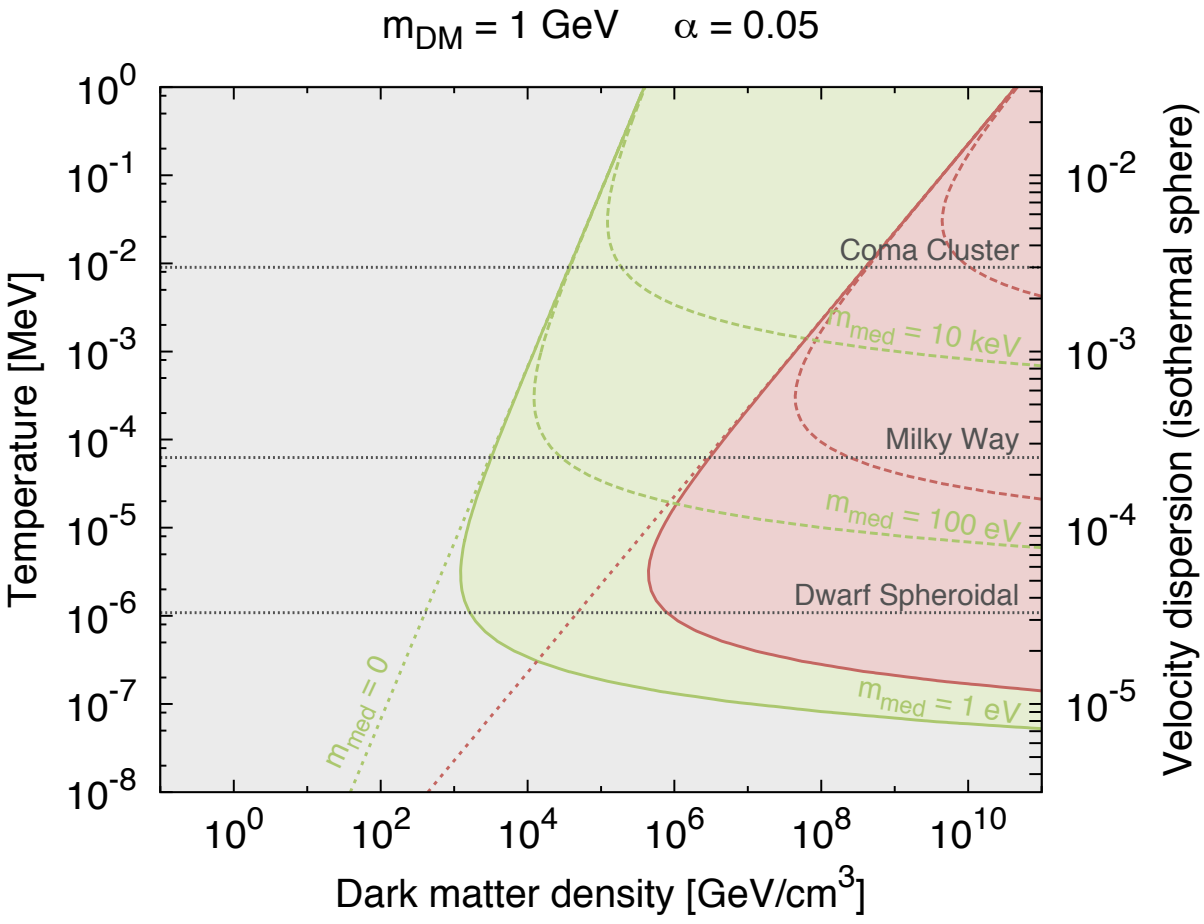

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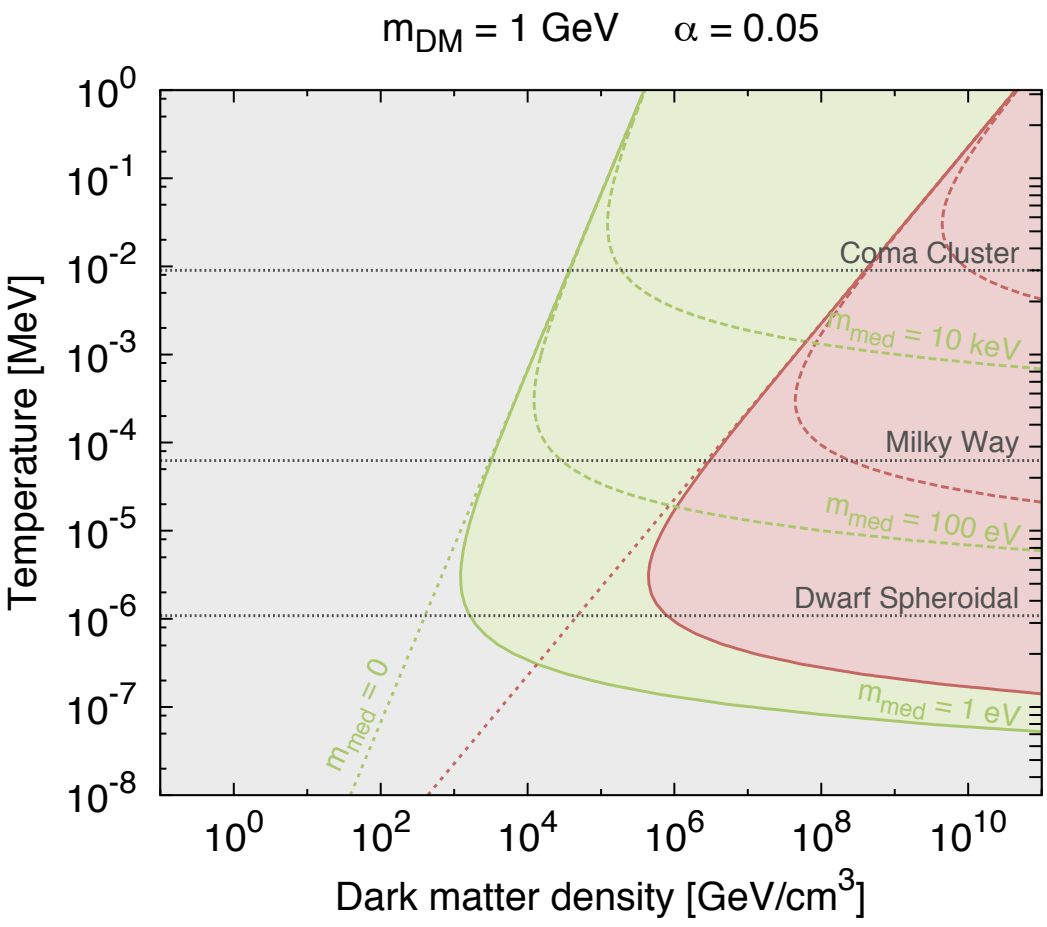

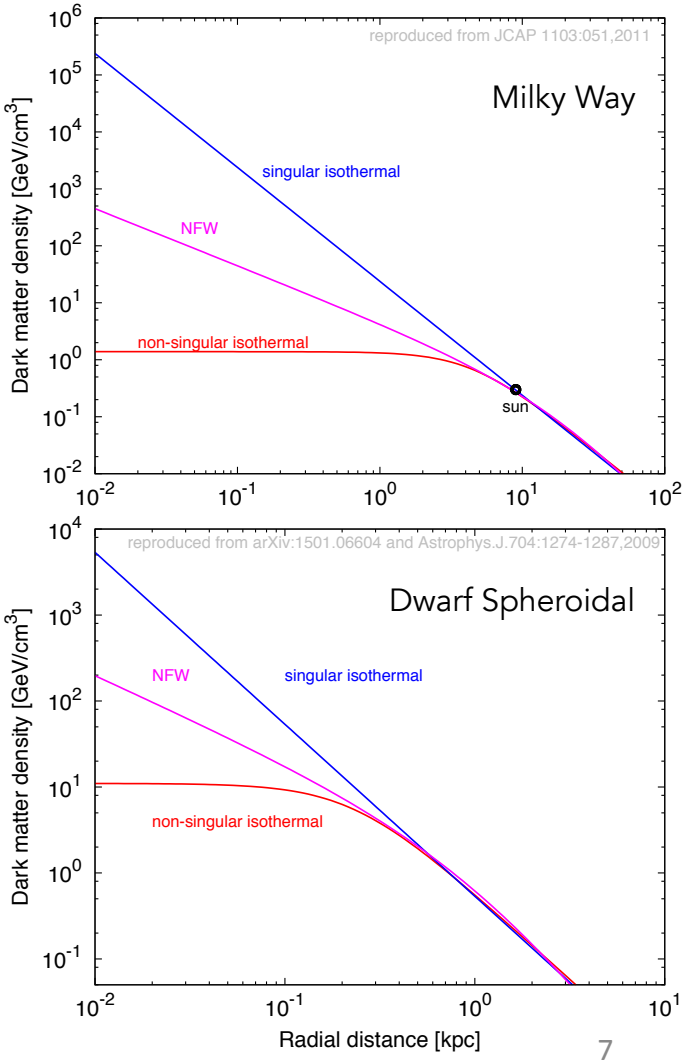

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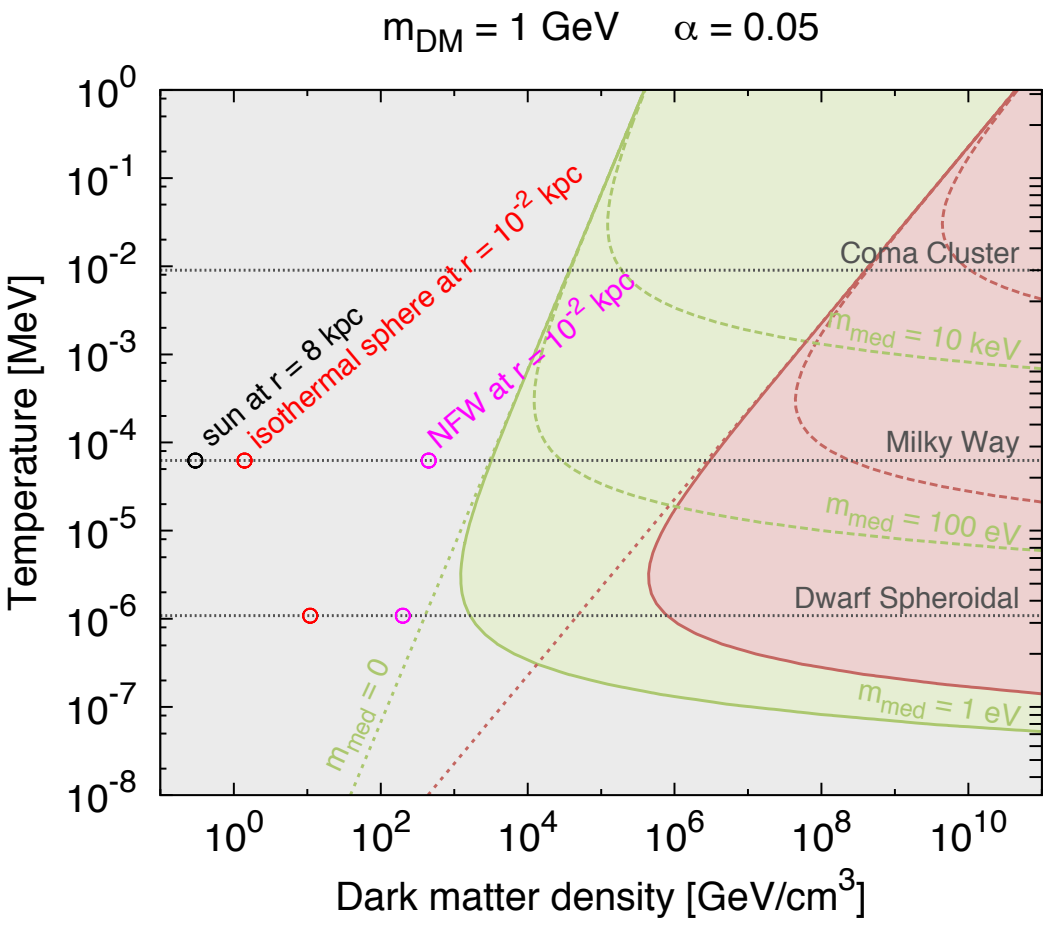
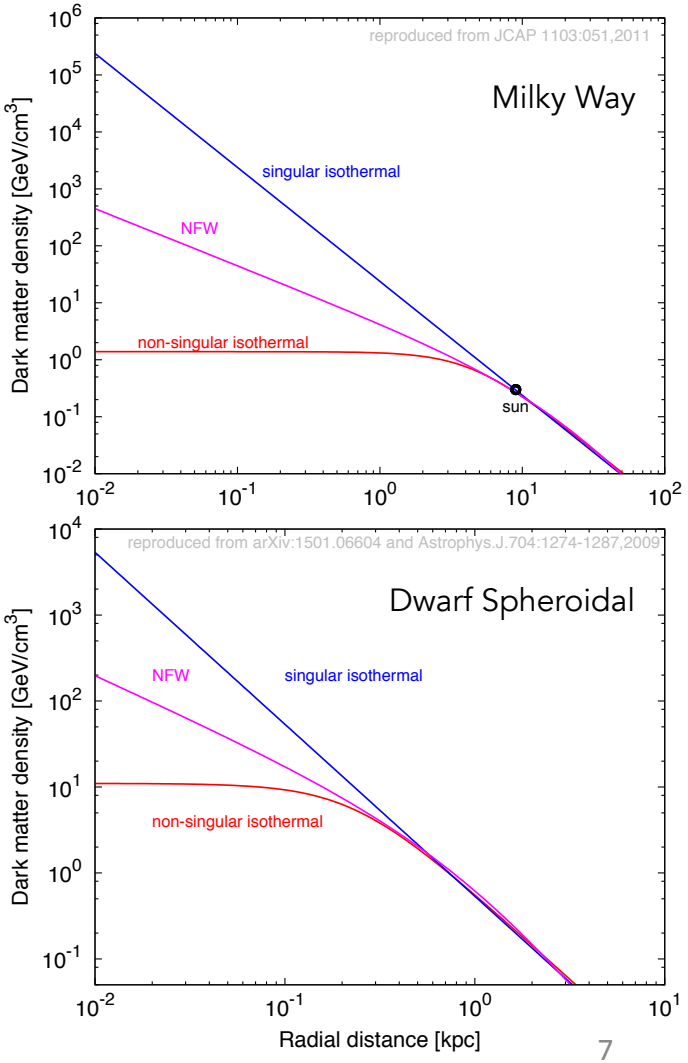
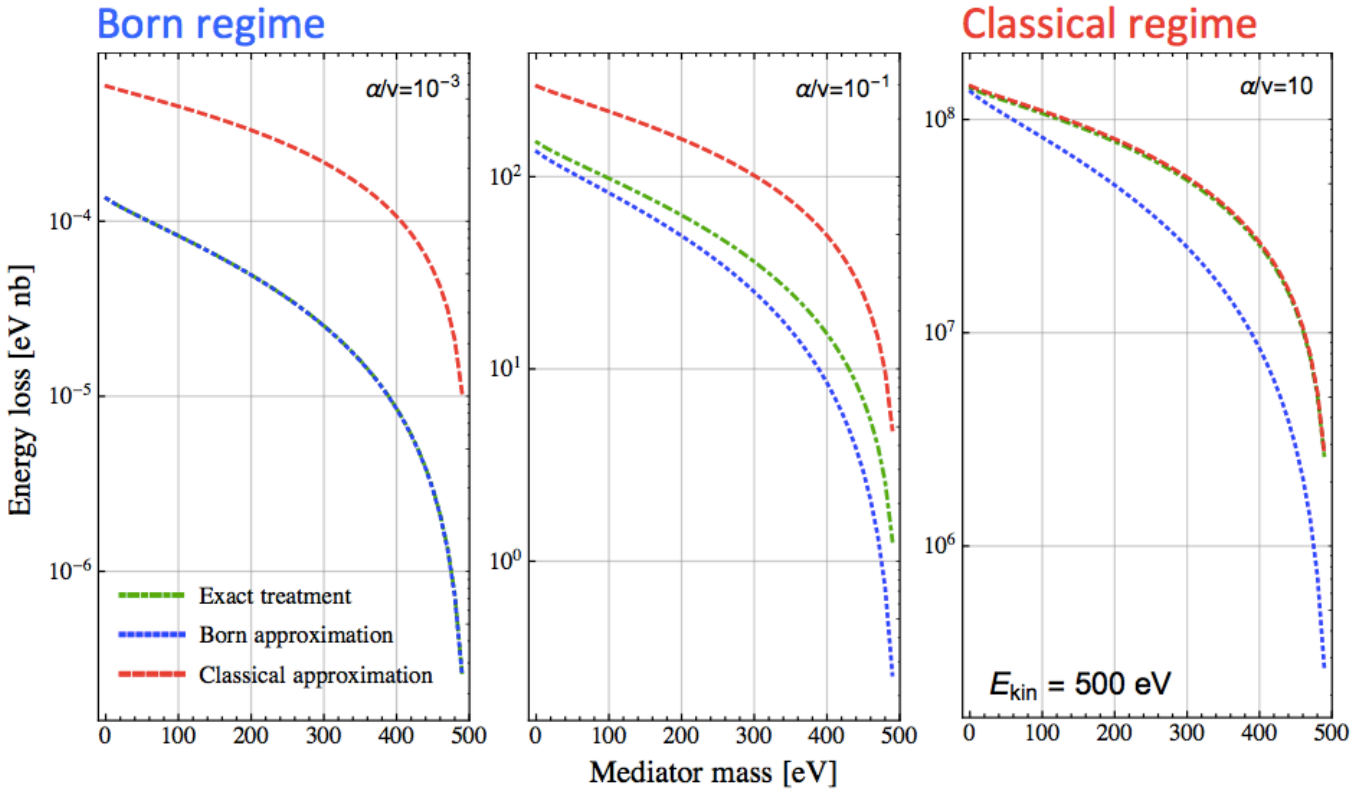




Backup

Perturbative vs. Non-perturbative



Exact treatment: Coulomb wave functions as initial and final states.
Born approximation: 1st order Born wave functions
Classical approximation: quasi classical trajectories for colliding particles

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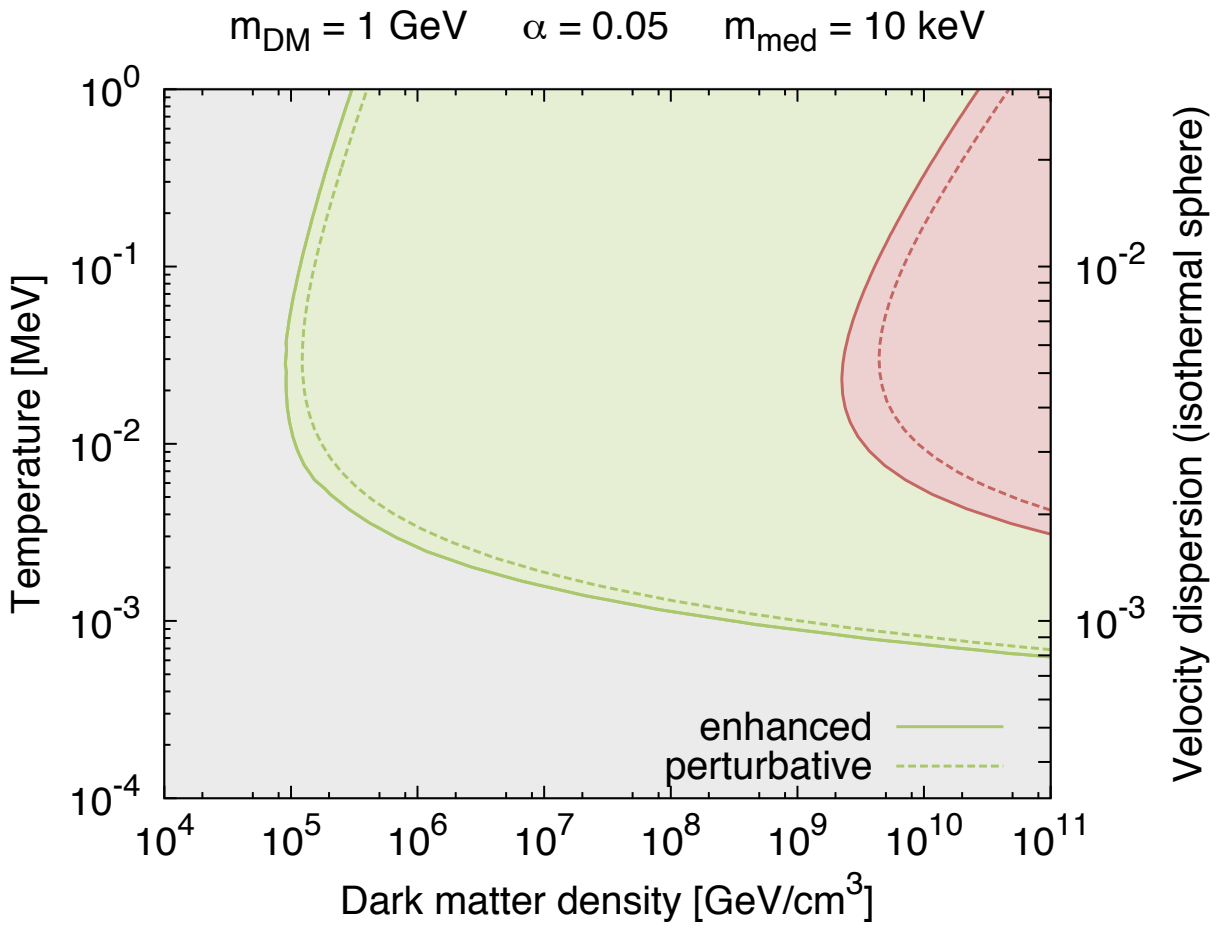

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Constraints on the SIDM-Models

(to be looked into)

Assuming the dark sector is decoupled from the SM sector

- No detection constraints
- DM not in thermal equilibrium with SM in early universe

But constraints for

- Elastic self-interaction cross section (e.g. Bullet cluster, halo triaxiality)

- N_{eff} (effective relativistic degrees of freedom at CMB decoupling)
  a light mediator would contribute to N_{eff} altering the time of BBN and therefore the abundance of light elements in the universe

- Dark acoustic oscillations
  a light mediator would cause radiation pressure in the dark sector before CMB and distort the CMB spectrum