Lyman-α constraints on Freeze-in and SuperWIMPs

Quentin Decant
In collaboration with
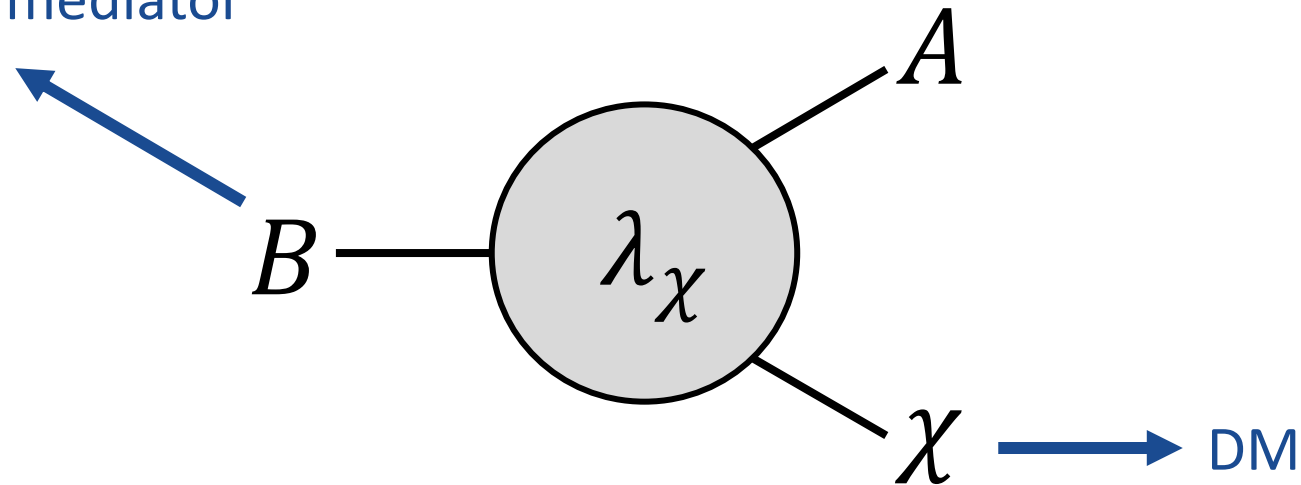J. Heisig, D. C. Hooper, L. Lopez-Honorez
JCAP03(2023)041

DM production from decays

Particle in thermal equilibirum
with SM bath ≡ "mediator"
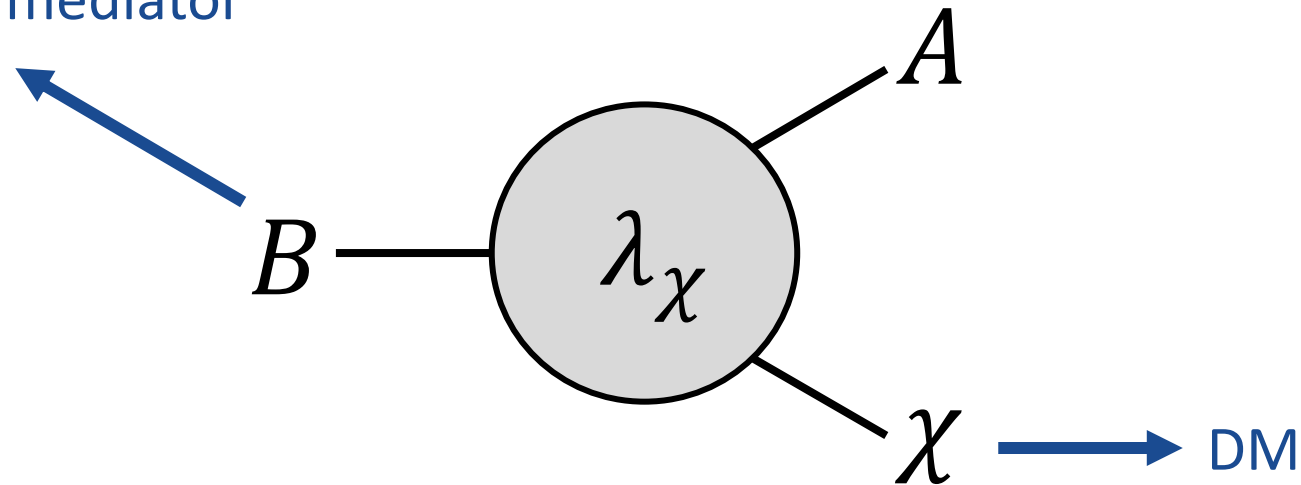

See also e.g.:
[Hall'09, Co'15, Hessler'16, d'Eramo'17, Heeck'17, Boulebname'17, Brooijmans'18, Garny'18, Calibbi'18, No'19, …]

DM production from decays

Particle in thermal equilibirum
with SM bath ≡ "mediator"

Relevant parameters:

- Masses: m_B & m_χ
- Coupling: λ_χ

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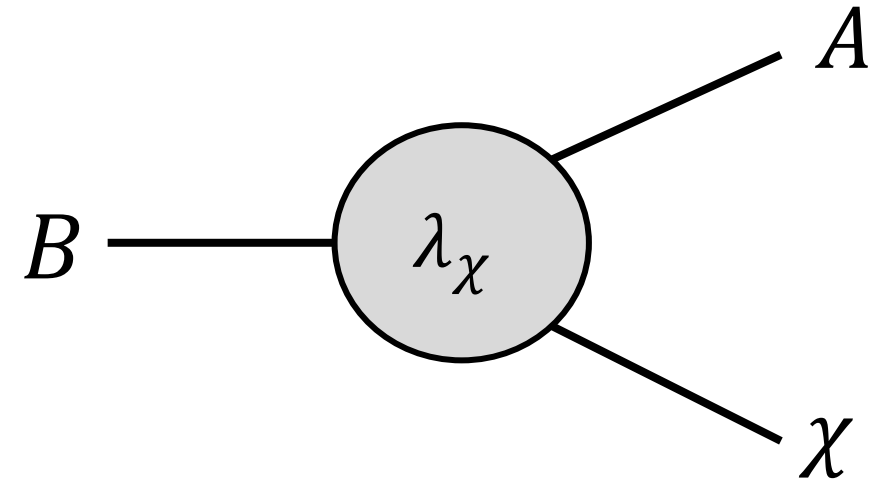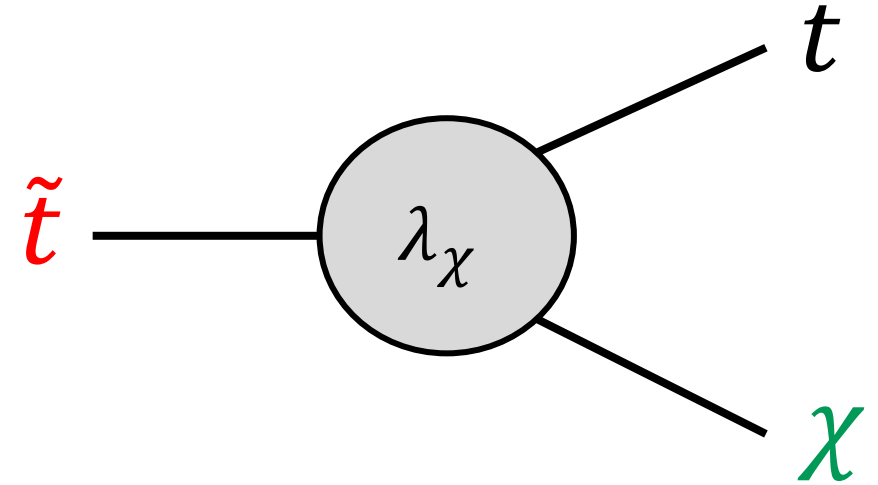
Freeze-in and SuperWIMP's

"Standard" Freeze-in:

DM produced from **rare** decays of B,

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

➡️ DM never in equilibrium with SM

SuperWIMP:

If $B \rightarrow$ SM+SM not allowed $\boxed{\lambda_\chi \ll 10^{-6}}$ ➡️ B can be long-lived

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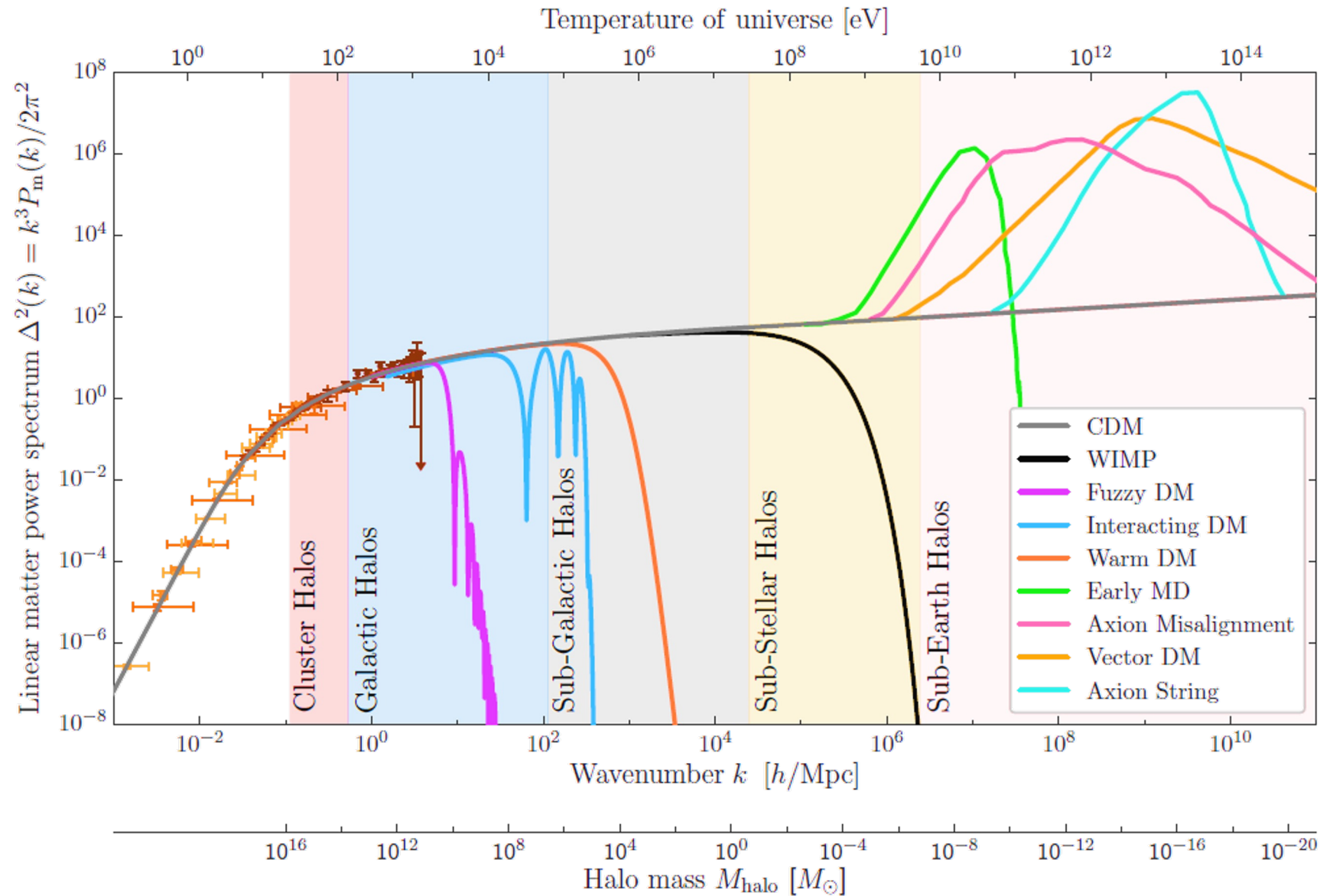
If B ➡ SM+SM not allowed ➡ B can be long-lived

Example model (top-philic DM): [See:Garny, Heisig,Lülf, Hufnagel 1802.00814]

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

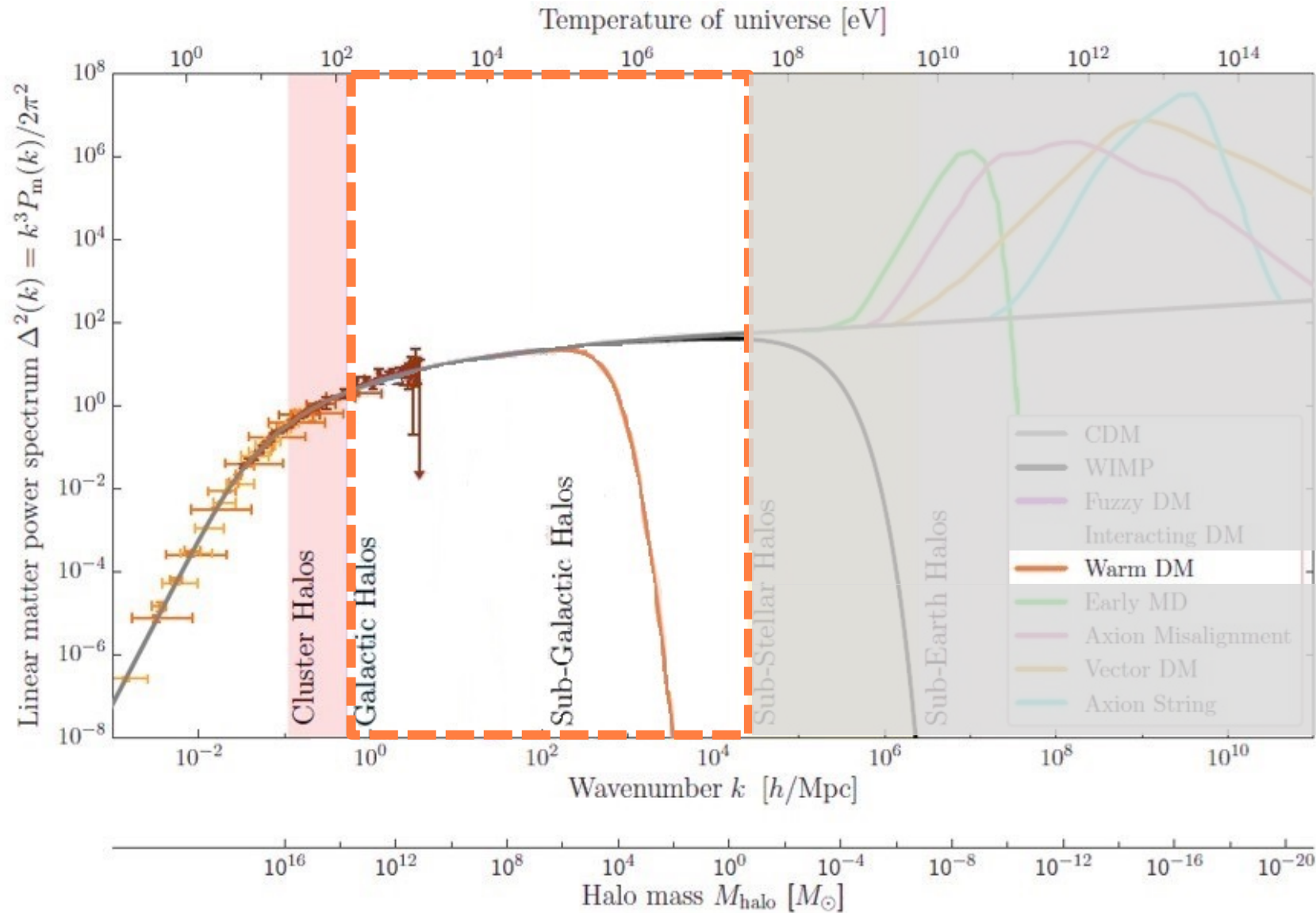Colored Scalar = Mediator

Majorana Fermion = DM

Non-Cold Dark Matter (NCDM)
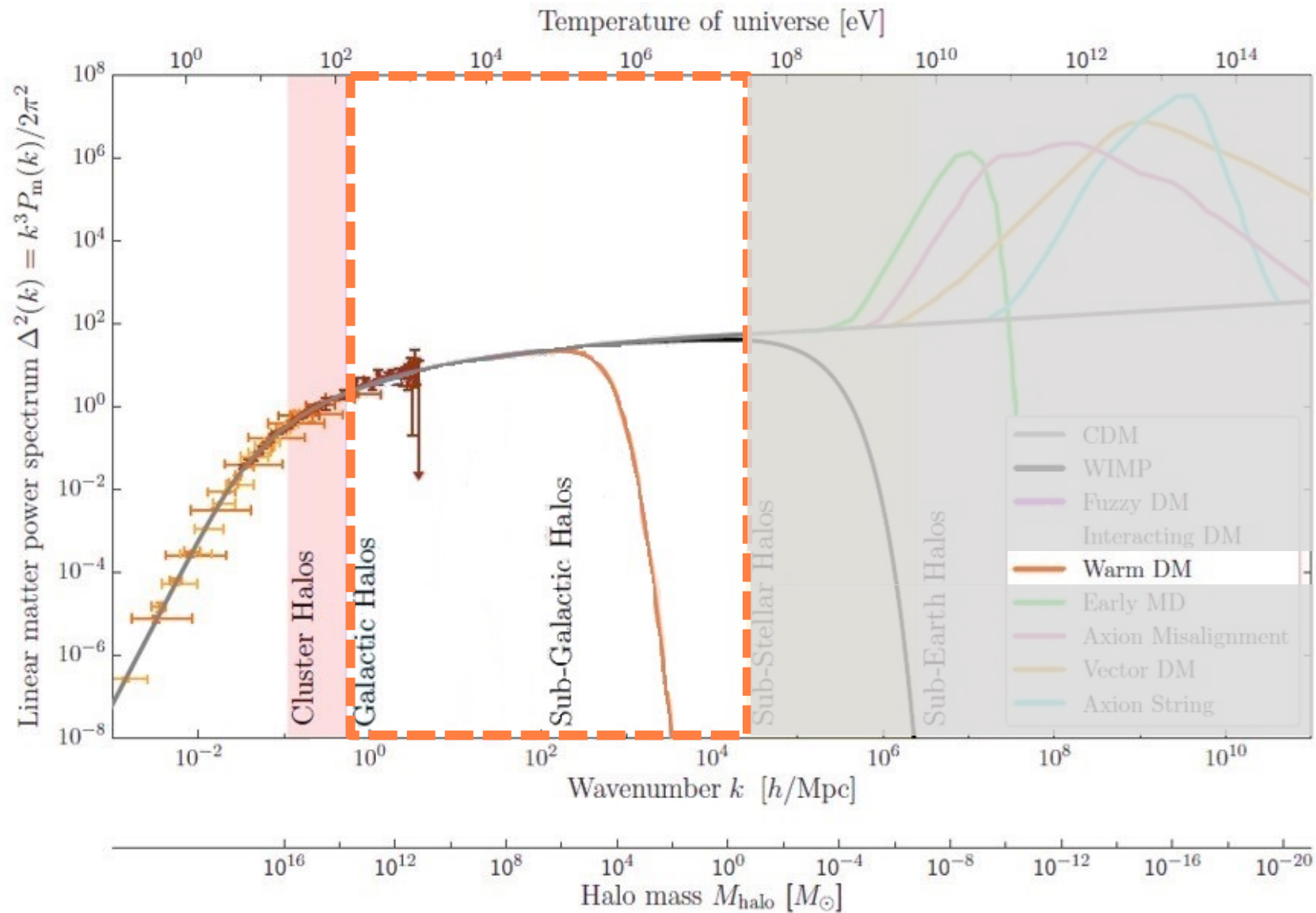

[Bechtol+'22
(Snowmass2021)]

Non-Cold Dark Matter (NCDM)

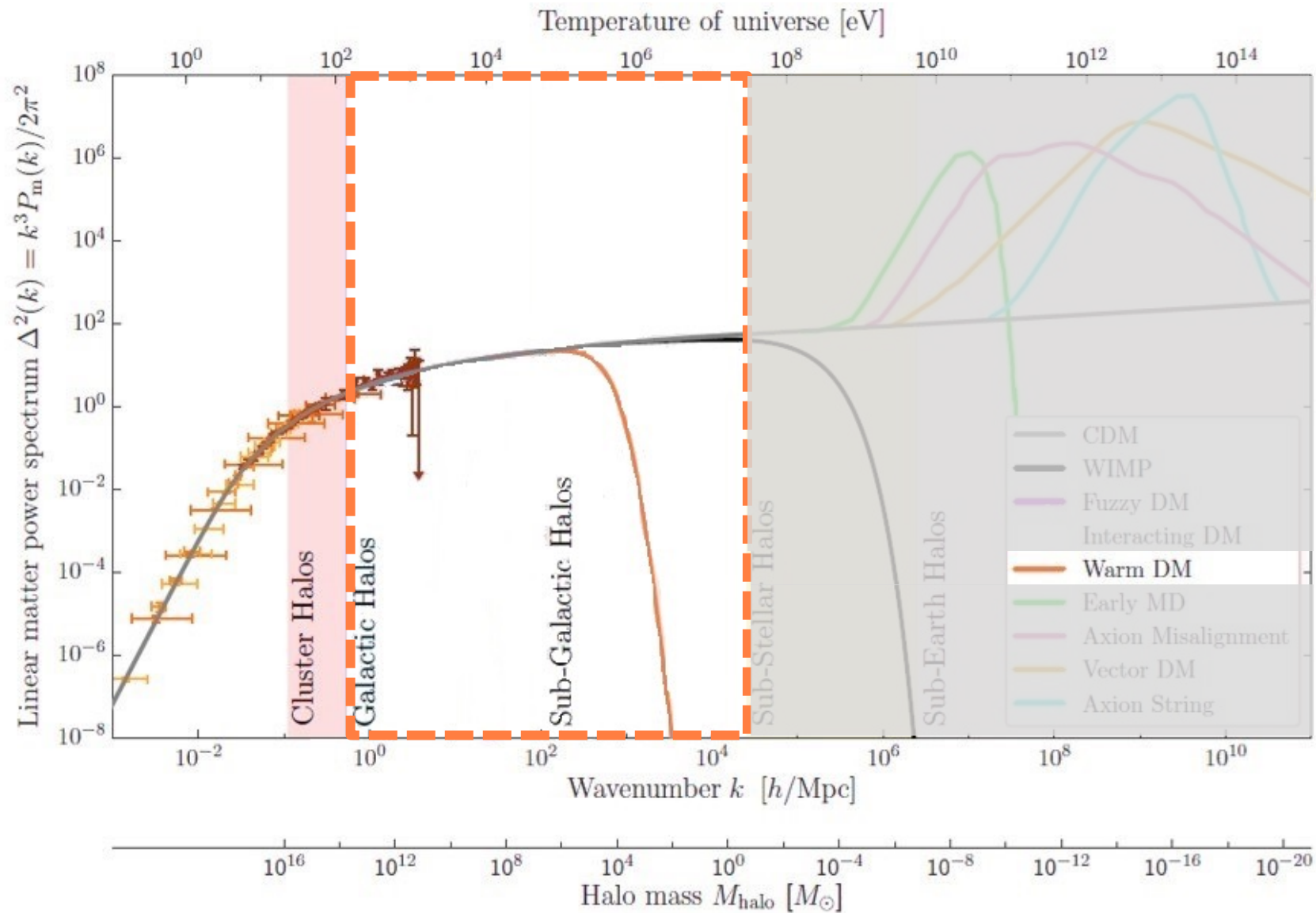Warm Dark Matter (WDM) = DM is produced with non-negligible velocity

[Bechtol+'22 (Snowmass2021)]

Non-Cold Dark Matter (NCDM)

Temperature of universe [eV]

Linear matter power spectrum $\Delta^2(k) = k^3 P_m(k)/2\pi^2$

Cluster Halos
Galactic Halos
Sub-Galactic Halos
Sub-Stellar Halos
Sub-Earth Halos

- CDM
- WIMP
- Fuzzy DM
- Interacting DM
- **Warm DM**
- Early MD
- Axion Misalignment
- Vector DM
- Axion String

Wavenumber k [h/Mpc]

Halo mass M_{halo} [$M_\odot$]

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)

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

Free-streaming erases structure on small scales

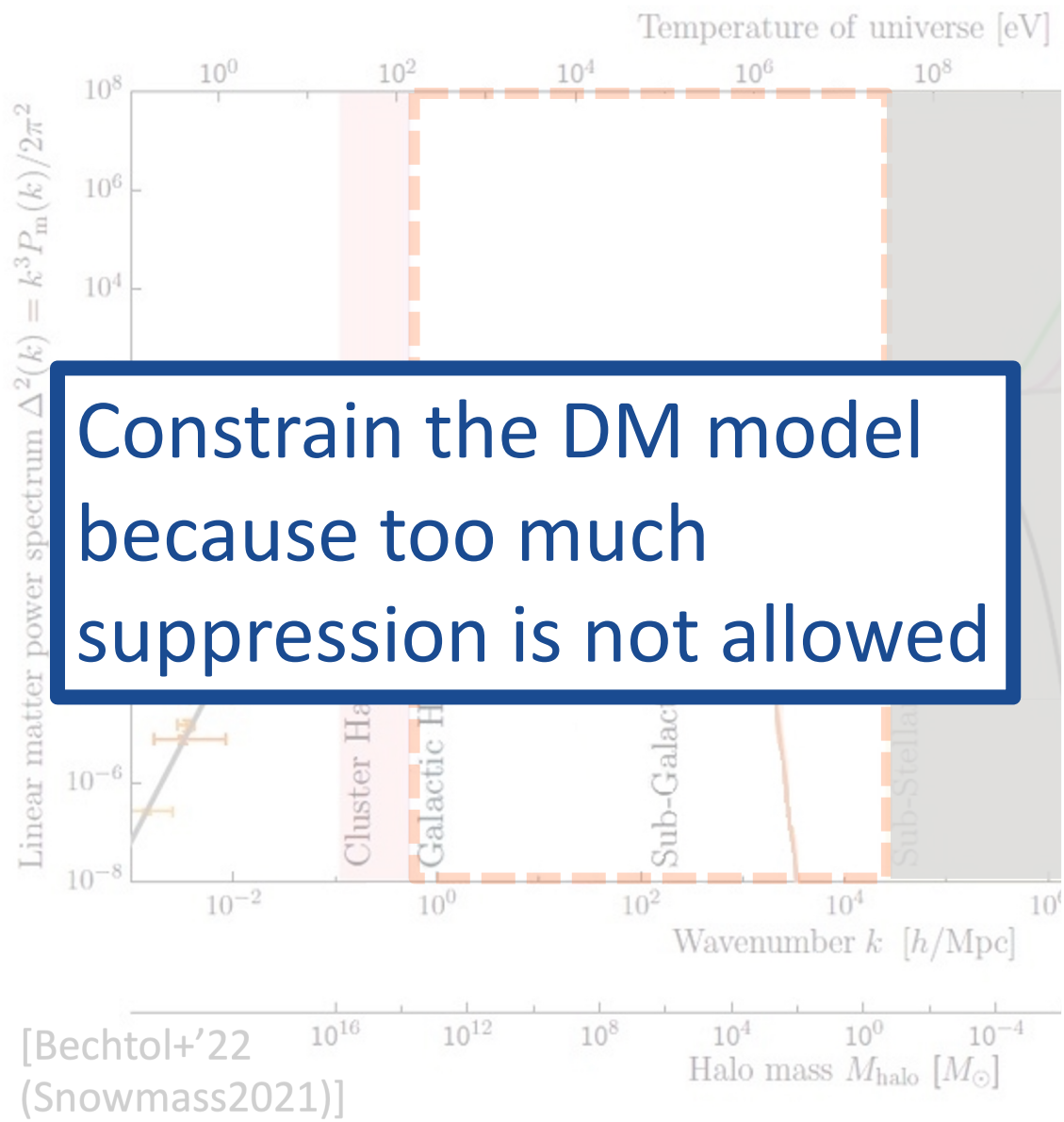Useful representation: Transfer function = NCDM/CDM

[Bechtol+'22 (Snowmass2021)]

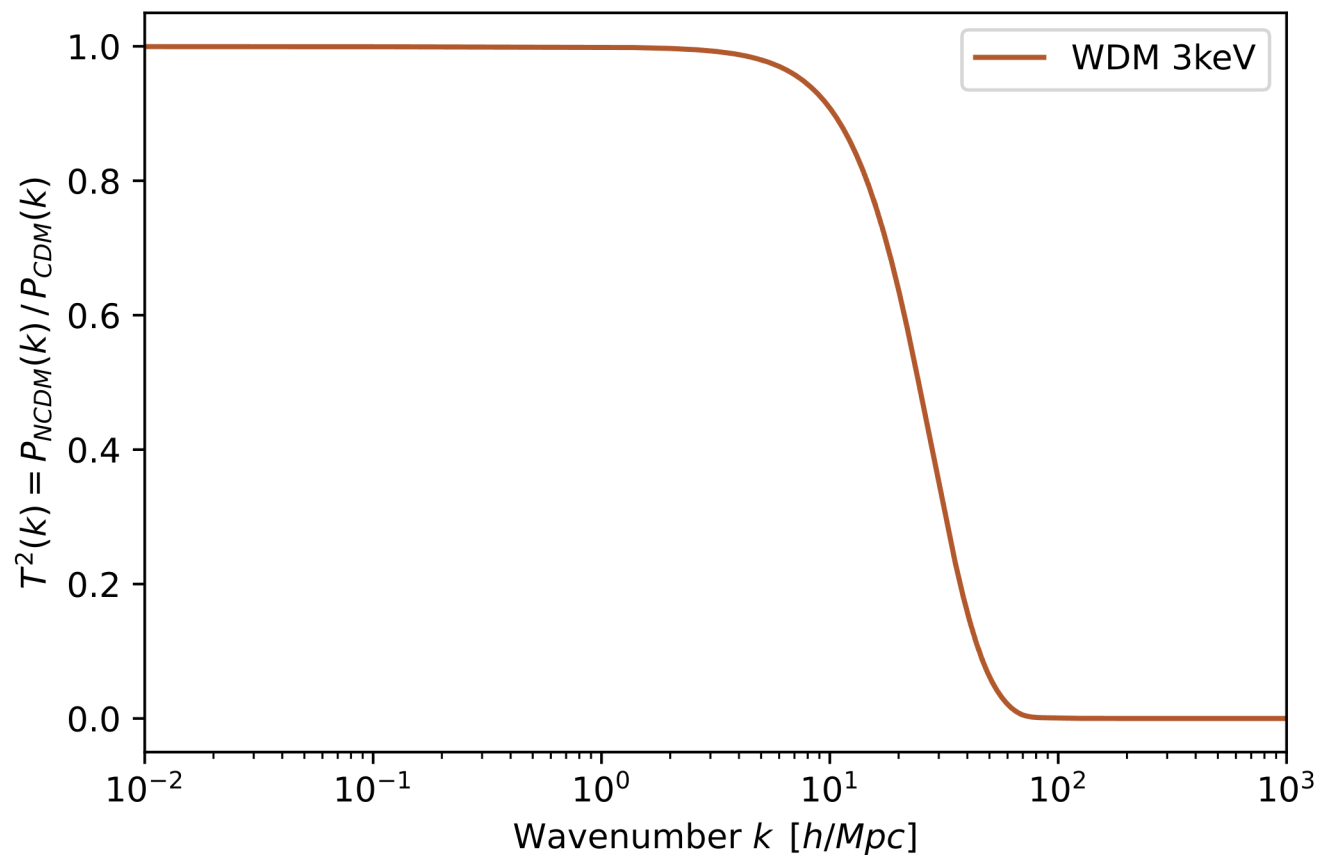# Non-Cold Dark Matter (NCDM)

Transfer function = NCDM/CDM

[Bechtol+'22 (Snowmass2021)]
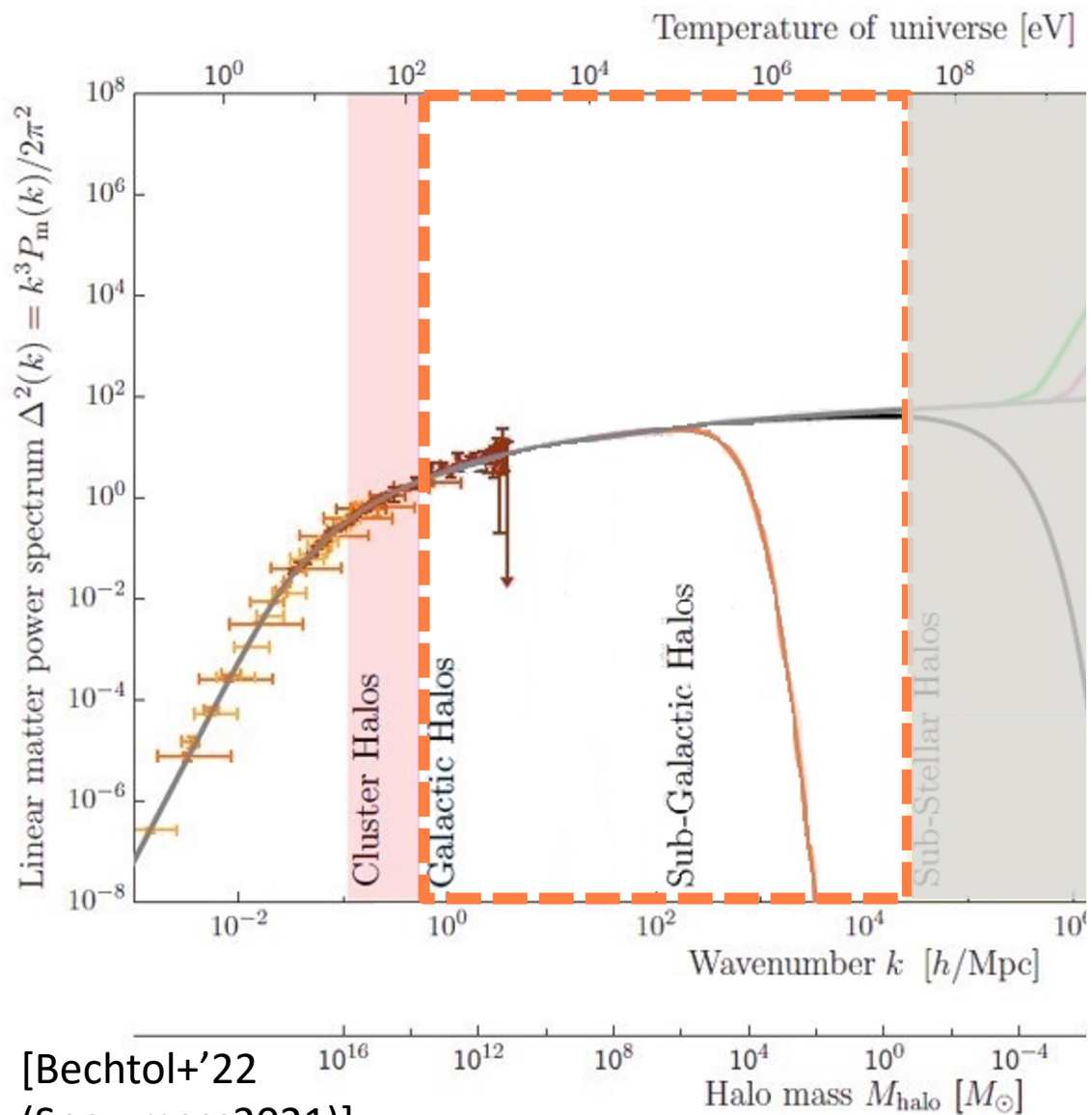
Non-Cold Dark Matter (NCDM)
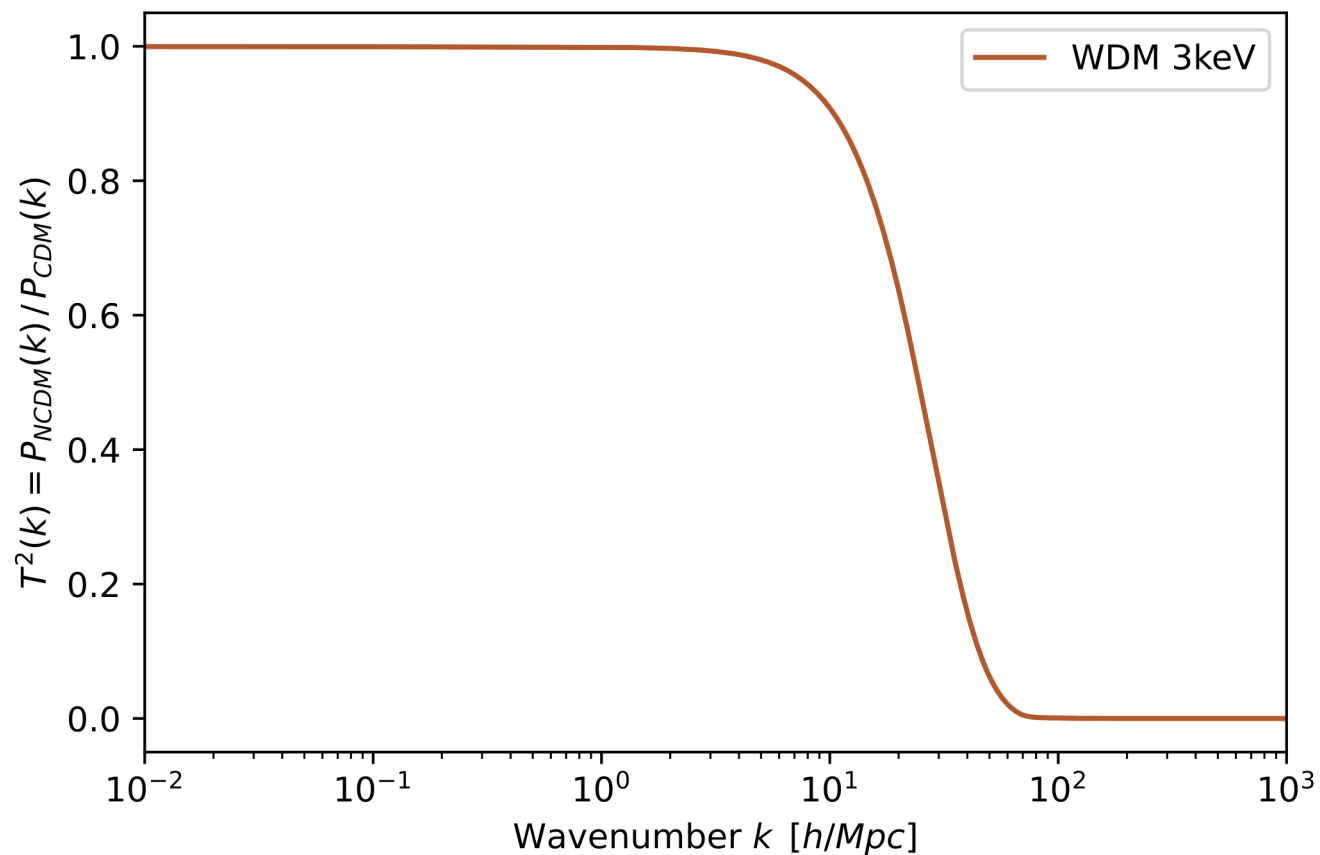
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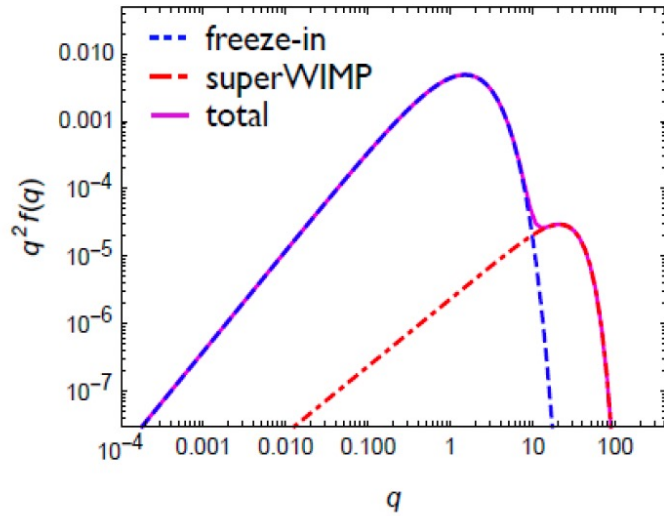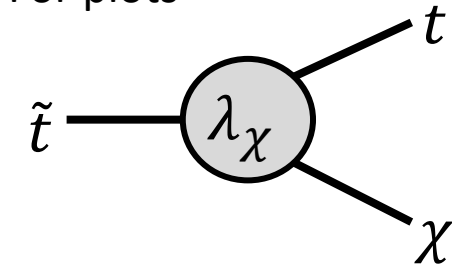Constrain the DM model because too much suppression is not allowed

[Bechtol+'22 (Snowmass2021)]

Free-streaming

Boltzmann code
CLASS

Free-streaming

Increasing lifetime of $\tilde{t}$

$\tilde{t}$ —— λ_χ $\longrightarrow$ t

χ
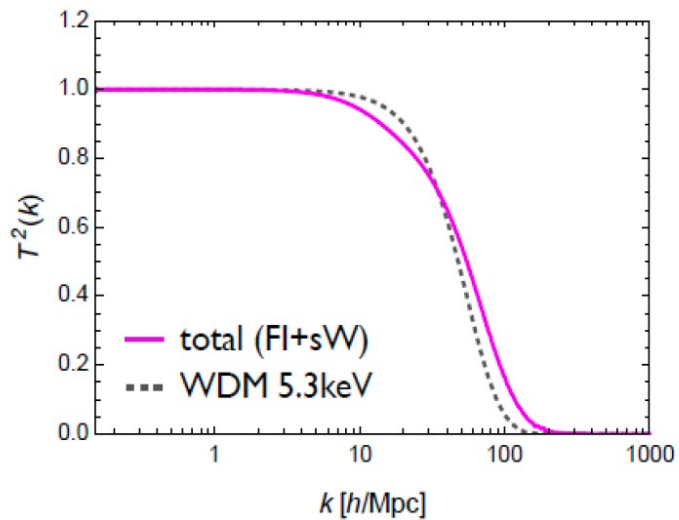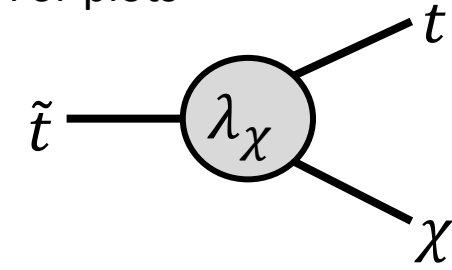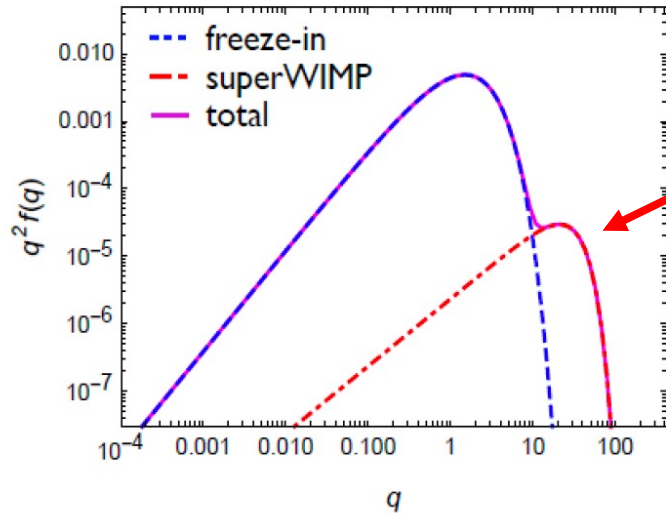
SuperWIMP contribution
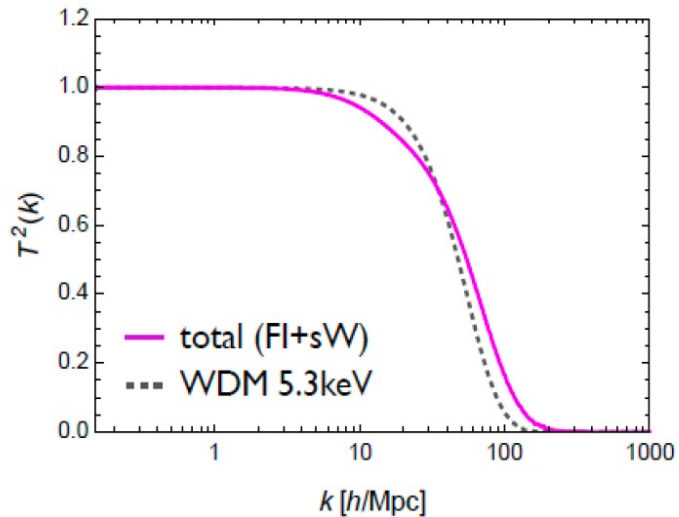
m_{DM} increases from 22keV $\rightarrow$ 77 MeV to fix the suppression scale
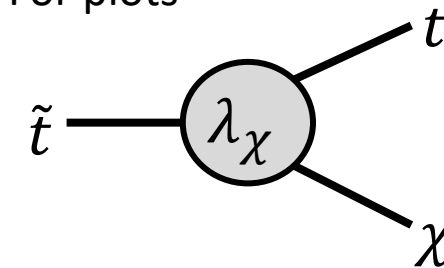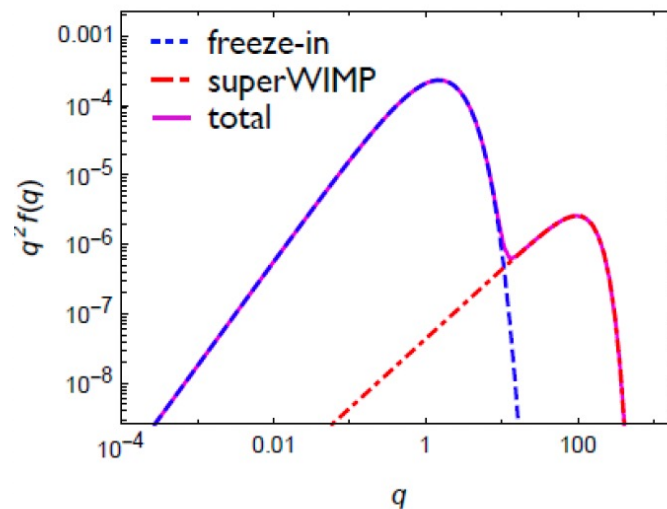
Free-streaming

Increasing lifetime of $\tilde{t}$

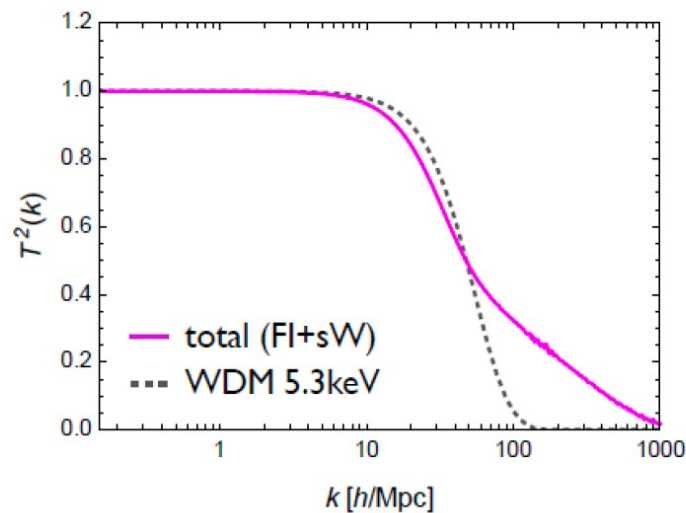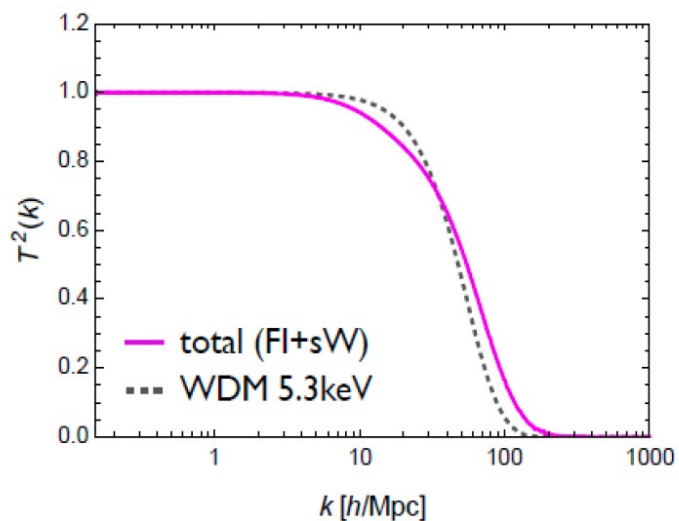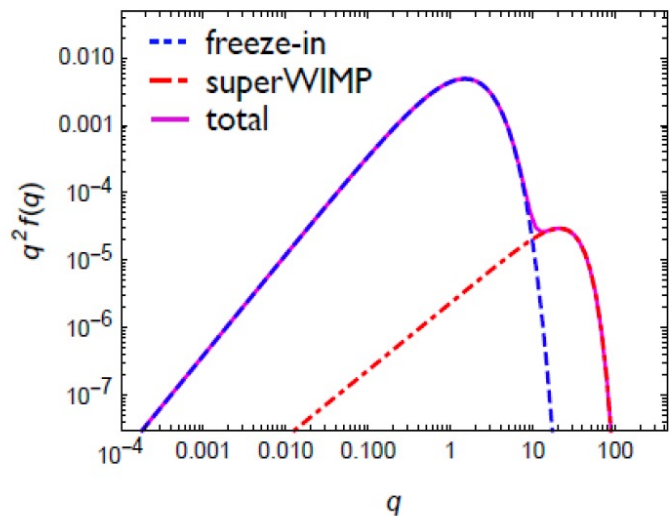m_{DM} increases from 22keV $\longrightarrow$ 77 MeV to fix the suppression scale
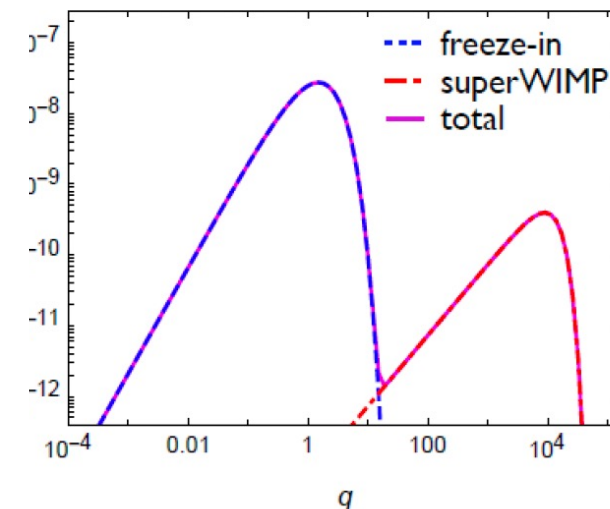
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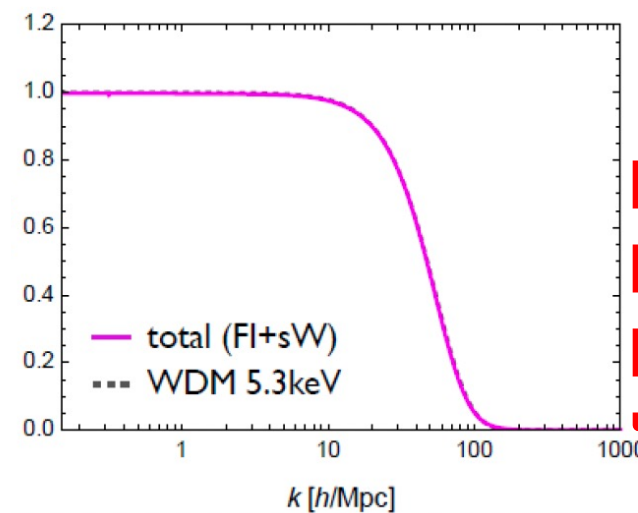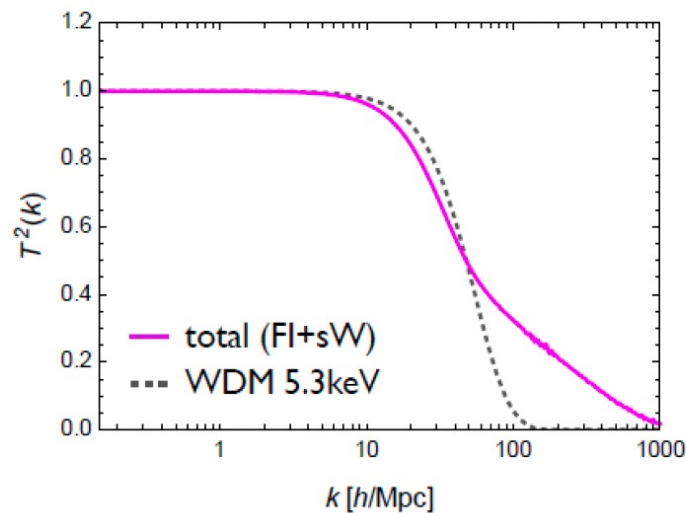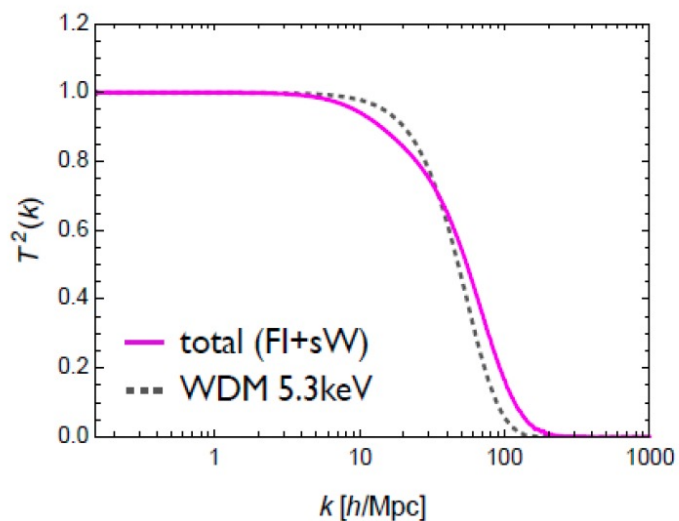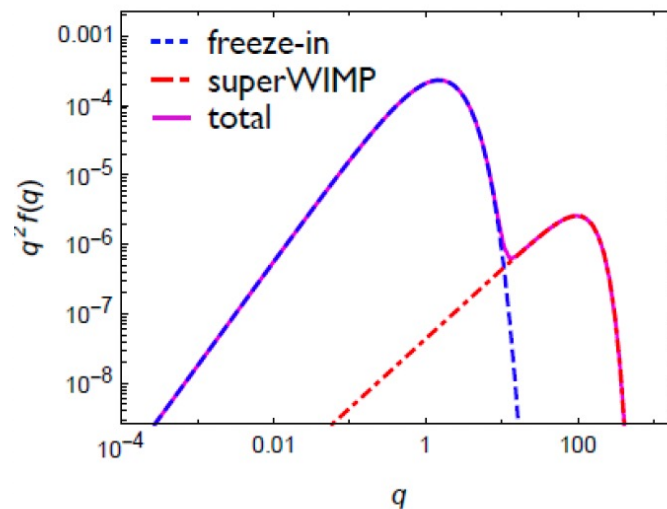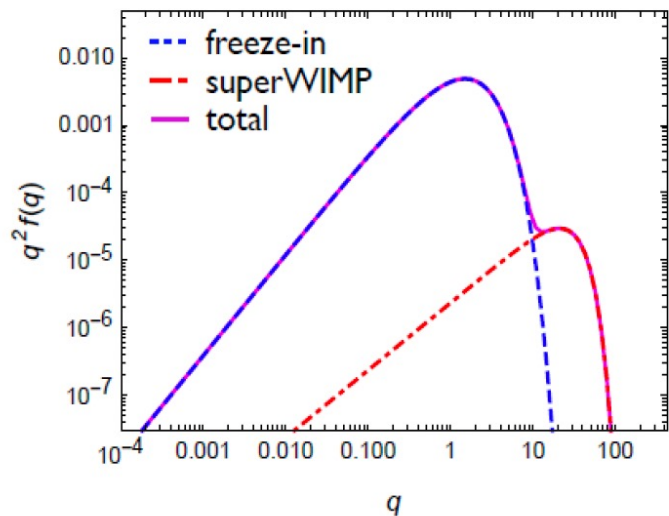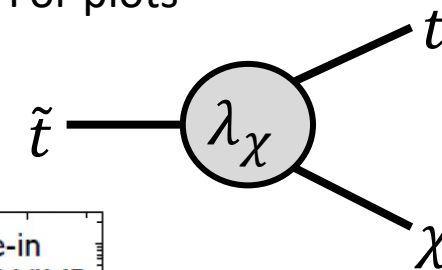
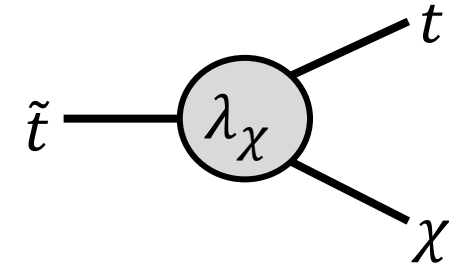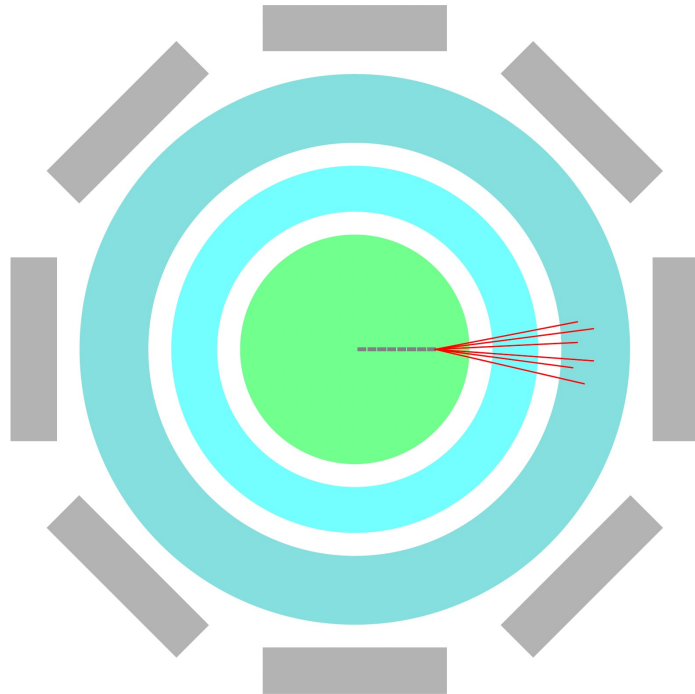m_{DM} increases from 22keV $\rightarrow$ 77 MeV to fix the suppression scale

Constraints: Collider

Increasing lifetime of $\tilde{t}$

Displaced Vertices (+ MET)

— Hadron

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MS
HCAL
ECAL
Tracker

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

Credits to Sam Junius for the figures.

Constraints: Collider

Increasing lifetime of $\tilde{t}$

$\tilde{t}$ —○ λ_χ — t
                    — χ

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Displaced Vertices (+ MET)
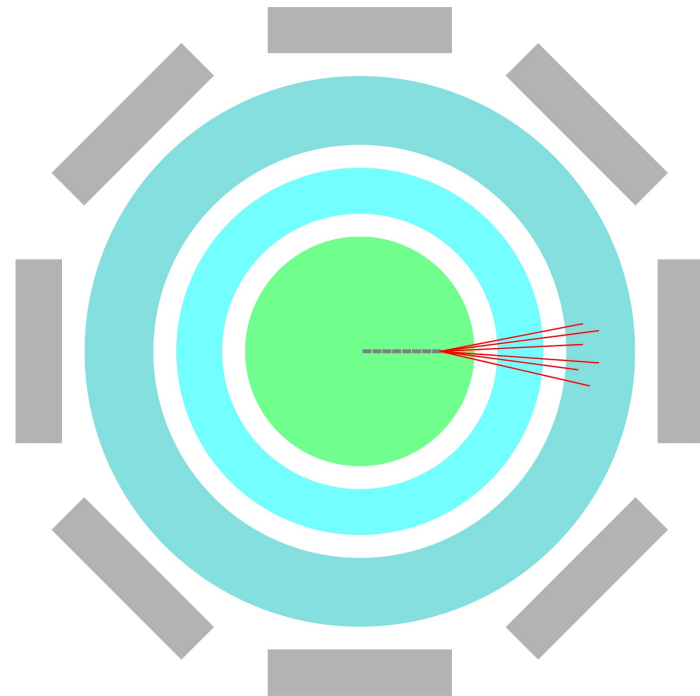
R-Hadron
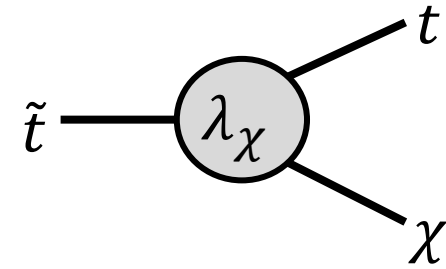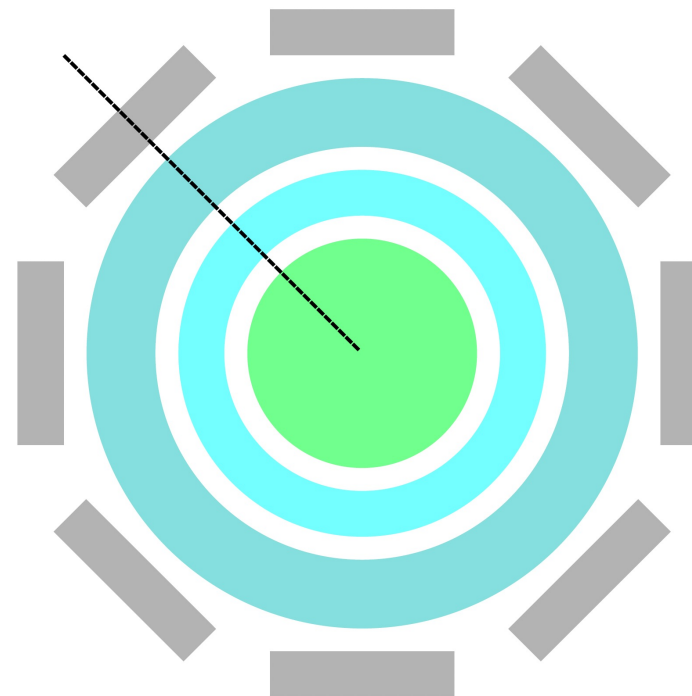
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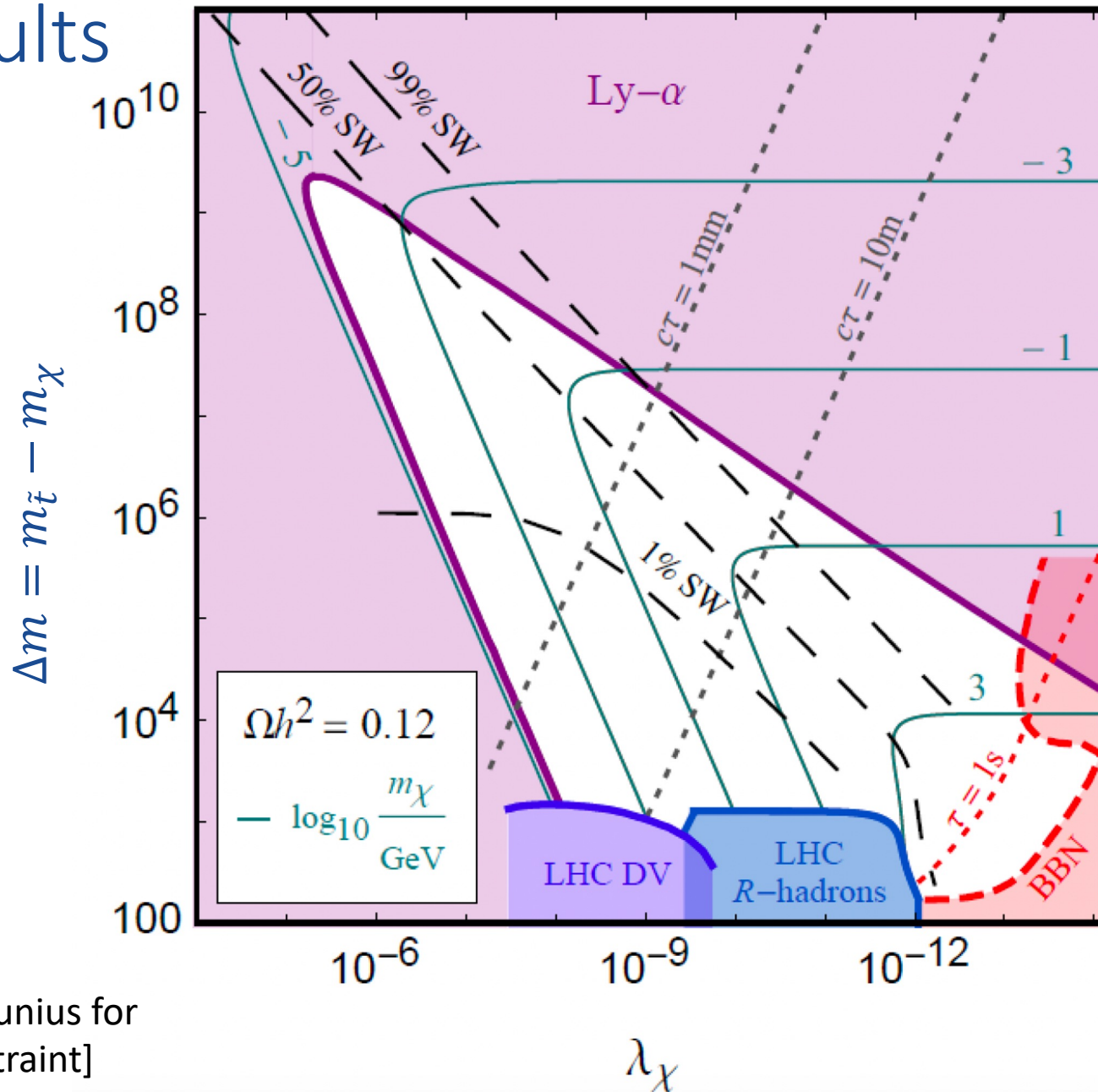■ ECAL
■ Tracker

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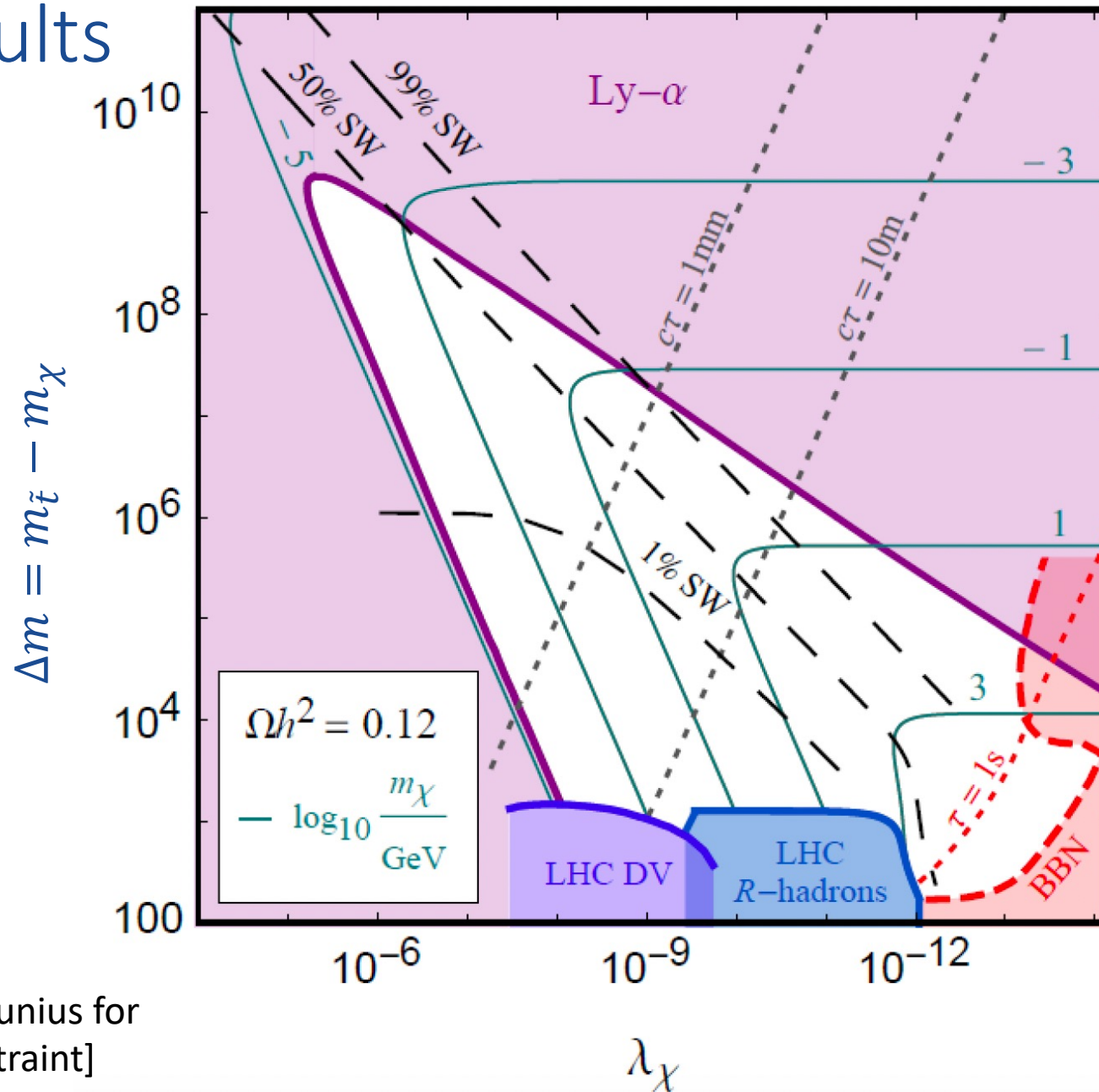
Ly-α region = constraints from the free-streaming suppression of the matter power spectrum

[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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What I didn't tell you (yet):

1) Generic model independent constraints from free-streaming

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

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Results

Thank you for your attention!

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

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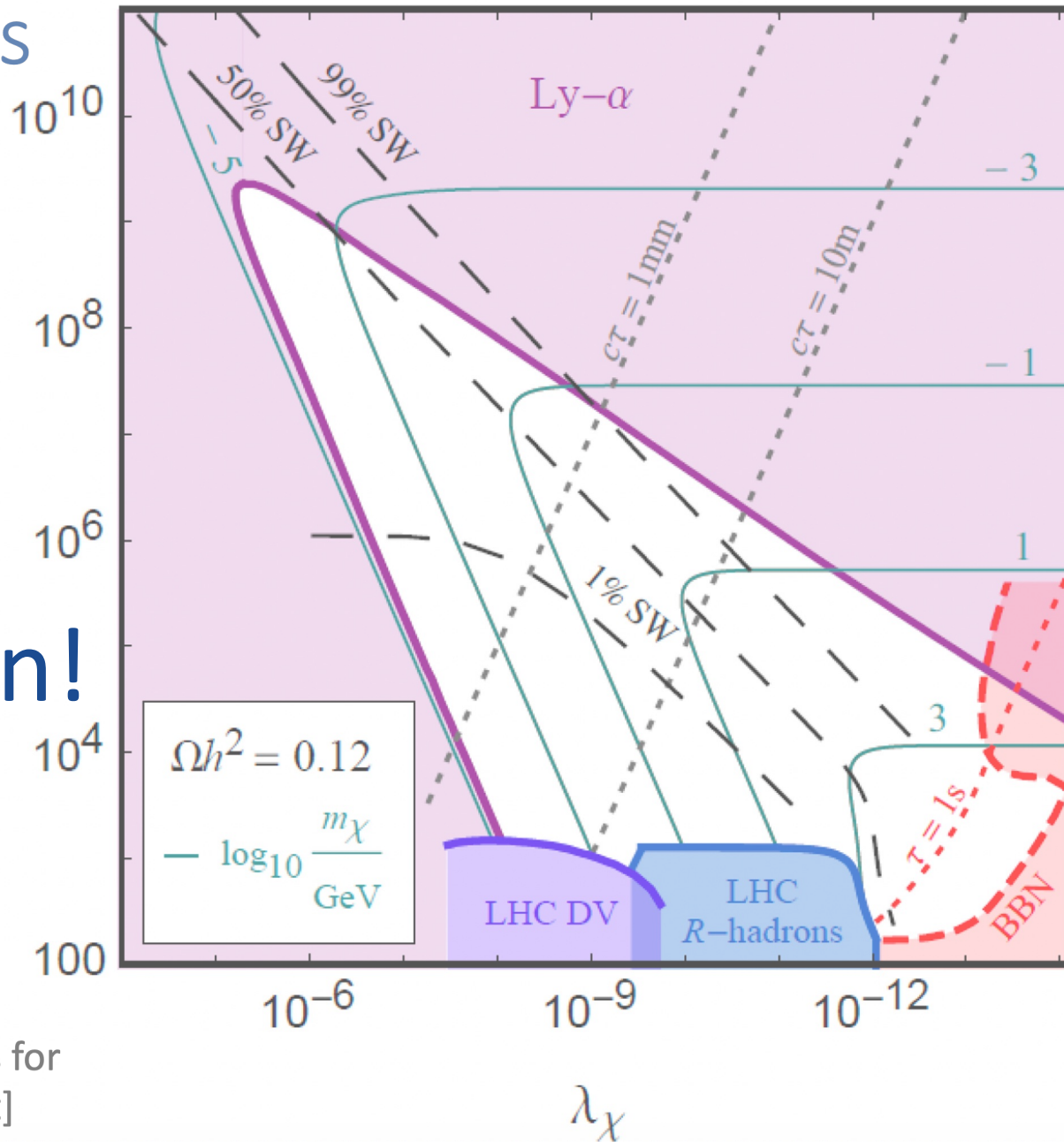**What I didn't tell you (yet):**

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