Lyman-α constraints on Freeze-in and SuperWIMPs

Quentin Decant

In collaboration with:
J. Heisig, D. C. Hooper, L. Lopez-Honorez

JCAP03 (2022) 041

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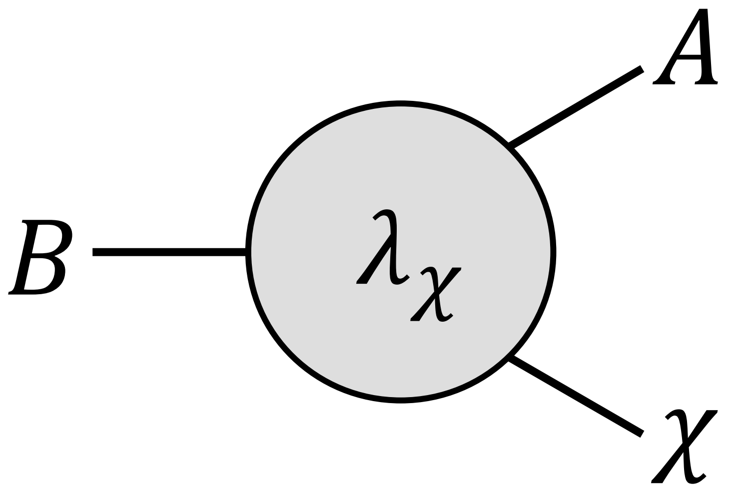
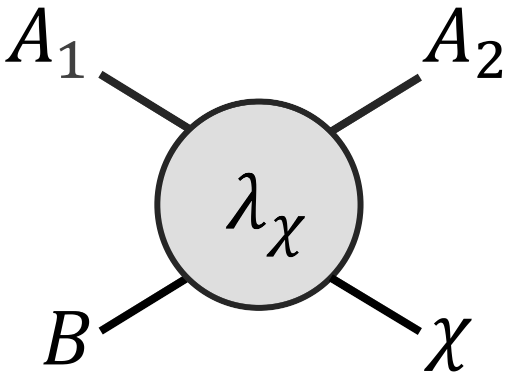
Dark Matter production





See also e.g.:
[Hall’09, Co’15, Hessler’16, d’Eramo’17, Heeck’17, Boulebname’17, Brooijmans’18, Garny’18, Calibbi’18, No’19, …]

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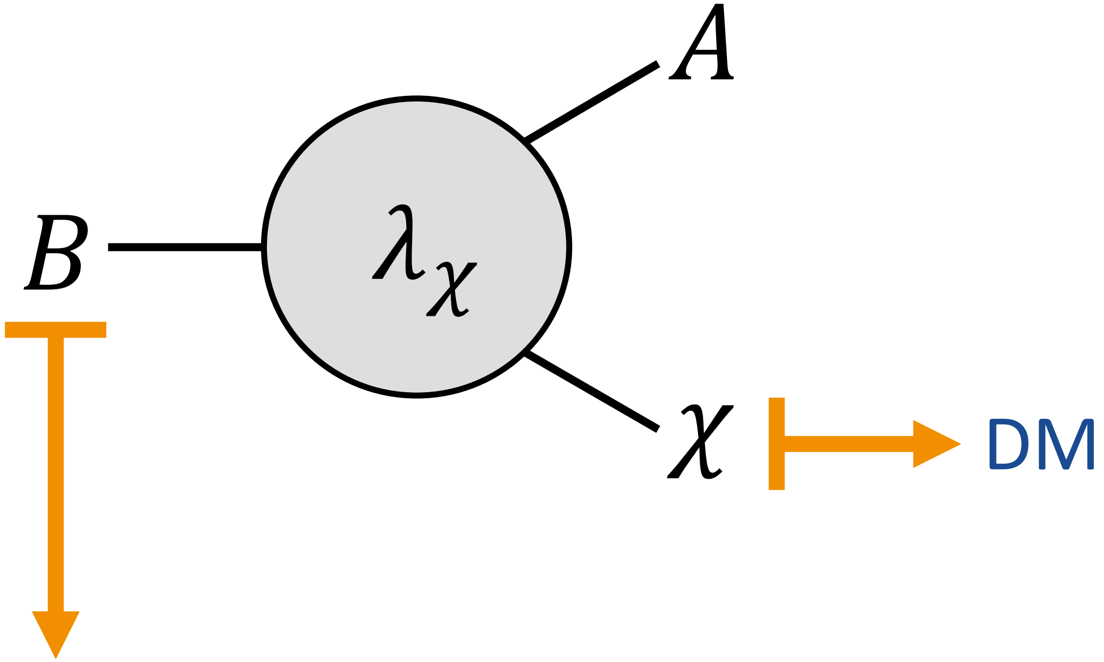

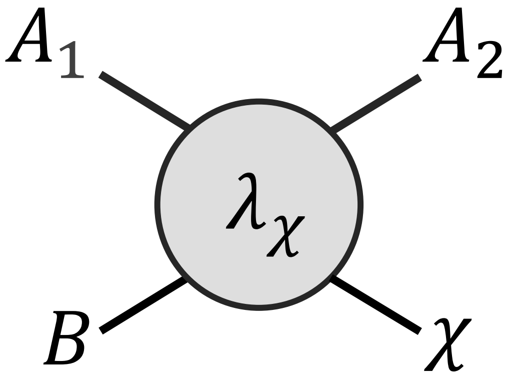

Particle in thermal equilibirum with SM bath ≡ “mediator”

See also e.g.:
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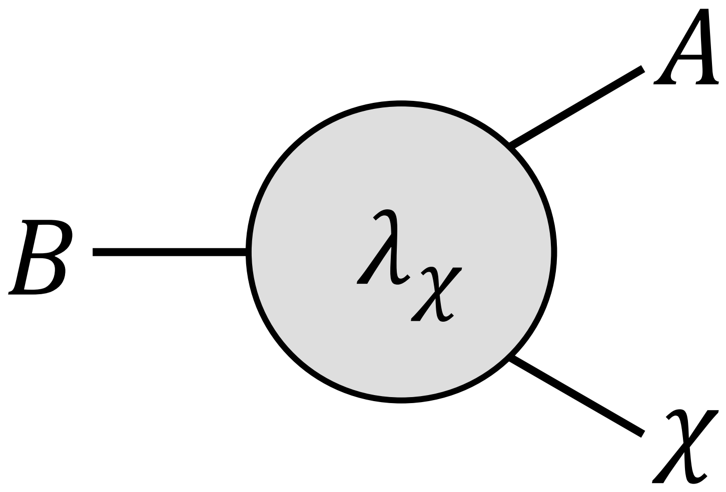

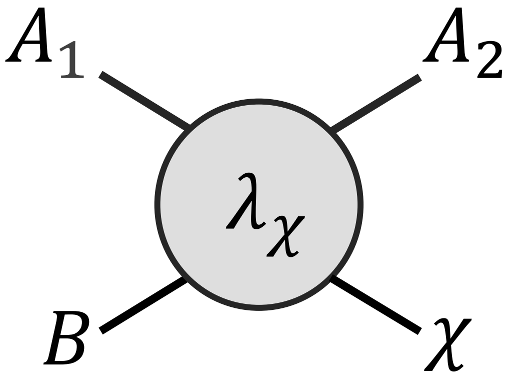

Relevant parameters:

- Masses: m_B & m_χ
- Coupling: λ_χ

See also e.g.:
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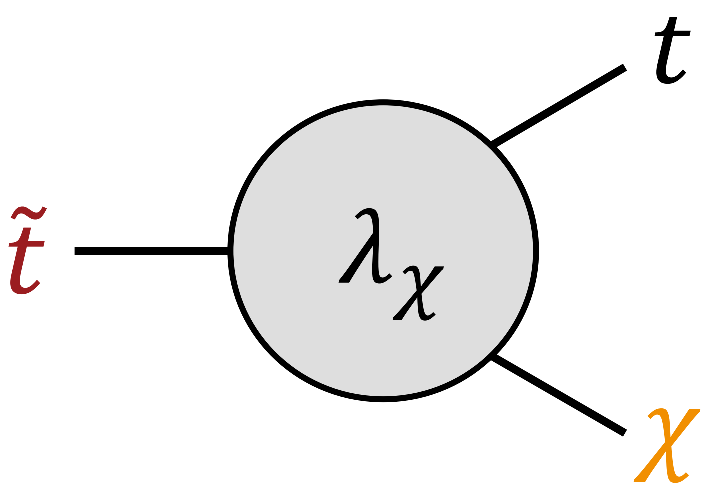
Freeze-in and SuperWIMP's

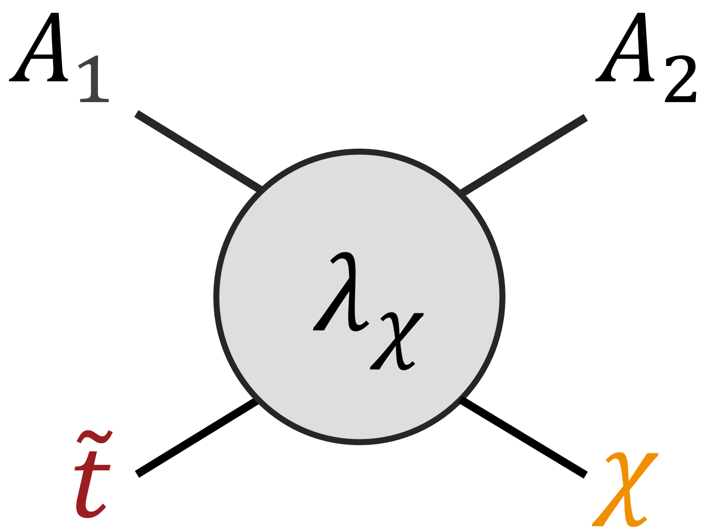
Example model (top-philic DM): [See: Garny, Heisig,Lülf, Hufnagel'18]

$$\mathcal{L}_{\rm int} \supset |D_\mu \tilde{t}|^2 + \lambda_\chi \tilde{t}\, \bar{t}\, \frac{1-\gamma_5}{2} \chi$$

Colored Scalar = Mediator

Majorana Fermion = DM



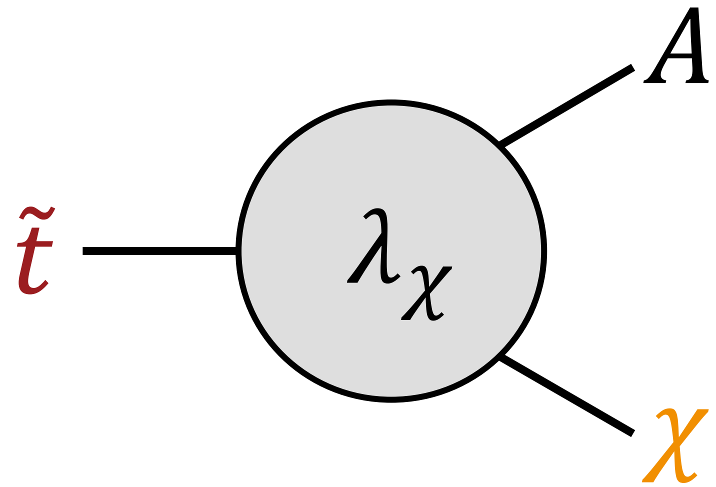


Freeze-in and SuperWIMP's

Freeze-in:

No initial abundance

Production from **rare** interactions of $\tilde{t}$



$$\lambda_\chi < 10^{-6}$$

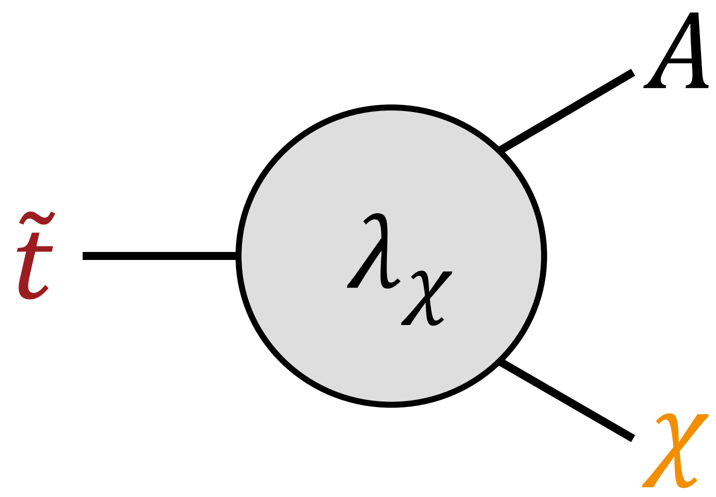
Freeze-in and SuperWIMP's

Freeze-in:

No initial abundance

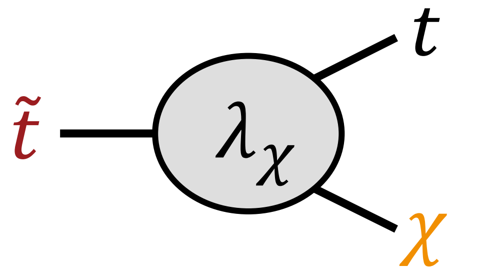
Production from **rare** interactions of $\tilde{t}$

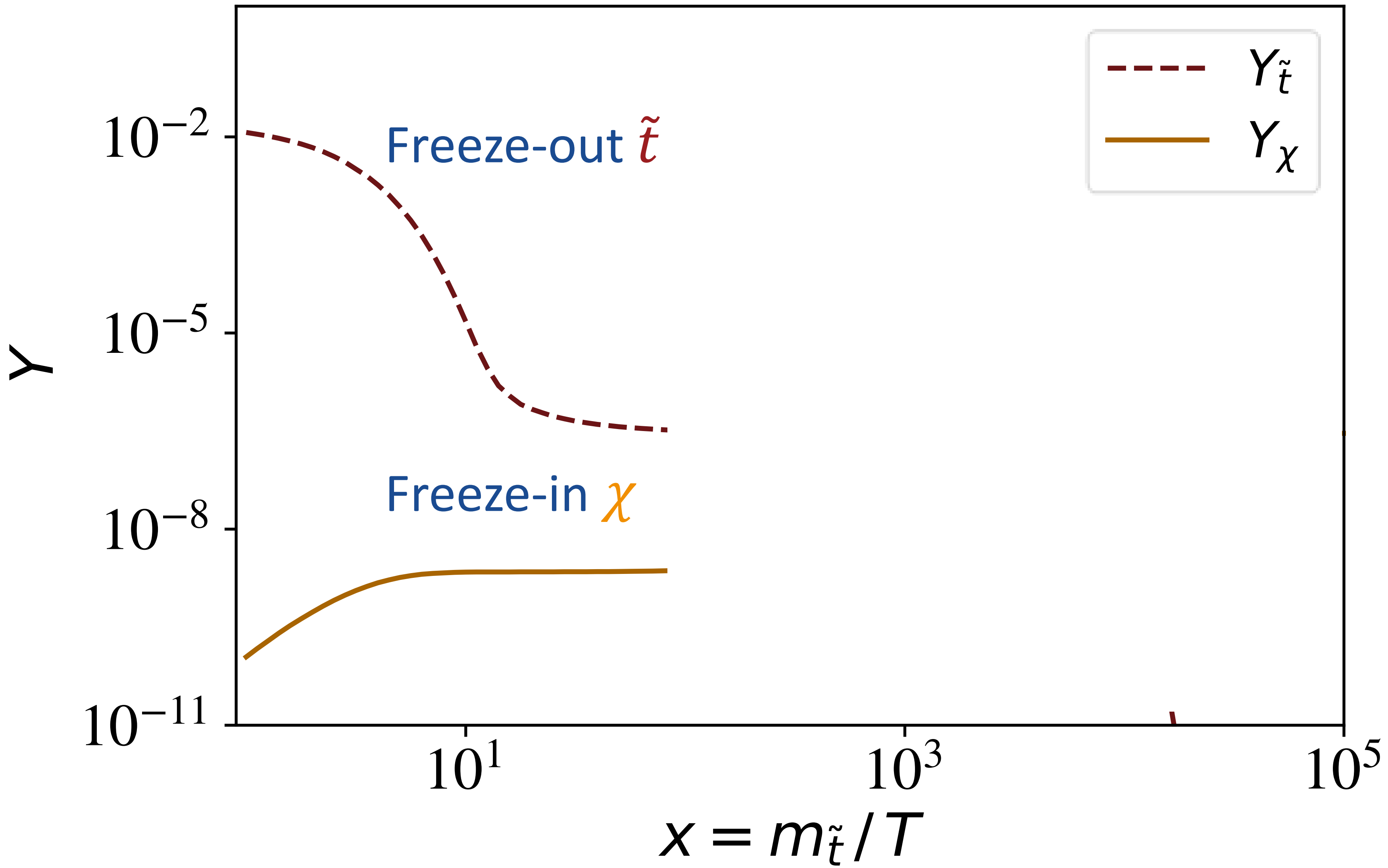
➡ No equilibrium SM ⟷ DM



$\lambda_\chi < 10^{-6}$

Yields from Freeze-in





Freeze-in and SuperWIMP's

Freeze-in:

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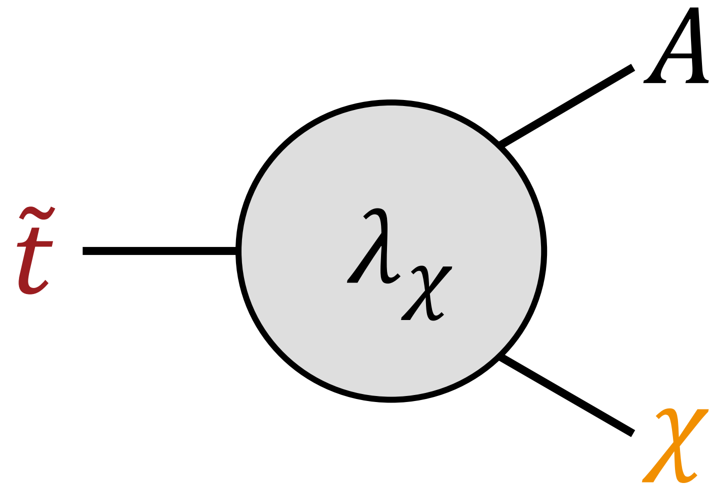
→ No equilibrium SM ⟷ DM



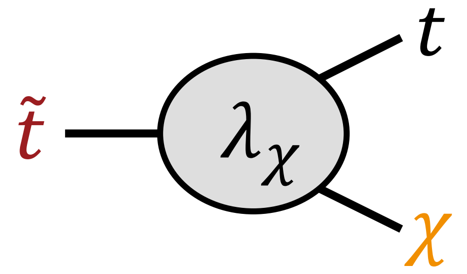
$\lambda_\chi < 10^{-6}$

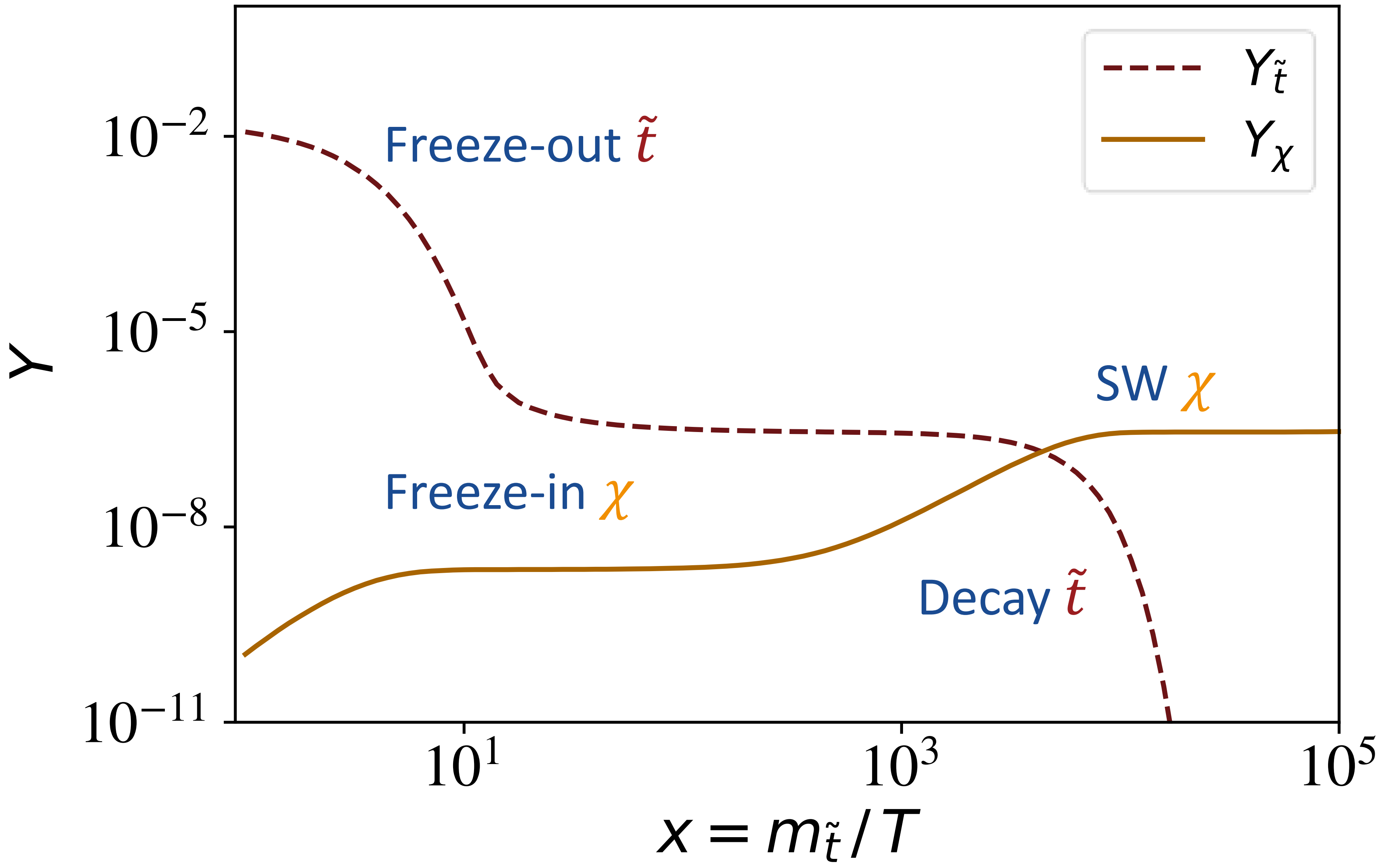
SuperWIMP:

$\tilde{t}$ ⟶̸ SM + SM

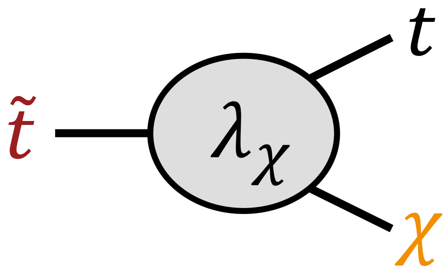
$\lambda_\chi \ll 10^{-6}$ → $\tilde{t}$ can be long-lived

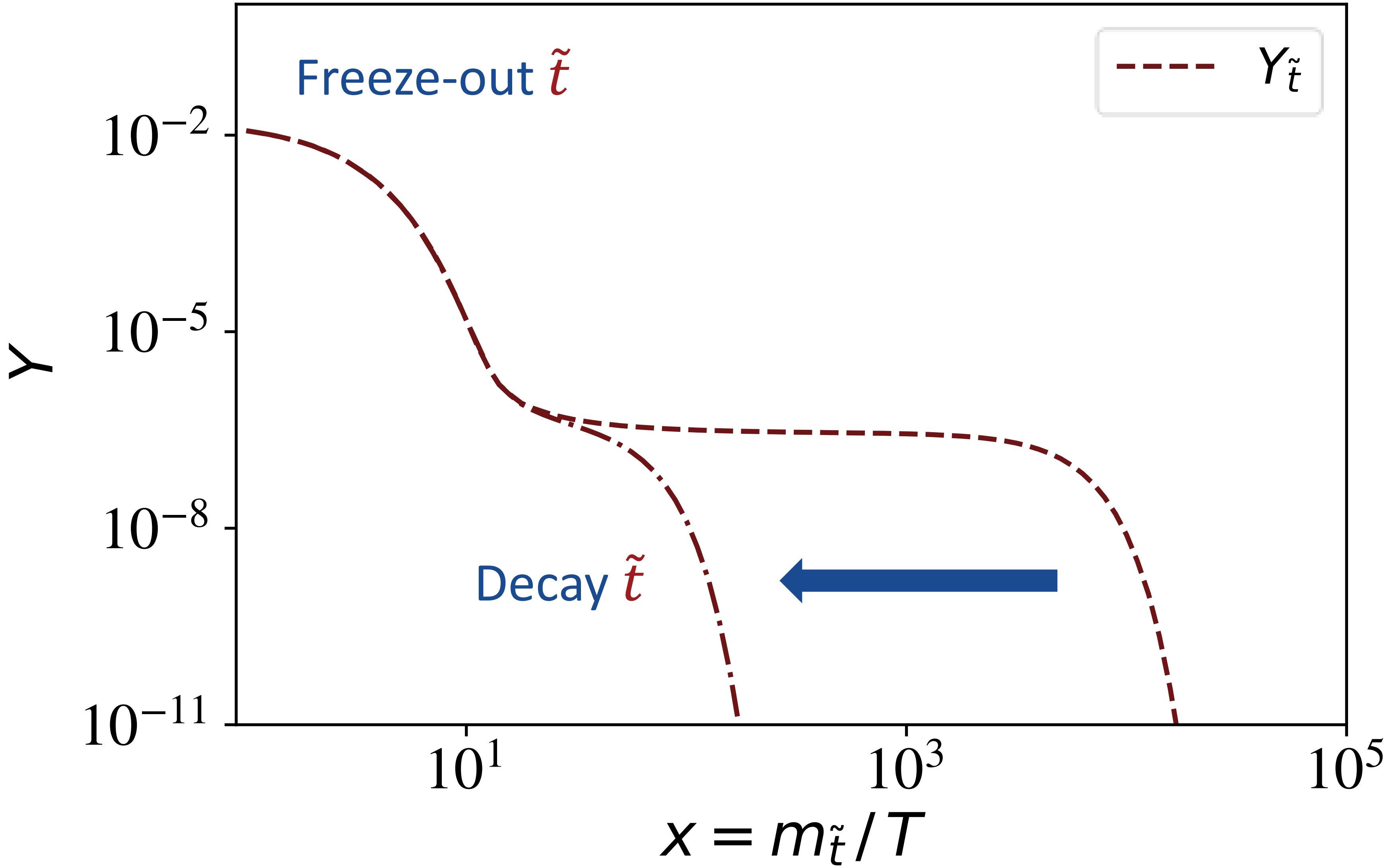
Yields from Freeze-in and SW





Decrease lifetime $\tilde{t}$





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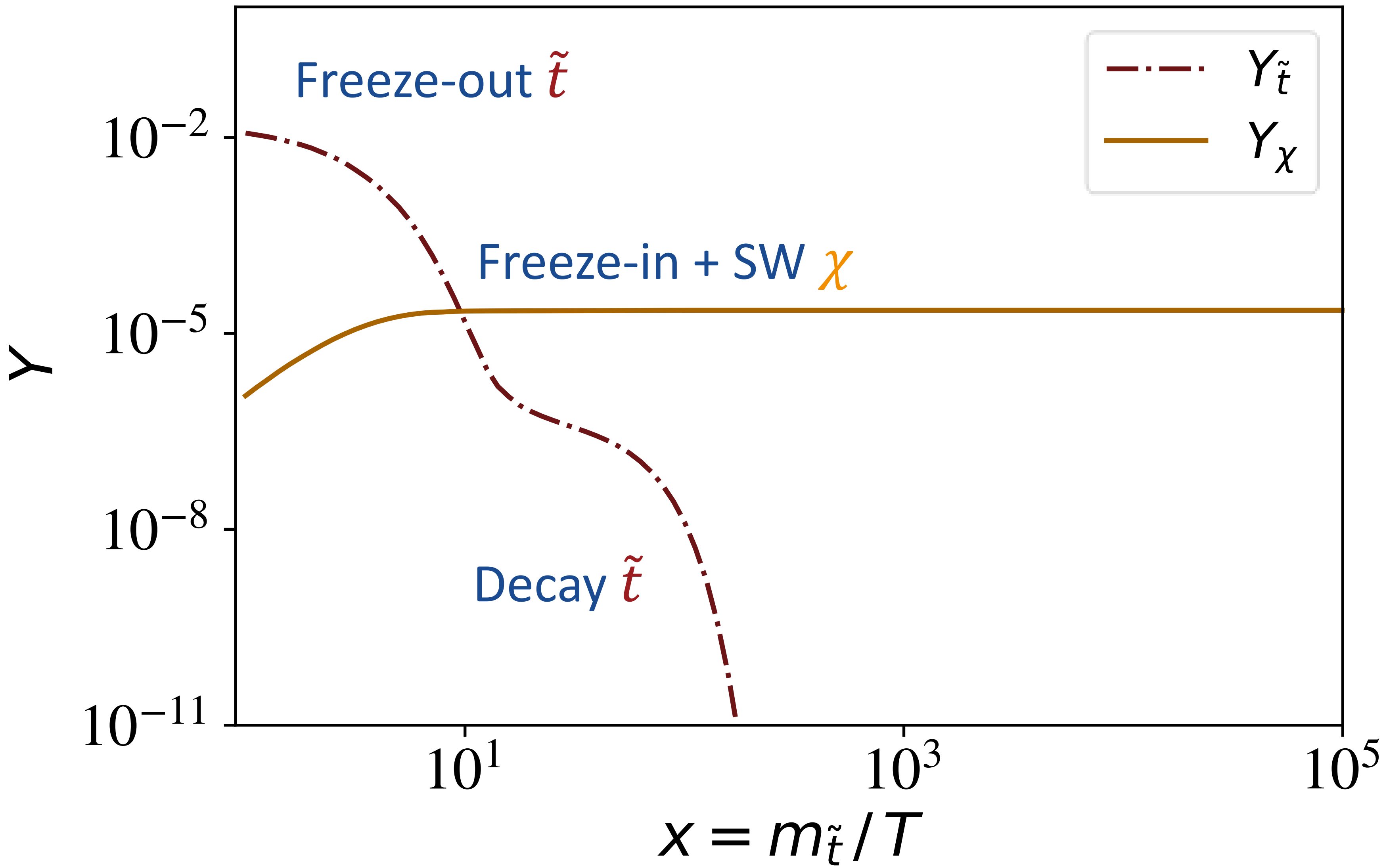
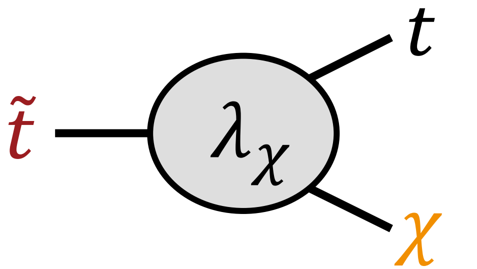
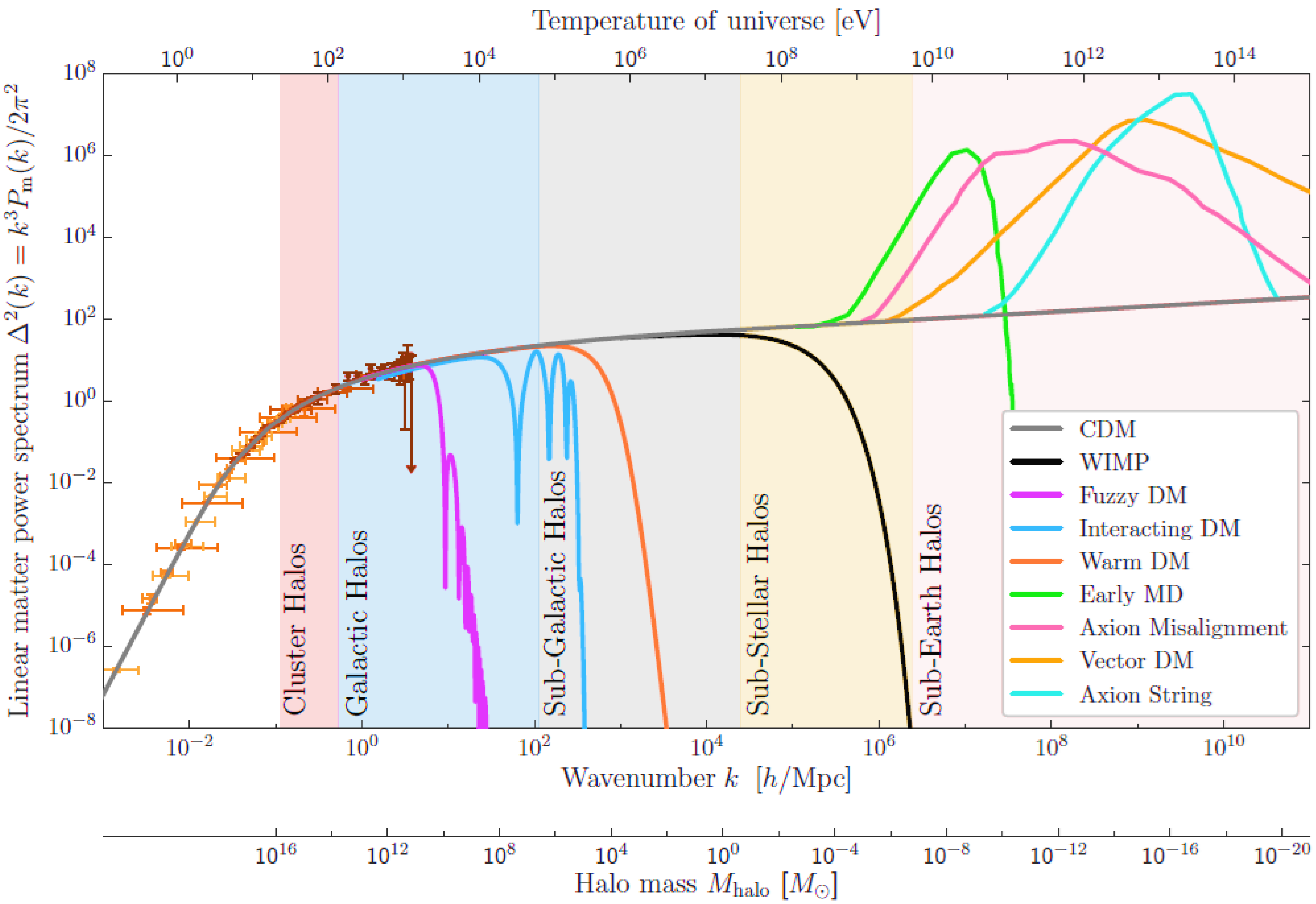




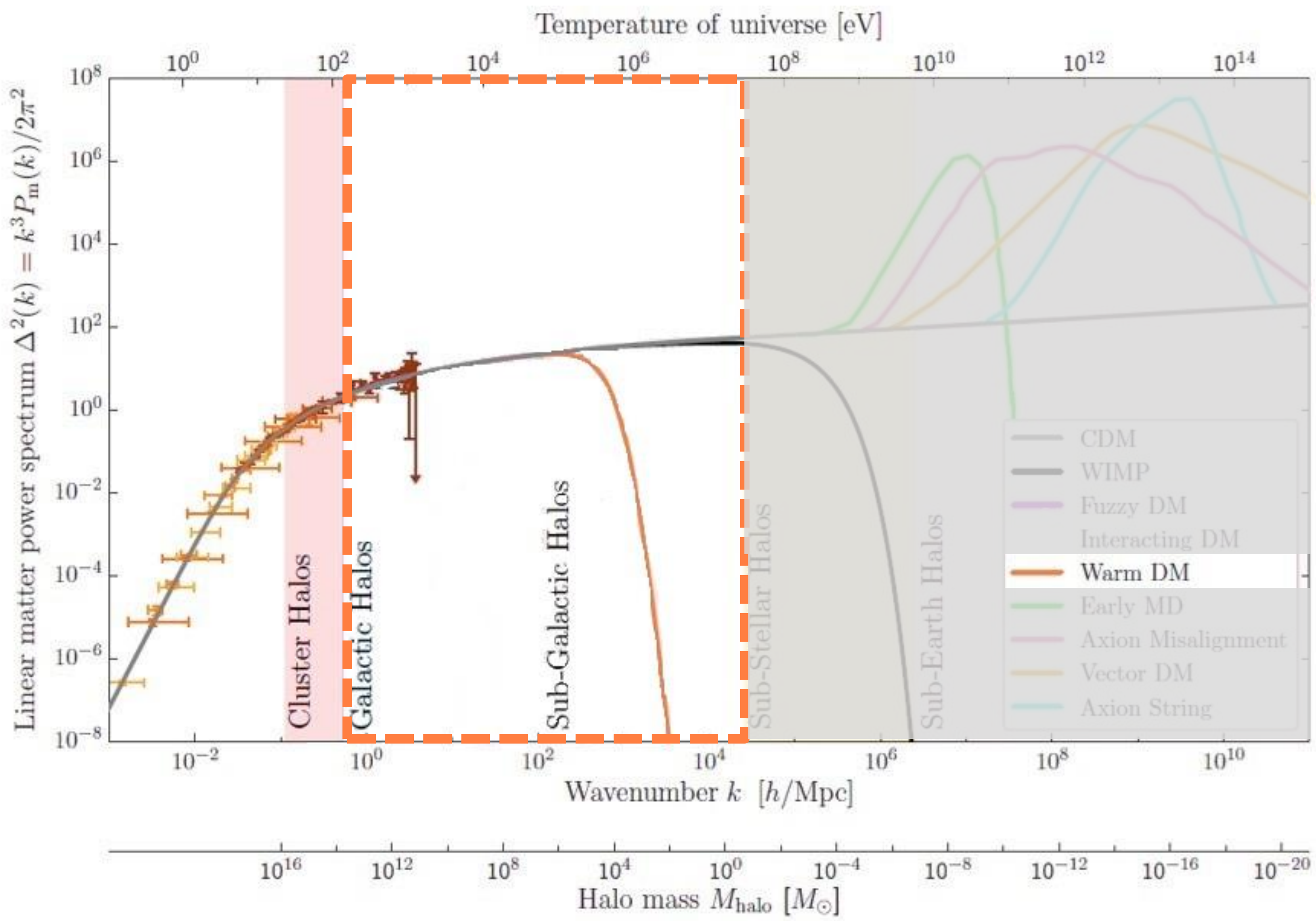
FI and SW as Non-Cold Dark Matter

Non-Cold Dark Matter (NCDM)



[Bechtol+’22 (Snowmass2021)]

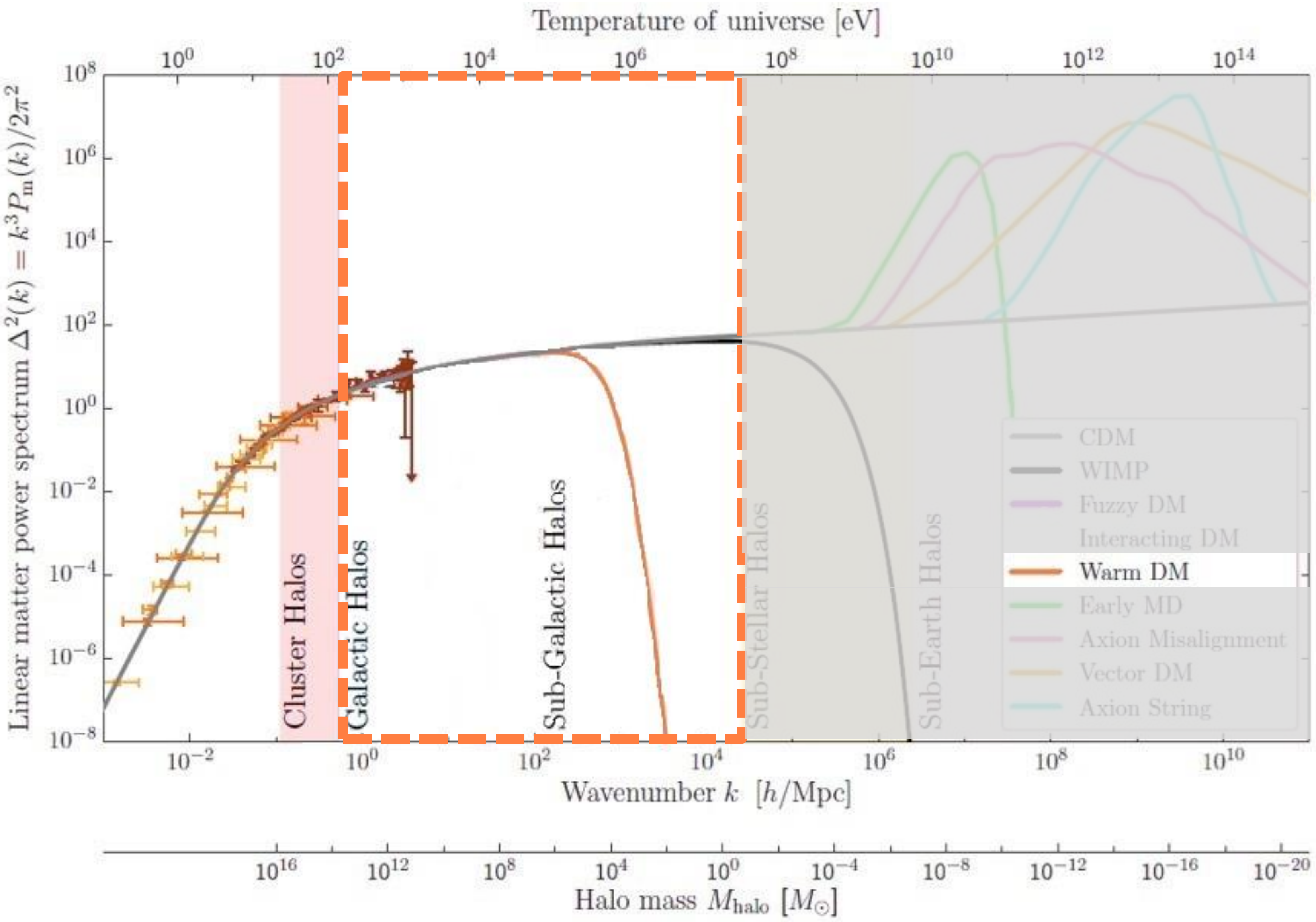
Non-Cold Dark Matter (NCDM)



Warm Dark Matter (WDM) = DM is produced with non-negligible velocity

[Bechtol+'22 (Snowmass2021)]

Non-Cold Dark Matter (NCDM)

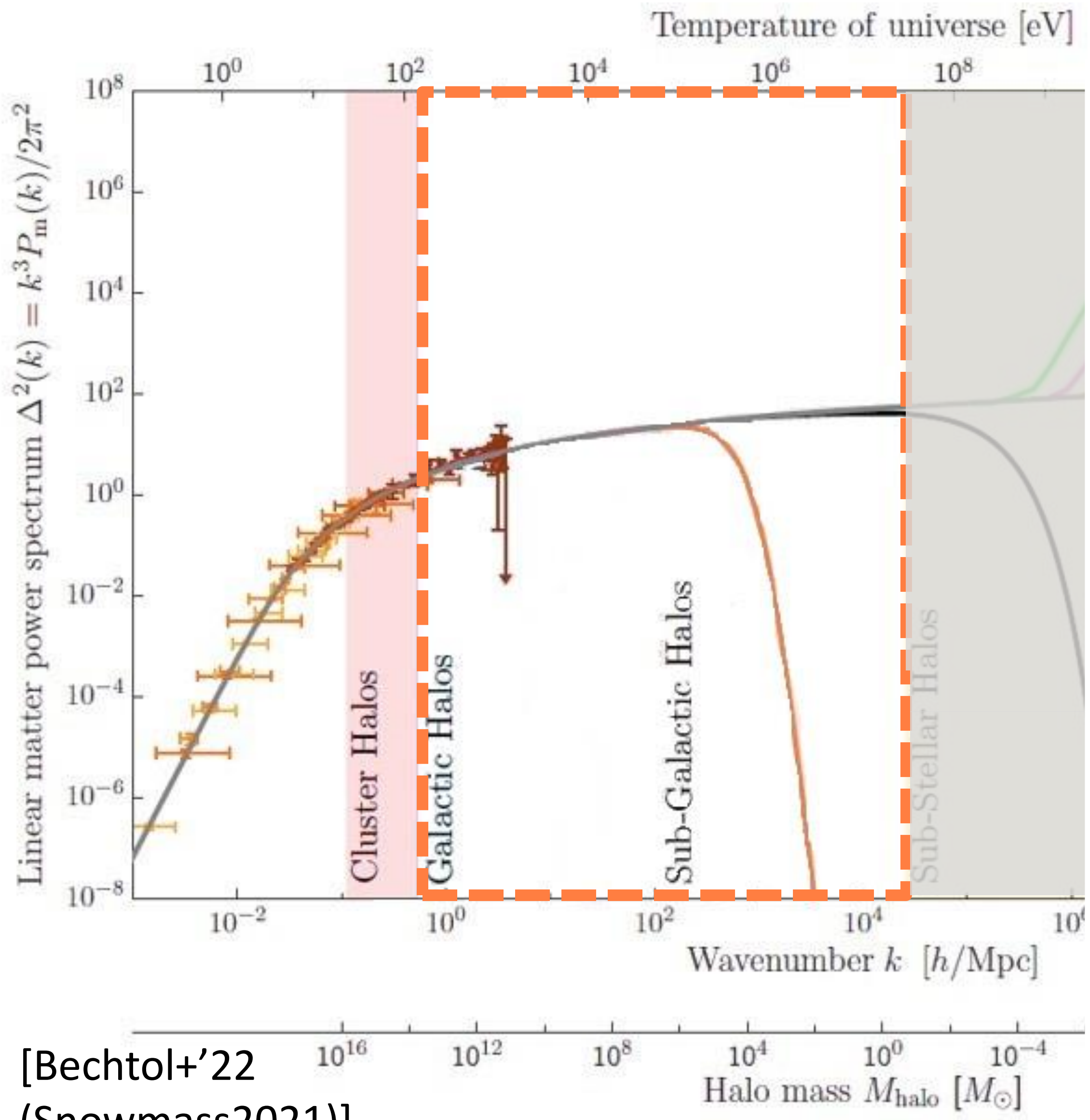


Warm Dark Matter (WDM) = DM is produced with non-negligible velocity

Free-streaming erases structure on small scales

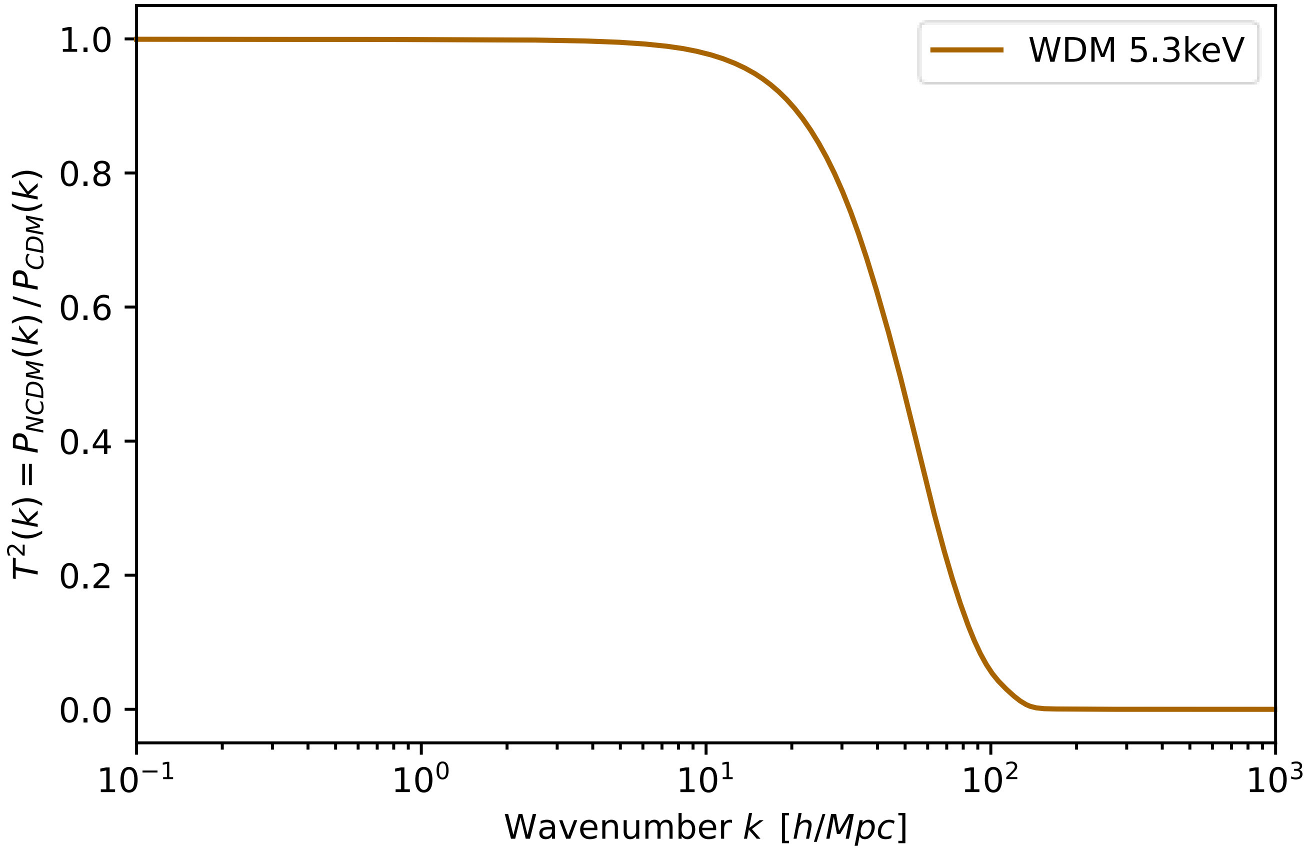
[Bechtol+'22 (Snowmass2021)]

Non-Cold Dark Matter (NCDM)



[Bechtol+'22 (Snowmass2021)]

Transfer function = NCDM/CDM



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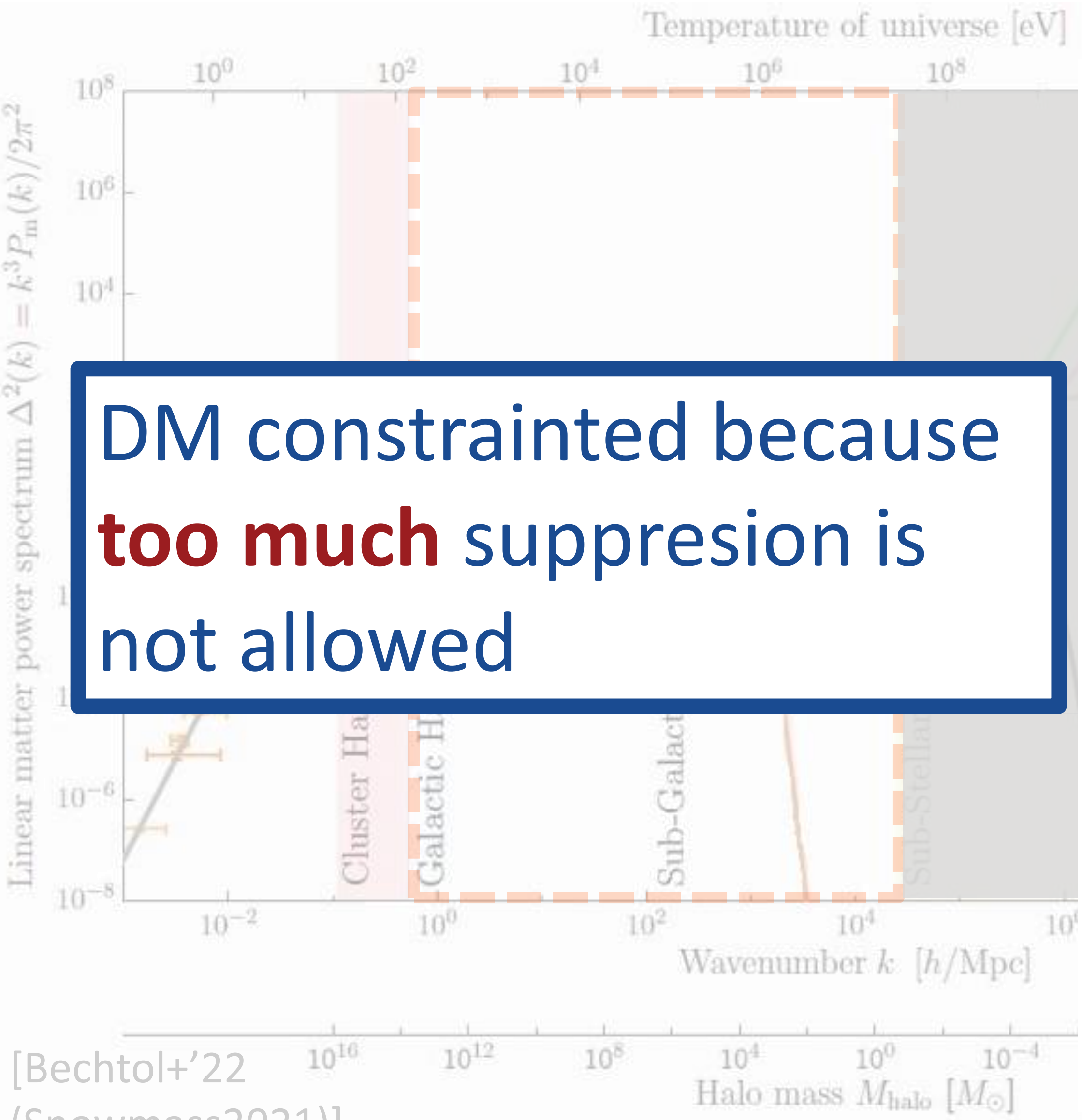
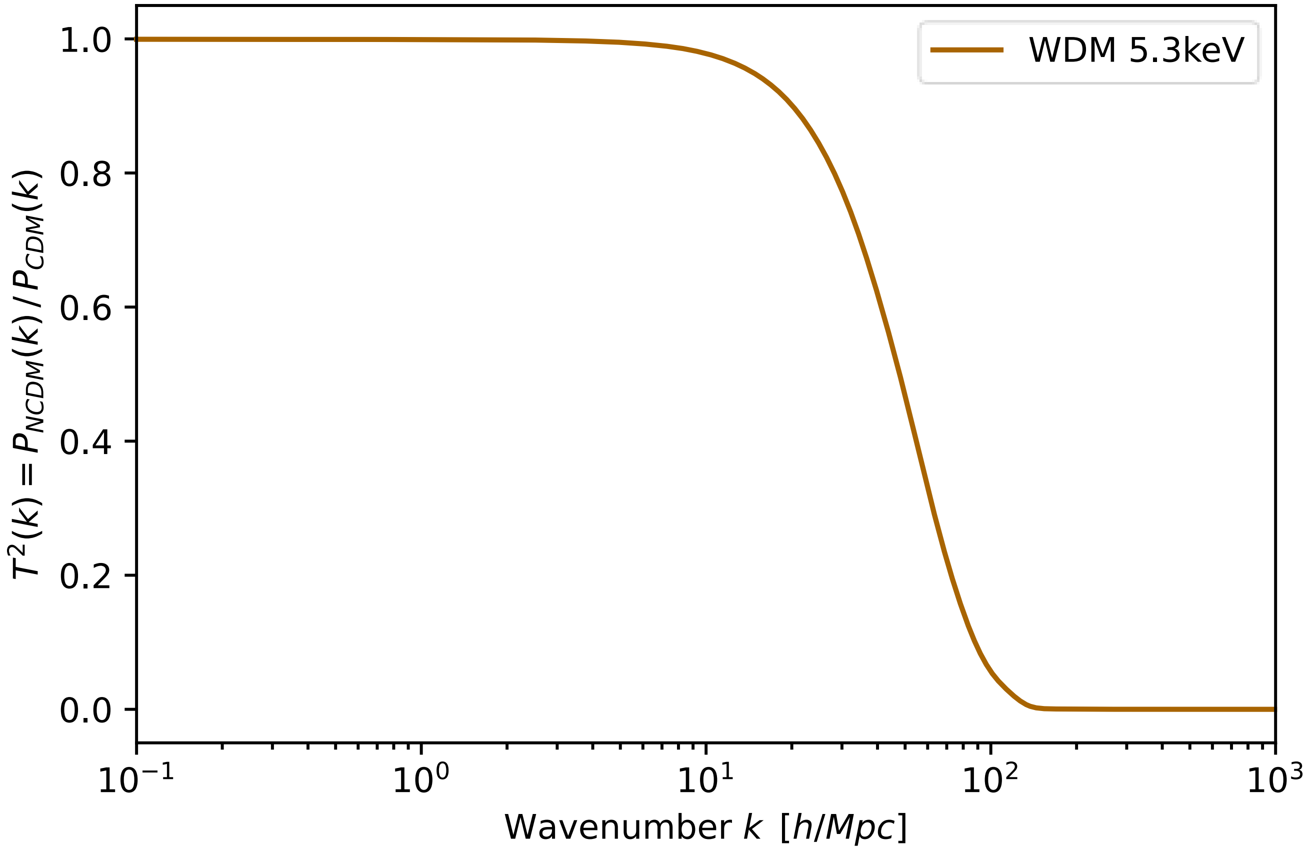


DM constrainted because **too much** suppresion is not allowed

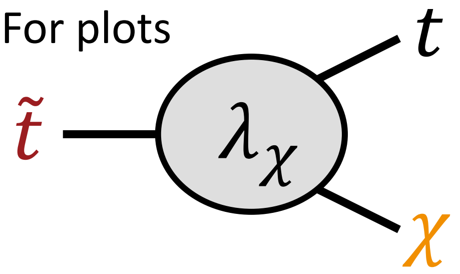
[Bechtol+'22 (Snowmass2021)]

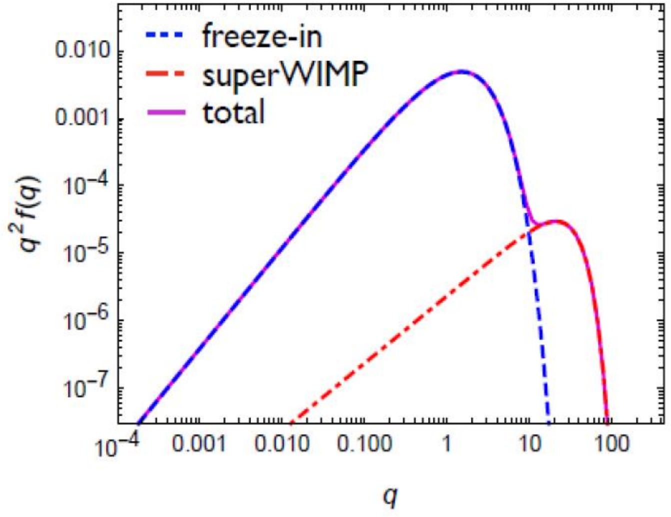
Transfer function = NCDM/CDM



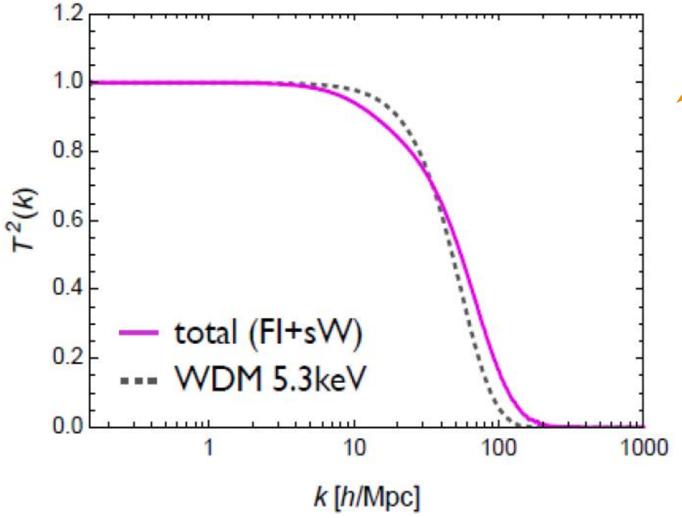
Free-streaming

[See: Heisig at EPS'21]
For plots





Boltzmann code
CLASS



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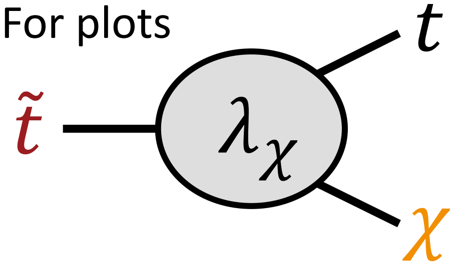
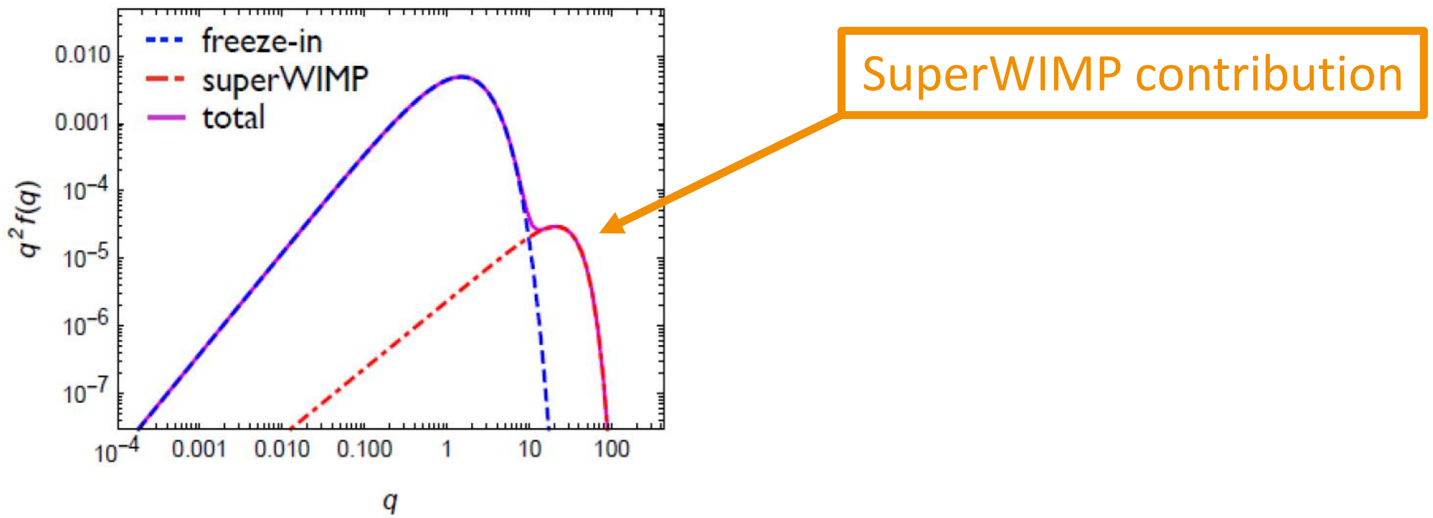
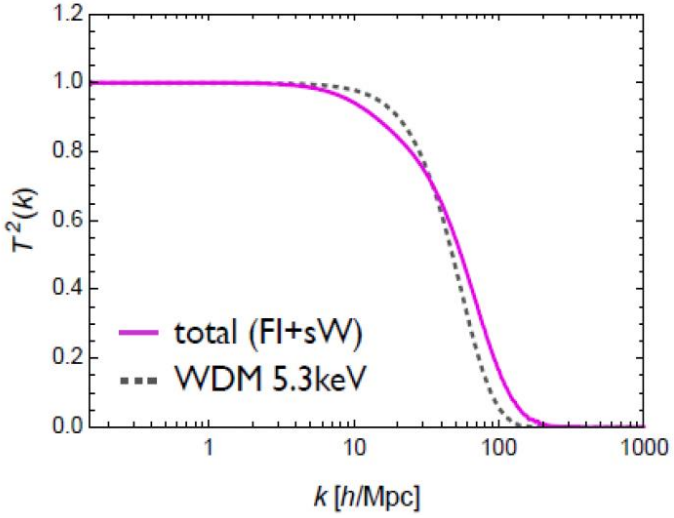


Increasing lifetime of $\tilde{t}$





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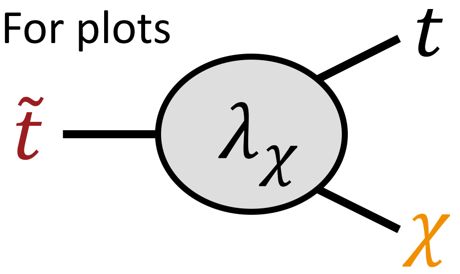
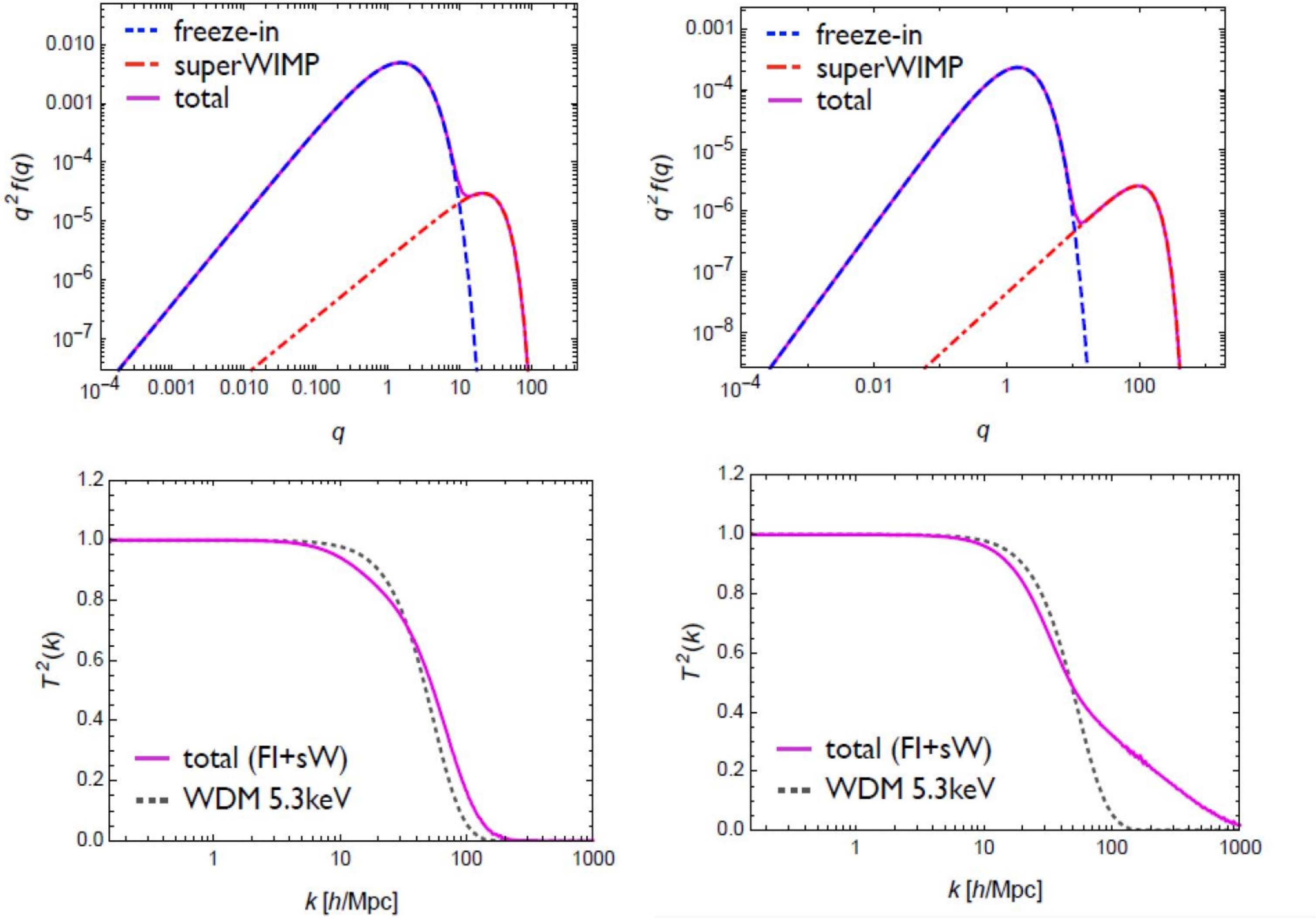


Increasing lifetime of $\tilde{t}$ →

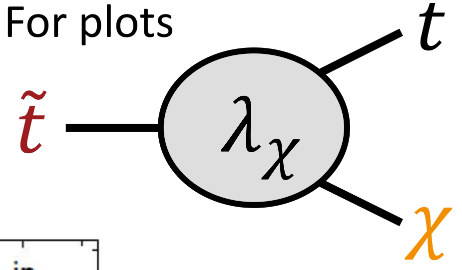


SW contribution goes to higher momentum

Shape changes due to mixture of FI and SW

Free-streaming

[See: Heisig at EPS'21]
For plots



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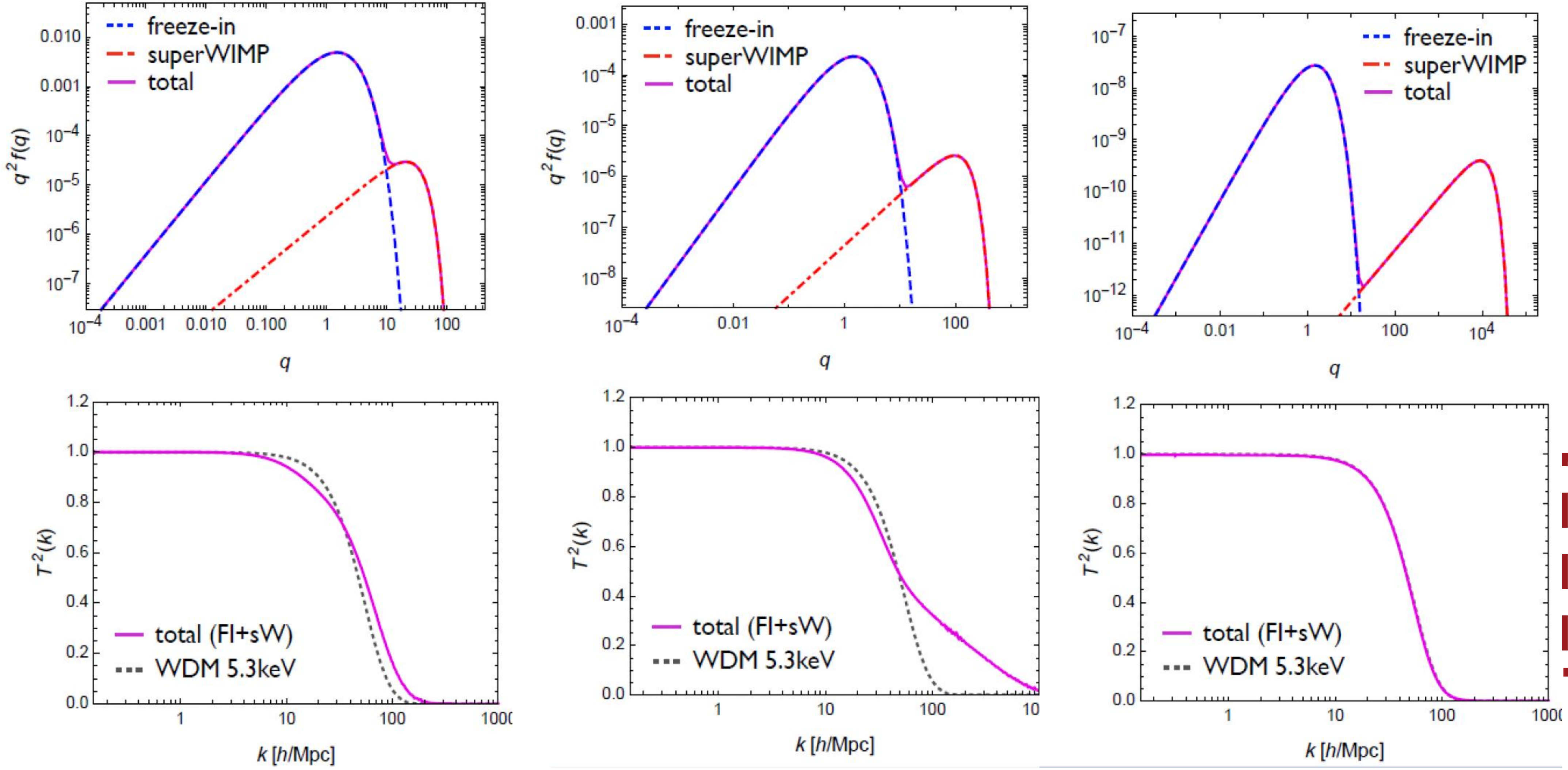
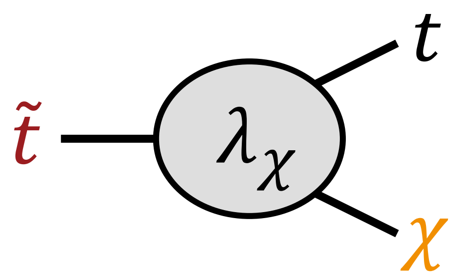


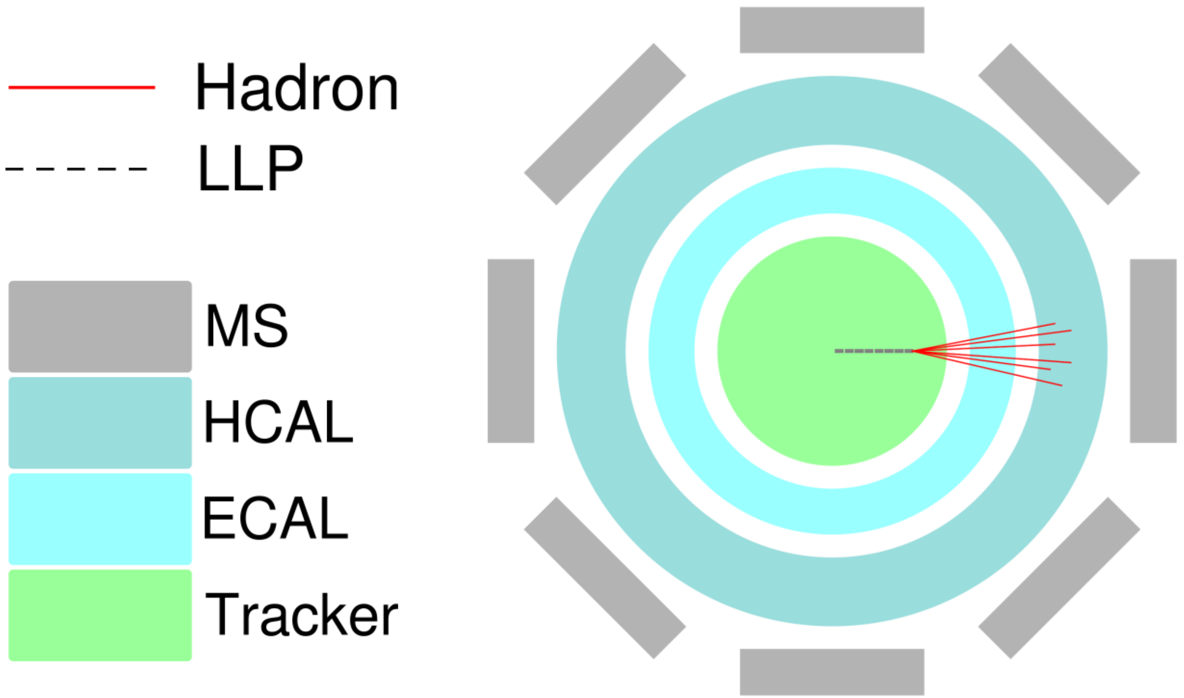
m_{DM} increases from 22keV → 77 MeV to fix the suppression scale

Tests and constraints of FI and SW

Method 1: Collider



Displaced Vertices (+ MET)



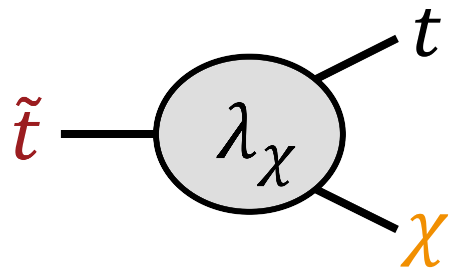
[See for example Calibbi'21 for details on searches]

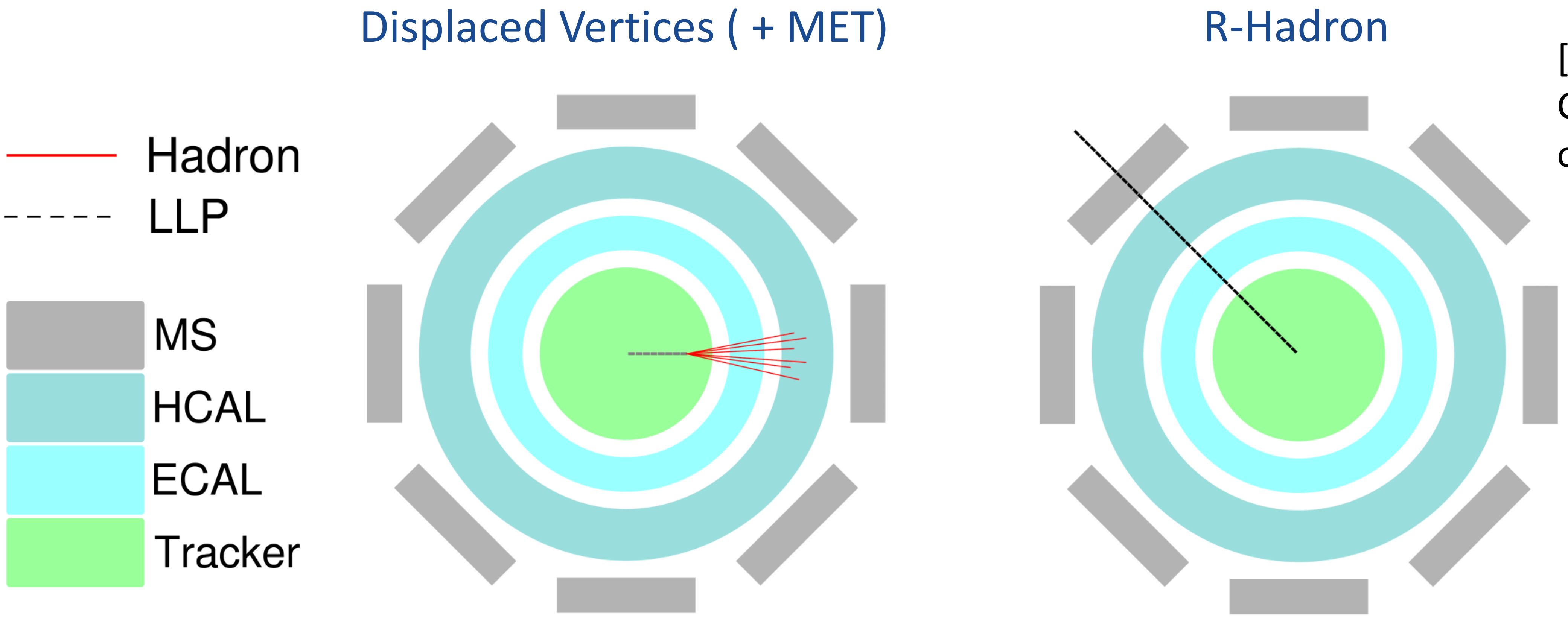
$\tilde{t}$ can be a long-lived particle

Credits to Sam Junius for the figures.

Method 1: Collider

Increasing lifetime of $\tilde{t}$

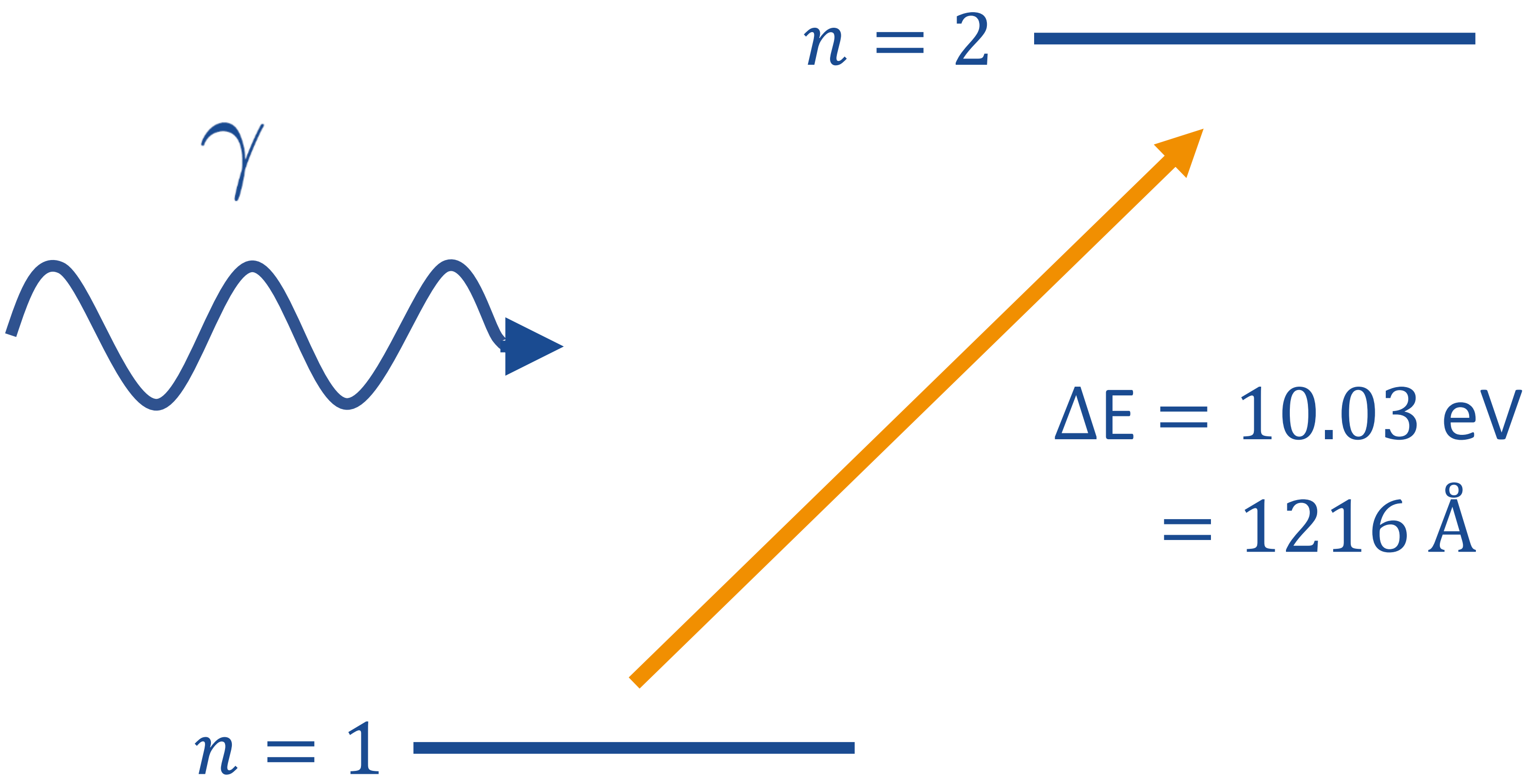




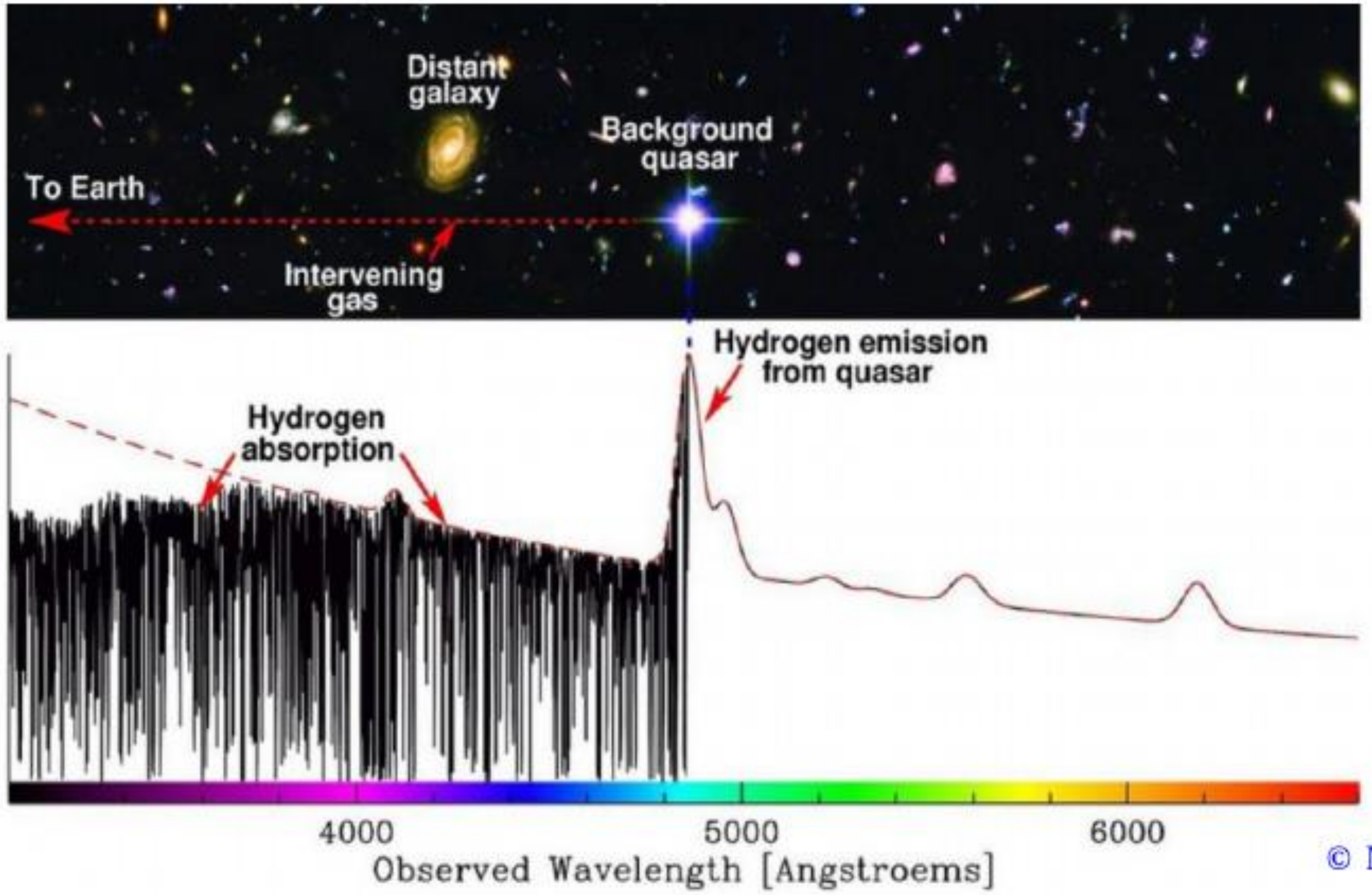
[See for example Calibbi'21 for details on searches]

Credits to Sam Junius for the figures.

Method 2: Lyman-α transition in neutral hydrogen

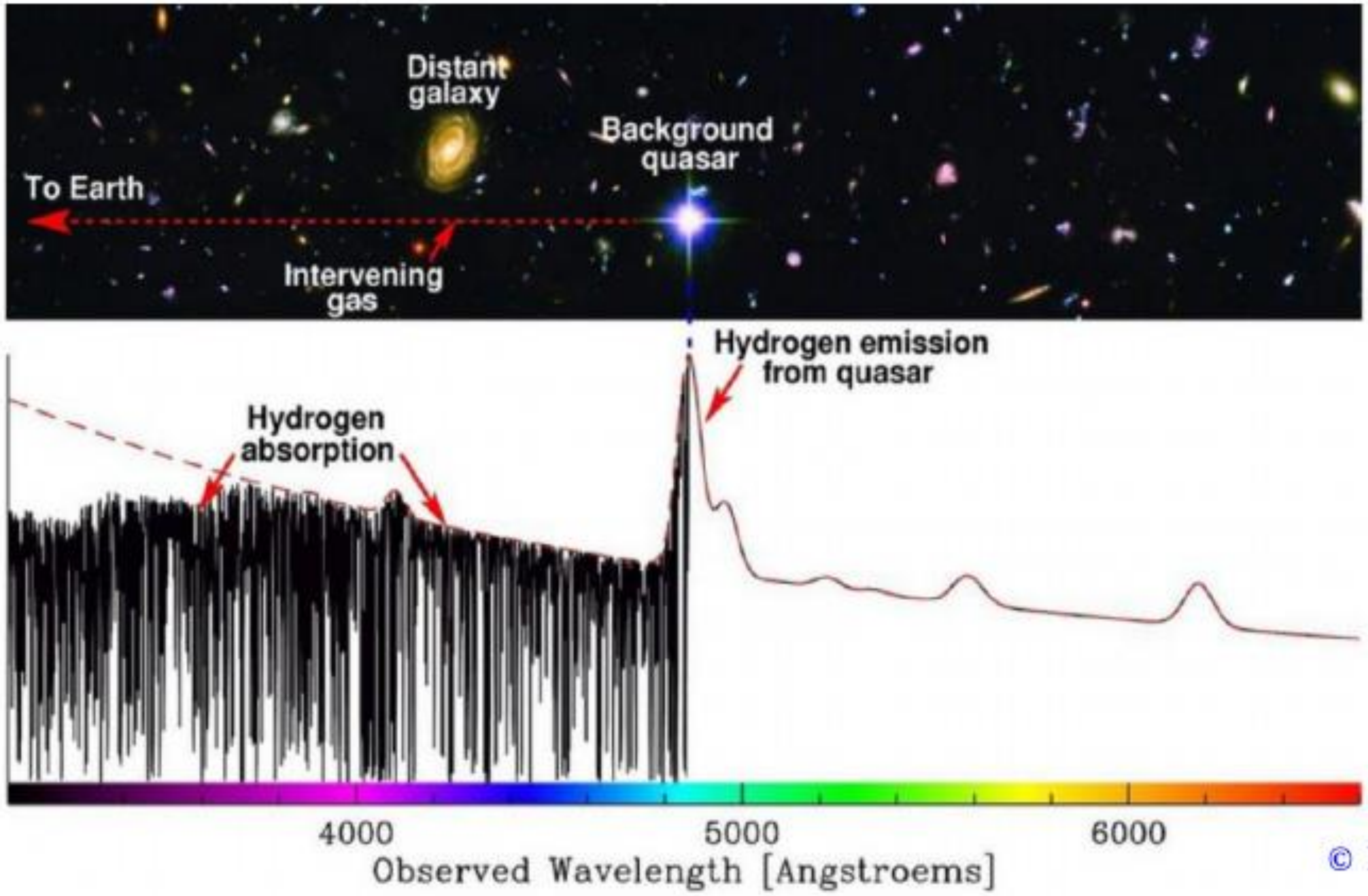


Lyman-α flux power spectrum



Quasars ($z \lesssim 6$) shine through H-cloud

Lyman-α flux power spectrum

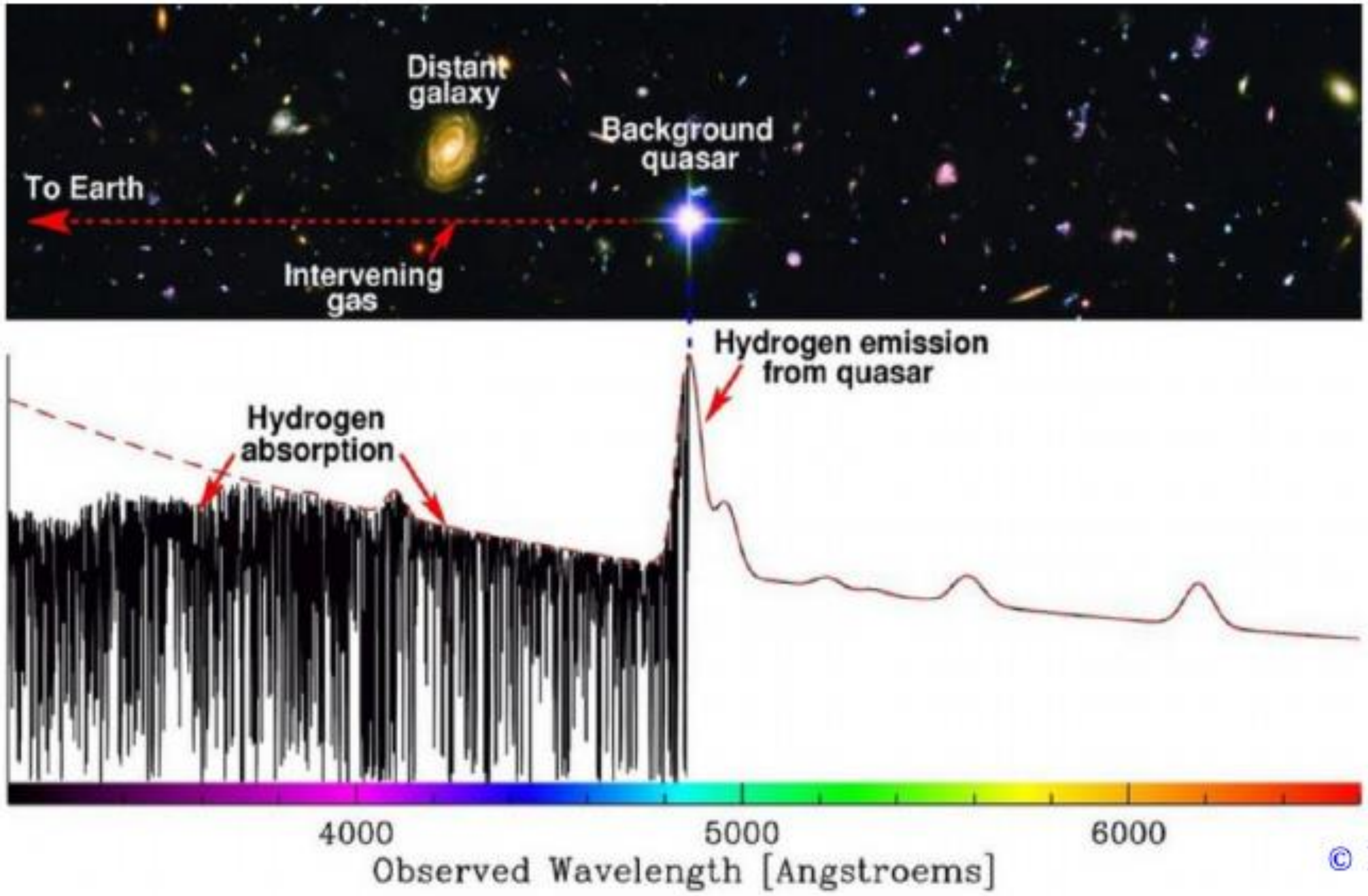


Quasars ($z \lesssim 6$) shine through H-cloud

Absorption at different z's results in shown profile

© M. Murphy

Lyman-α flux power spectrum



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Profile depends on distribution neutral H which follows the DM one

© M. Murphy

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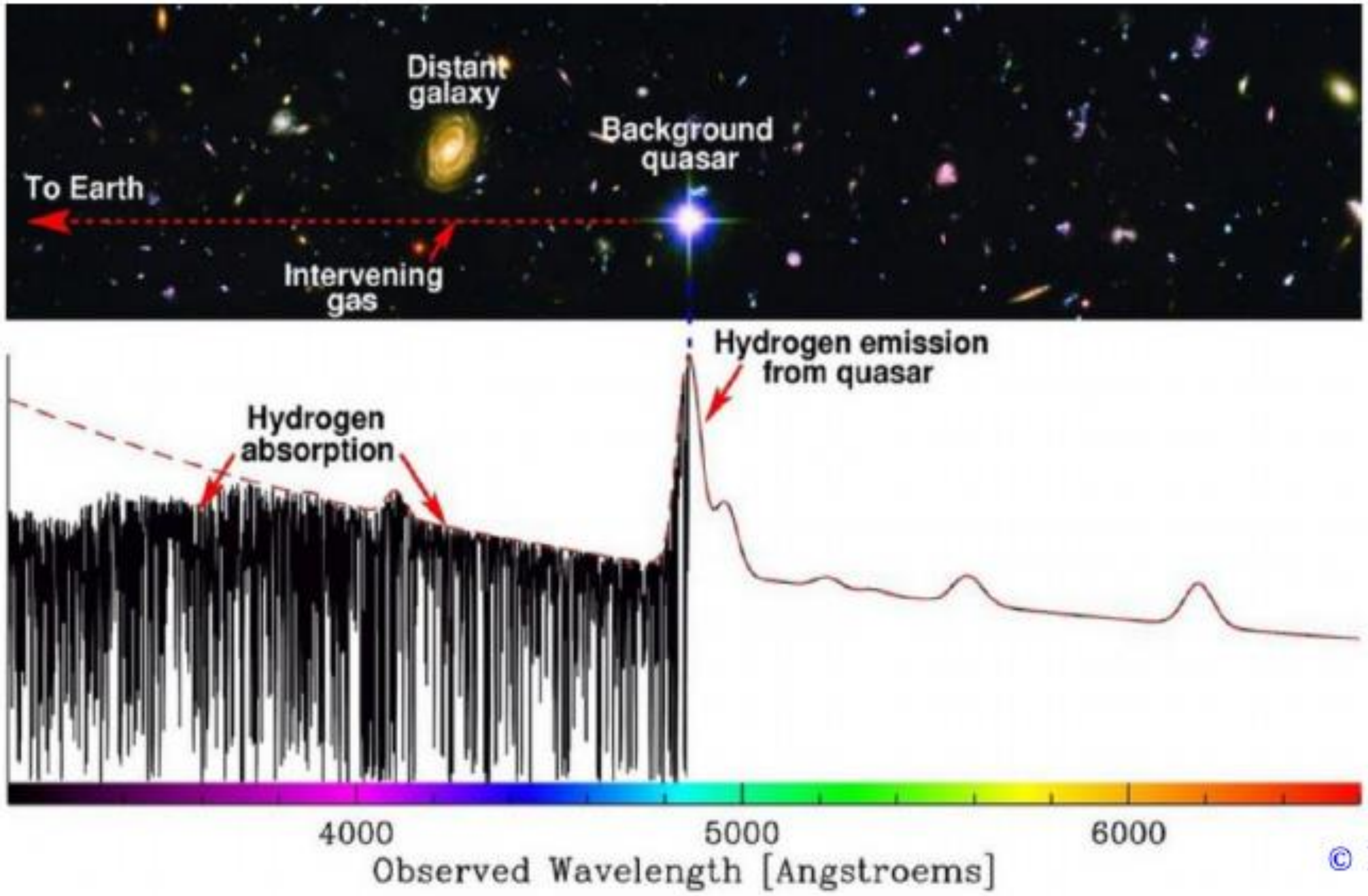

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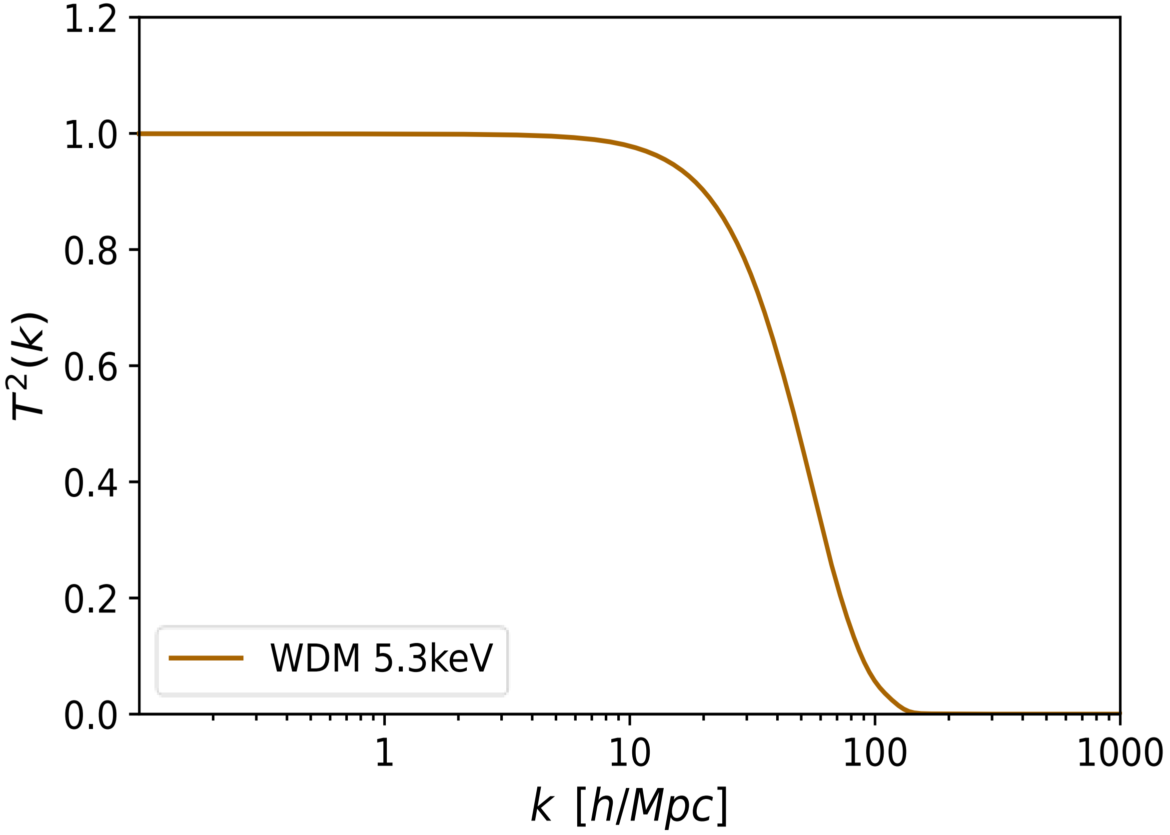
Expensive hydrodynamical simulations needed to extract constrains

© M. Murphy

Thermal WDM bound from Lyman-α

Thermal WDM bound: $m_{WDM} > 1.9 \; - 5.3$ keV

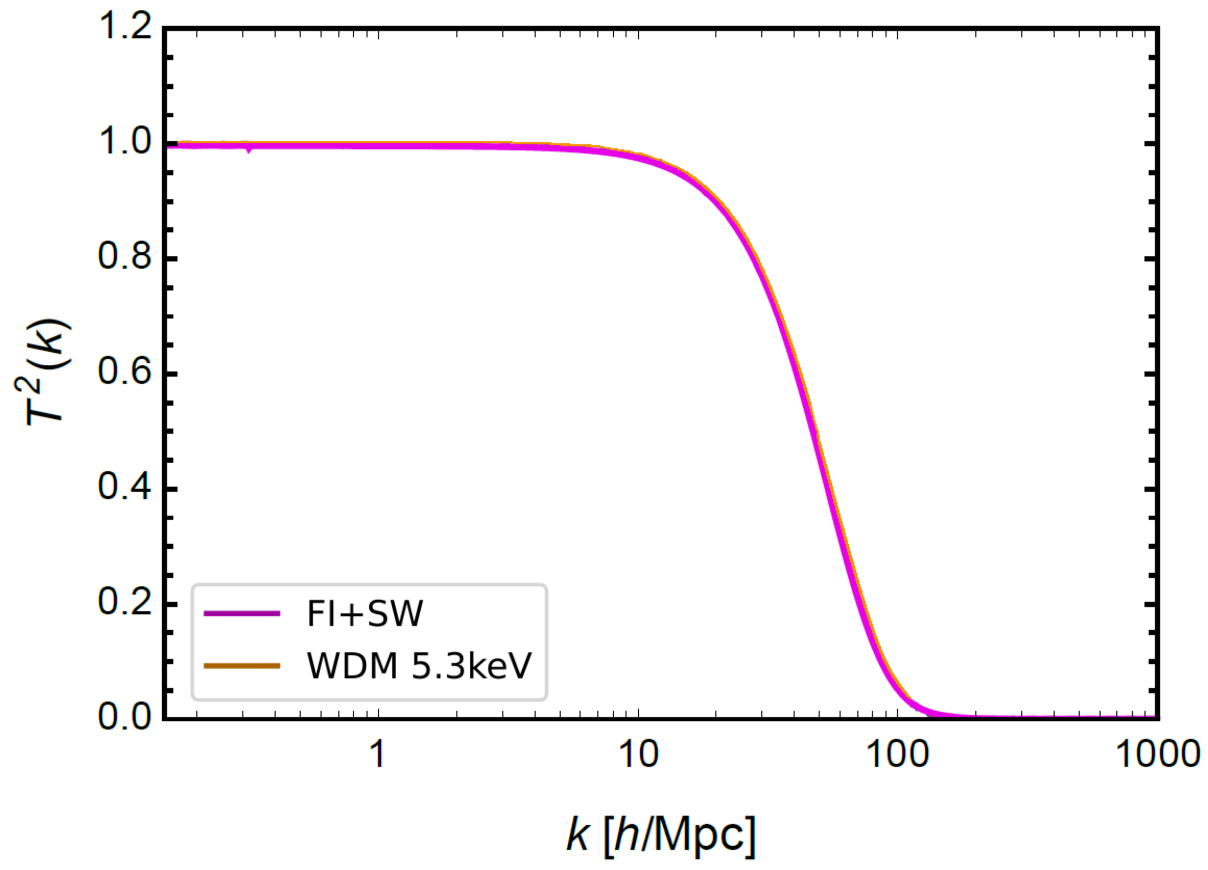
[Garzilli+’19; Palanque-Delabrouille+’19]



Recasting of thermal WDM bounds

$m_{WDM} > 1.9 - 5.3\text{ keV}$

[Garzilli+'19; Palanque-Delabrouille+'19]



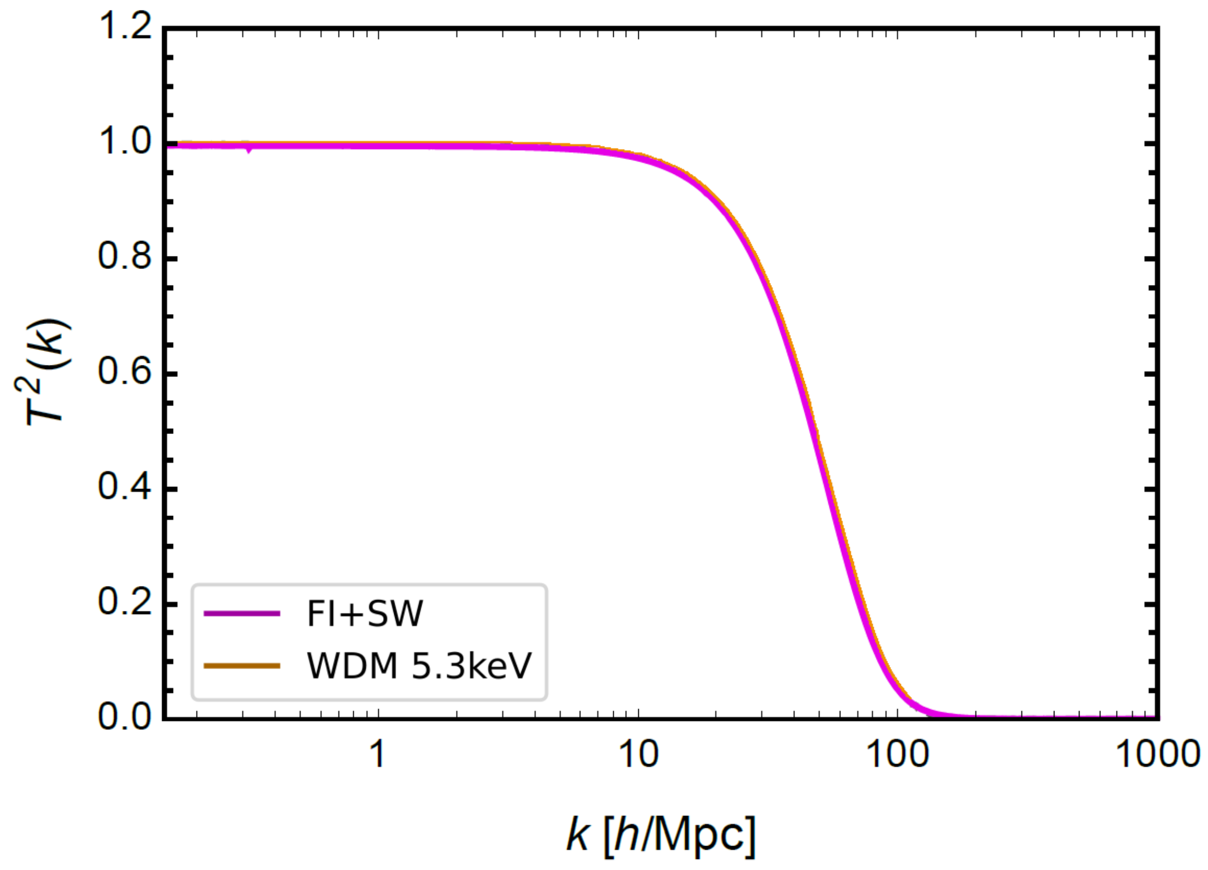
1 dominant process

Equate: $v_\chi^{rms} = v_{WDM}^{rms}$

Recasting of thermal WDM bounds

$m_{WDM} > 1.9 - 5.3$ keV

[Garzilli+'19; Palanque-Delabrouille+'19]



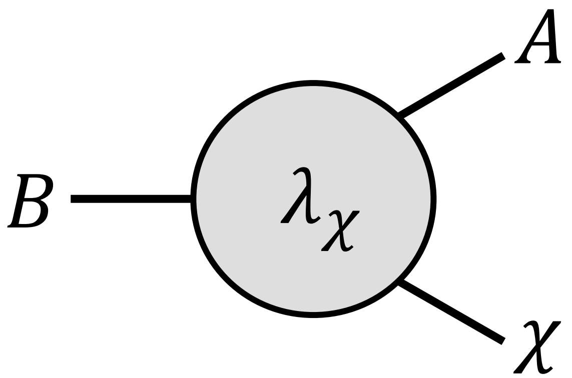
1 dominant process

Equate: $v_\chi^{rms} = v_{WDM}^{rms}$

FI: $m_\chi \gtrsim 16\,\text{keV} \times \delta$

SW:

$$\delta = \left(1 - \frac{m_A^2}{m_B^2}\right)$$



[For FI see also: Heeck+'17, Boulebnane+18, D'Eramo+'20]

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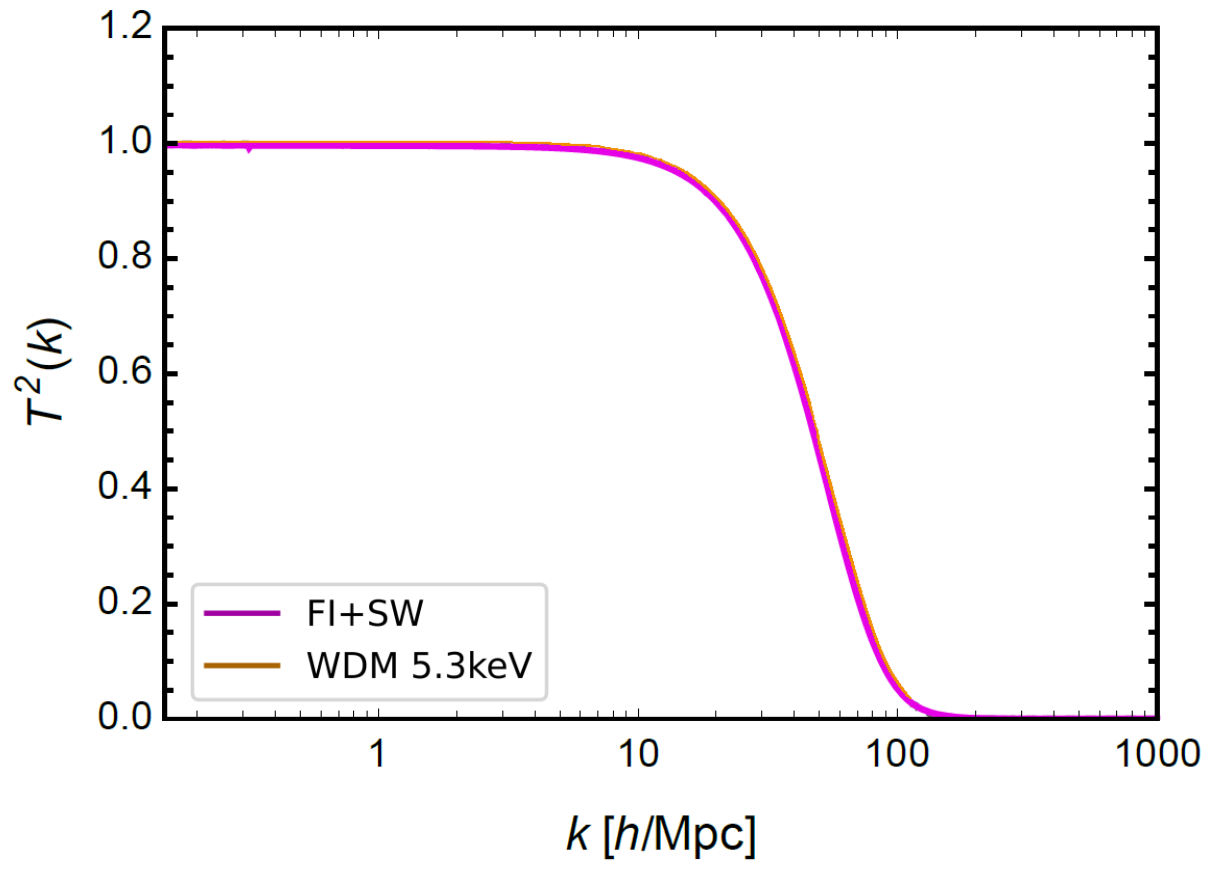

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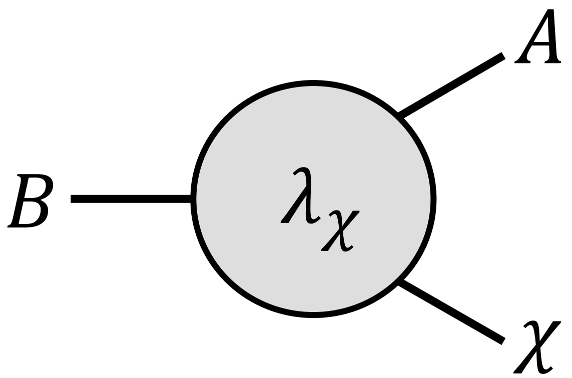
Equate: $v_\chi^{rms} = v_{WDM}^{rms}$

FI: $m_\chi \gtrsim 16\,\mathrm{keV} \times \delta$

SW: $m_\chi \gtrsim 3.8\,\mathrm{keV} \times \delta \times (R_\Gamma)^{-1/2}$

$$\delta = \left(1 - \frac{m_A^2}{m_B^2}\right)$$



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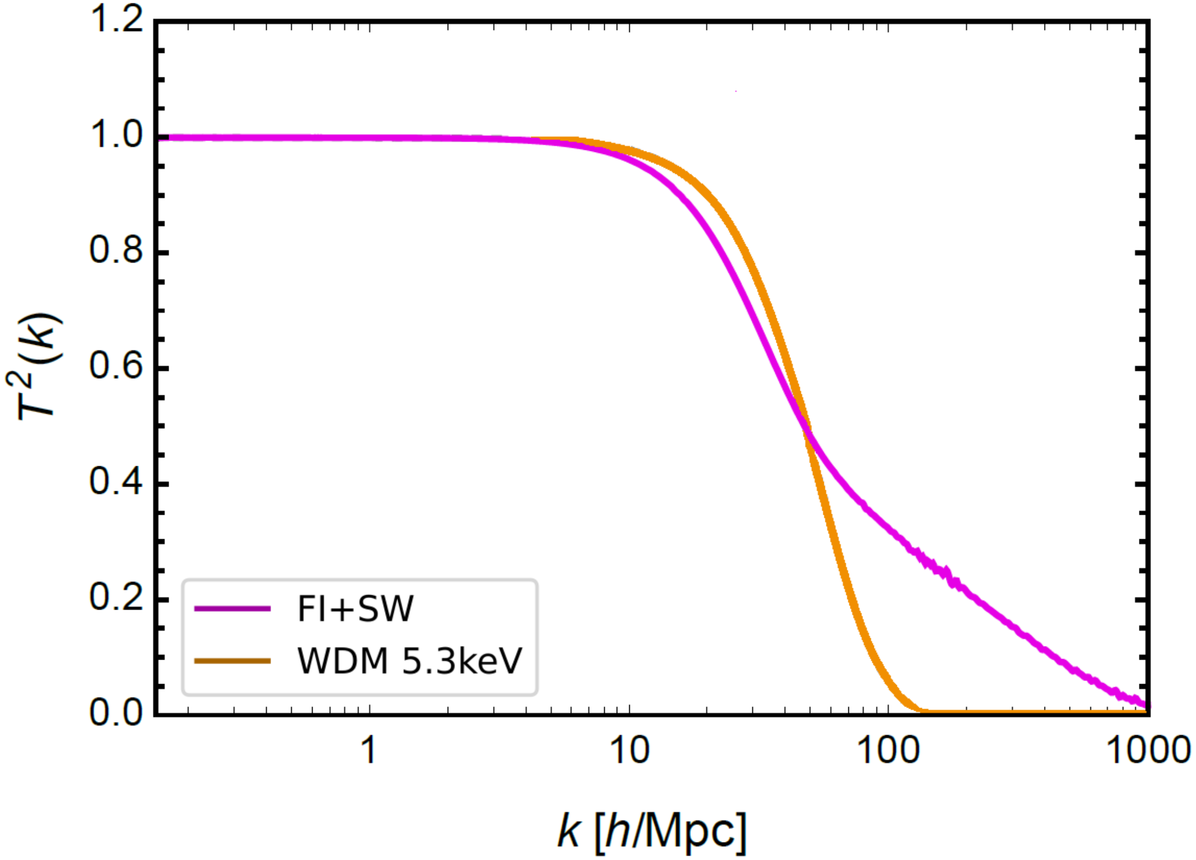

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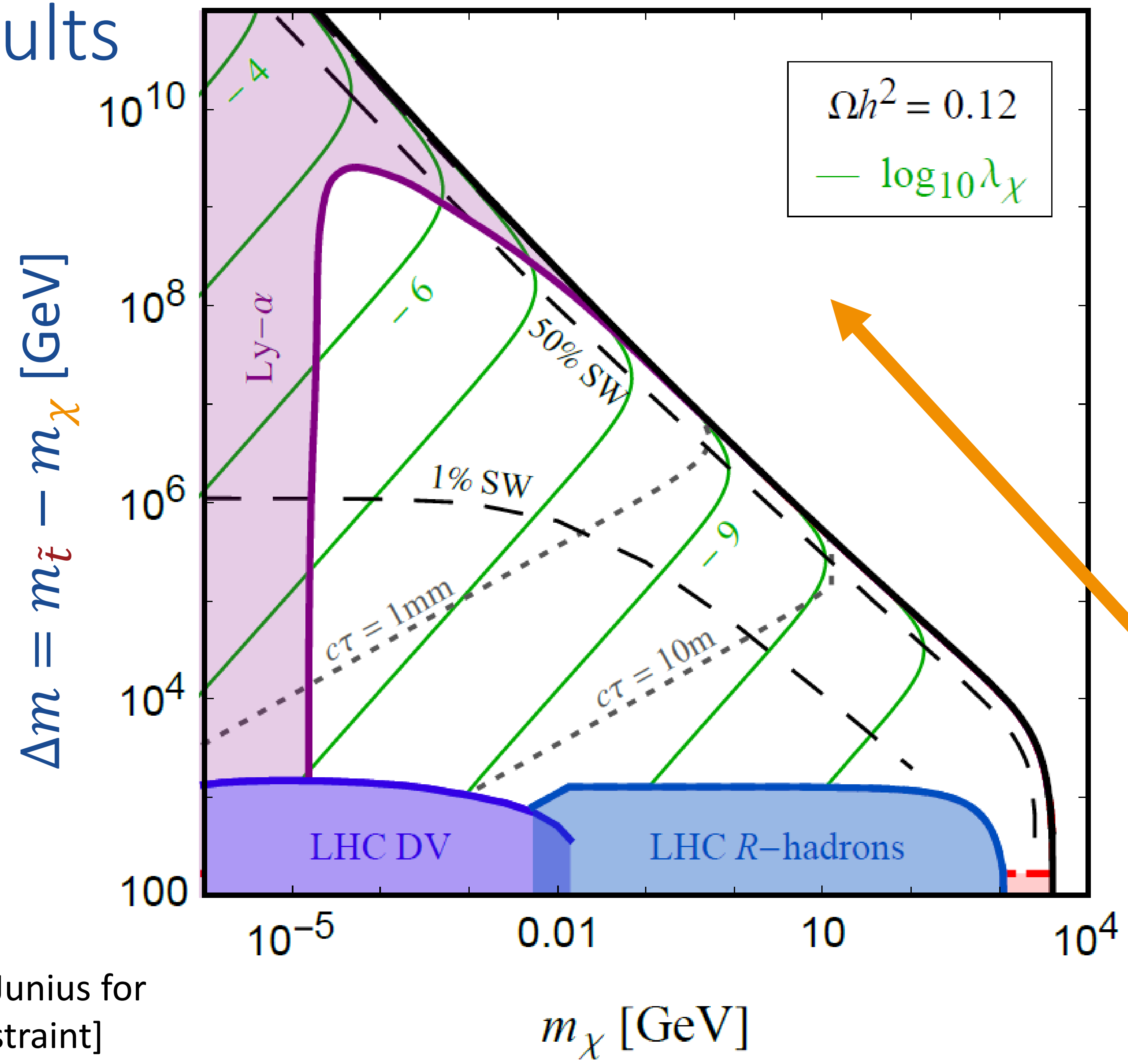
No dominant process

Area-criterium [Schneider '16, Murgia+'17]

Results



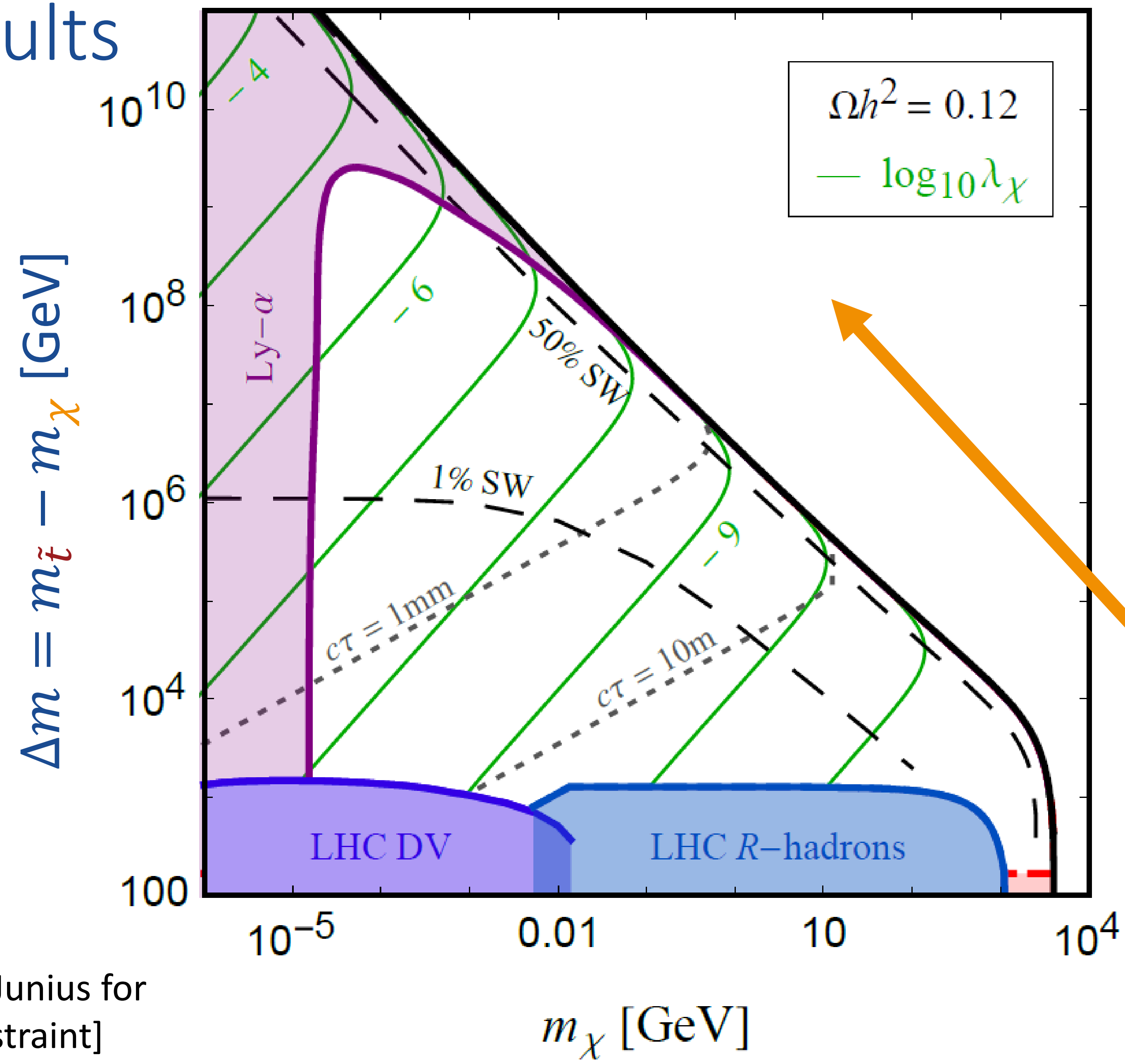
Relevant parameters:

- Masses: $m_{\tilde{t}}$ & m_χ
- Coupling: λ_χ

Excluded because overproduction of DM

[Credits to Sam Junius for the LHC-DV constraint]

Results



Ly-α region = constraints from the free-streaming suppression of the matter power spectrum

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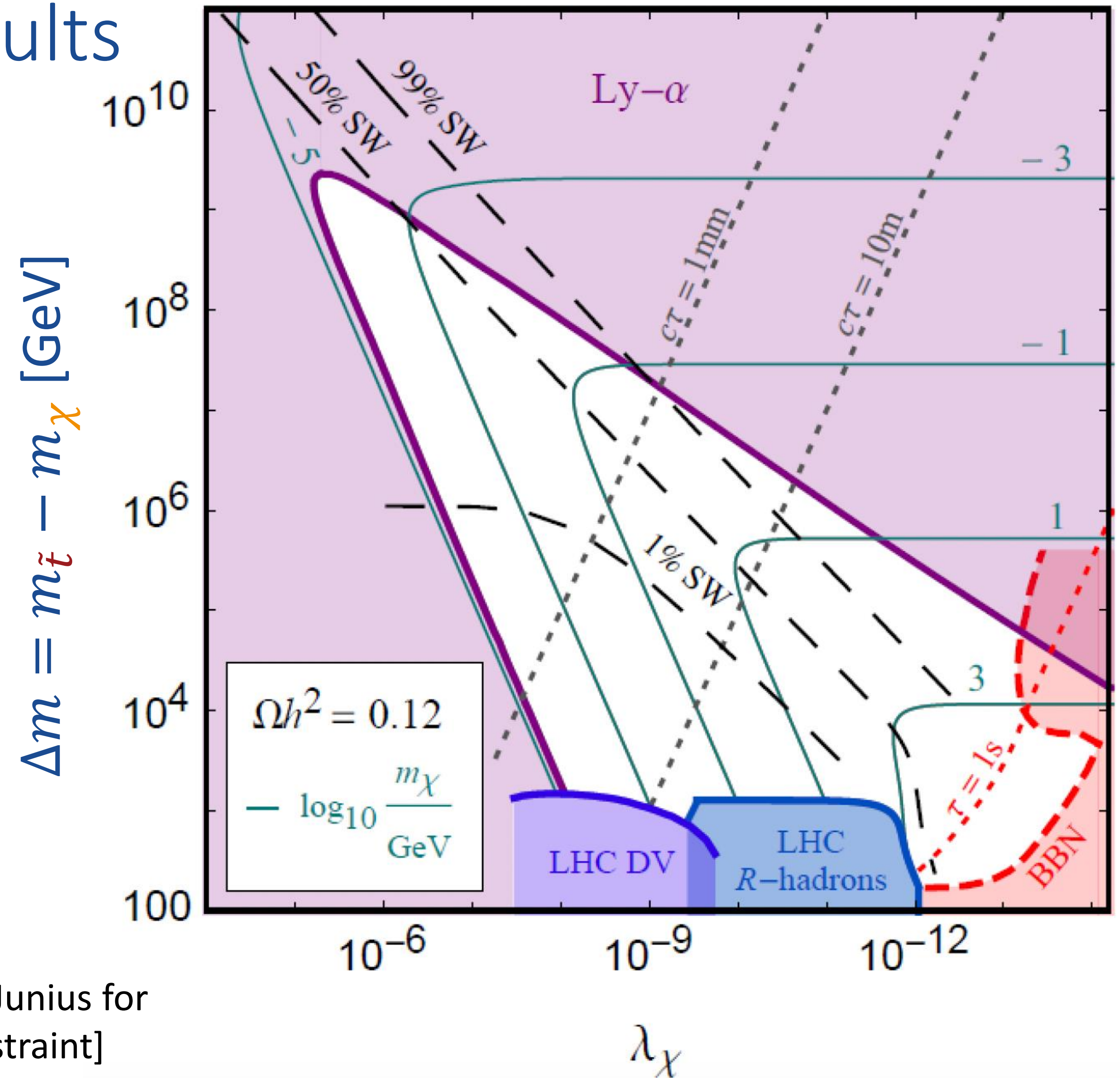
Results



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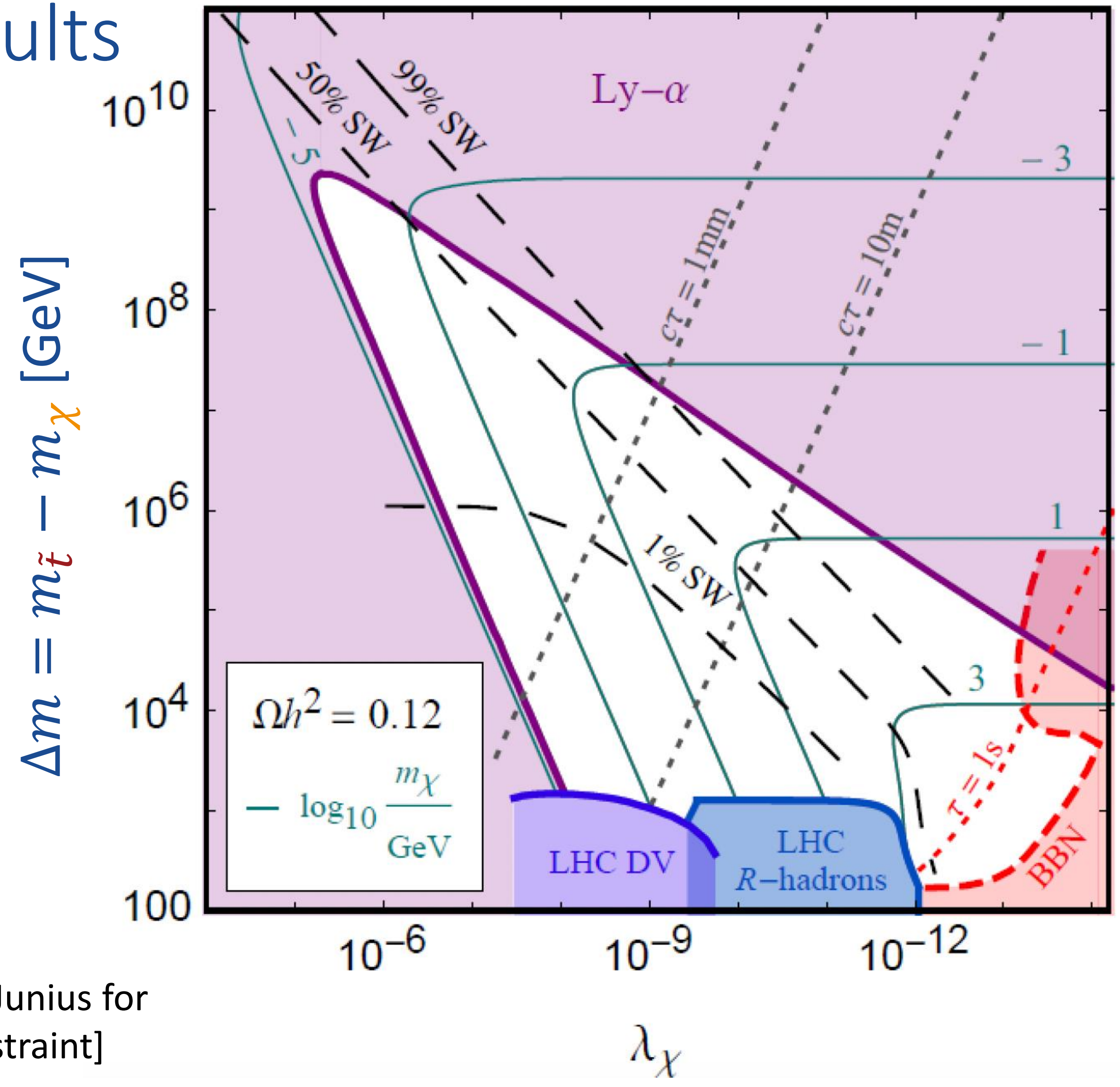

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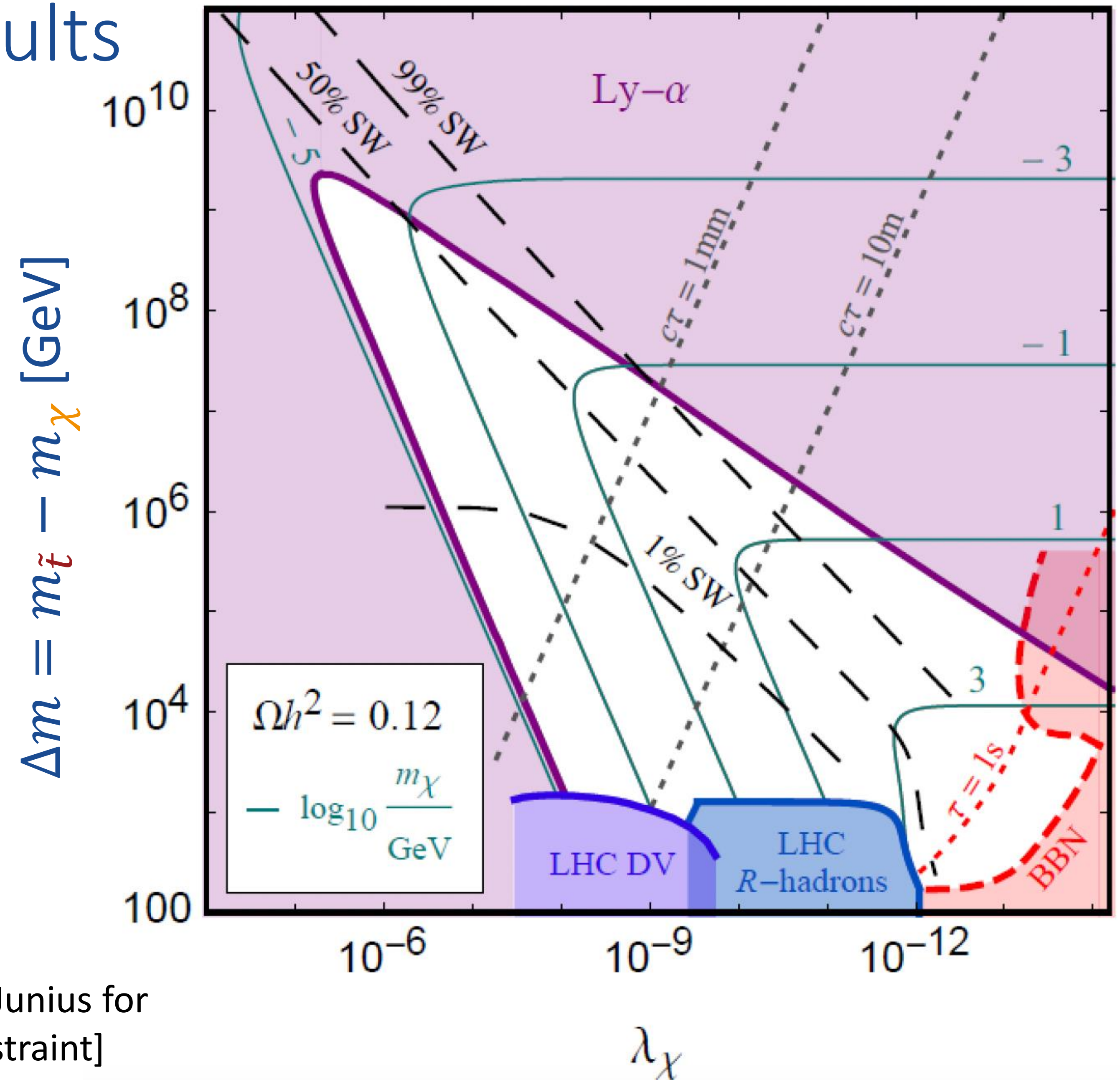
Ly-α region = constraints from the free-streaming suppression of the matter power spectrum

To conclude:

Strong complementarity between cosmology and colliders

Results



[Credits to Sam Junius for the LHC-DV constraint]

Ly-α region = constraints from the free-streaming suppression of the matter power spectrum

To conclude:

Strong complementarity between cosmology and colliders

Public code to run CLASS in case of freeze-in and superWIMP: https://github.com/dchooper/class_fisw

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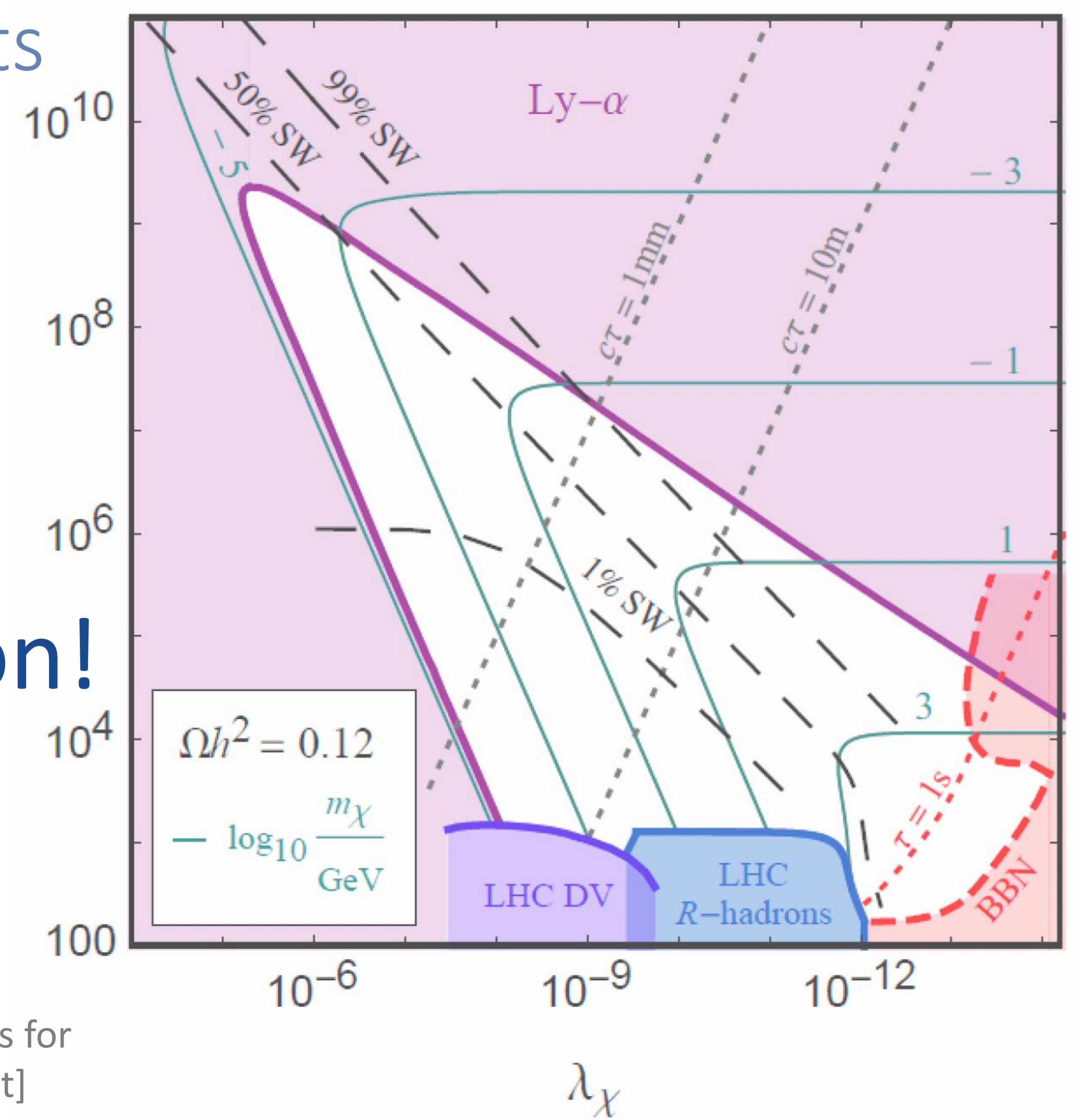
Thank you for your attention!



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