AXINO

~~AXION~~: AN ALTERNATIVE TO WIMP DARK MATTER

Kyu Jung Bae

TMEX 2020, Quy Nhon, Vietnam

Jan. 9, 2020

WIMP

$\lambda \sim \mathcal{O}(0.1)$

$m \sim 100\ \mathrm{GeV} - 1\ \mathrm{TeV}$

Stable

WIMP

thermal;
"freeze-out"

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Cold Dark Matter

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direct detection;
indirect searches: cosmic ray

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"freeze-out"

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Stable

collider searches:
LHC

direct detection;
indirect searches: cosmic ray

WIMP

Models with extended Elecroweak Sector; Higgs, ...

thermal; "freeze-out"

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direct detection; indirect searches: cosmic ray

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structure

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signals from decays;
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collider signals:
displaced vertex

signals from decays;
cosmic rays

ALTERNATIVE

What model?

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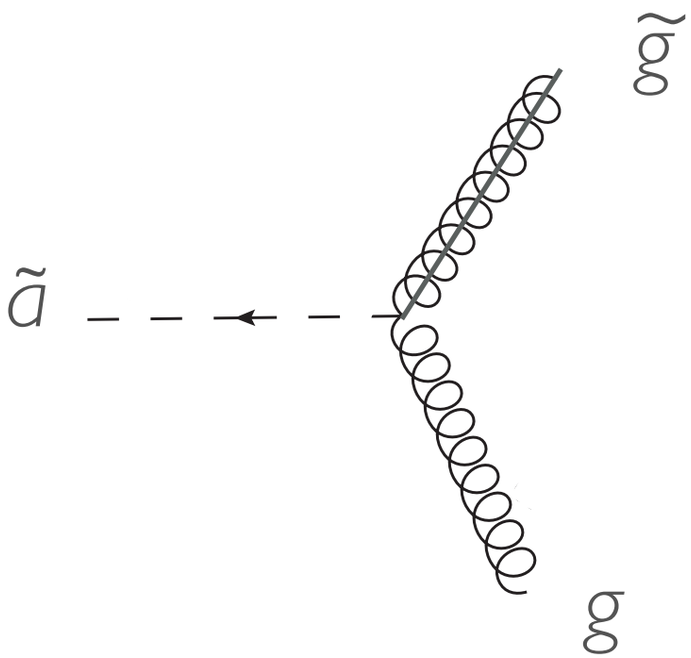
AXINO

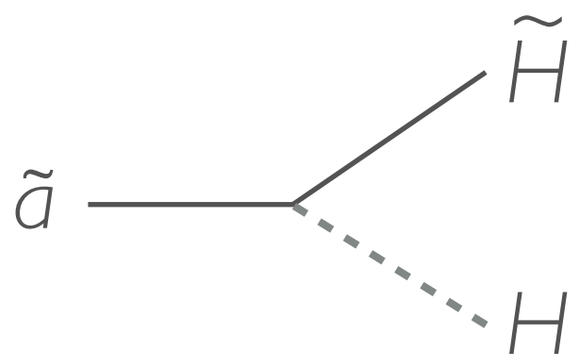
$\lambda \ll 0.1$ much weaker than "weak" interaction

Axion has couplings

$\frac{1}{f_a} a F \tilde{F}$ and/or $m^2 \frac{a}{f_a} H_u H_d$ → $\lambda \sim \frac{100\ \mathrm{GeV}}{10^{10}\ \mathrm{GeV}} \sim 10^{-8}$

Axino has similar couplings



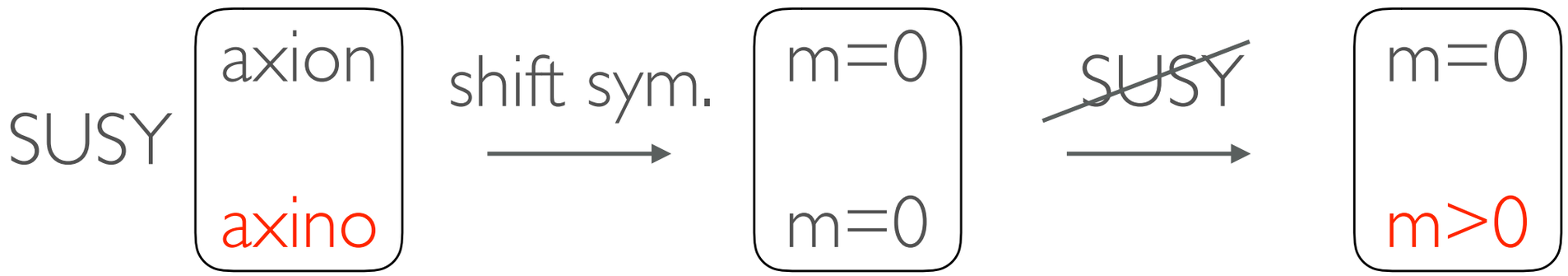


can be cold dark matter!

Covi, Kim, Roszkowski (99)

AXINO

$m \sim \mathrm{keV} - \ \mathrm{PeV}$



Axino mass ~ how axion communicates with SUSY breaking

~ highly model-dependent

metastable; decaying

- "sterile neutrino" ⟶ radiative decay
- decaying into gravitino

ALTERNATIVE TO WIMP

- Light axino dark matter: m~keV

  freeze-in production

  not following thermal distribution

  ⟶ impact on small scale

  long-lived particle searches at LHC

- Heavy axino dark matter

  Cold DM decaying into gravitino

  lifetime~age of the Universe

  ⟶ impact on small scale / altering H_0

  ⟶ signal of axions emitted from decay

OUTLINE

1. Introduction

2. Light Axino Dark Matter

3. Decaying Axino Dark Matter

4. Summary

OUTLINE

1. Introduction

2. **Light Axino Dark Matter**

3. Decaying Axino Dark Matter

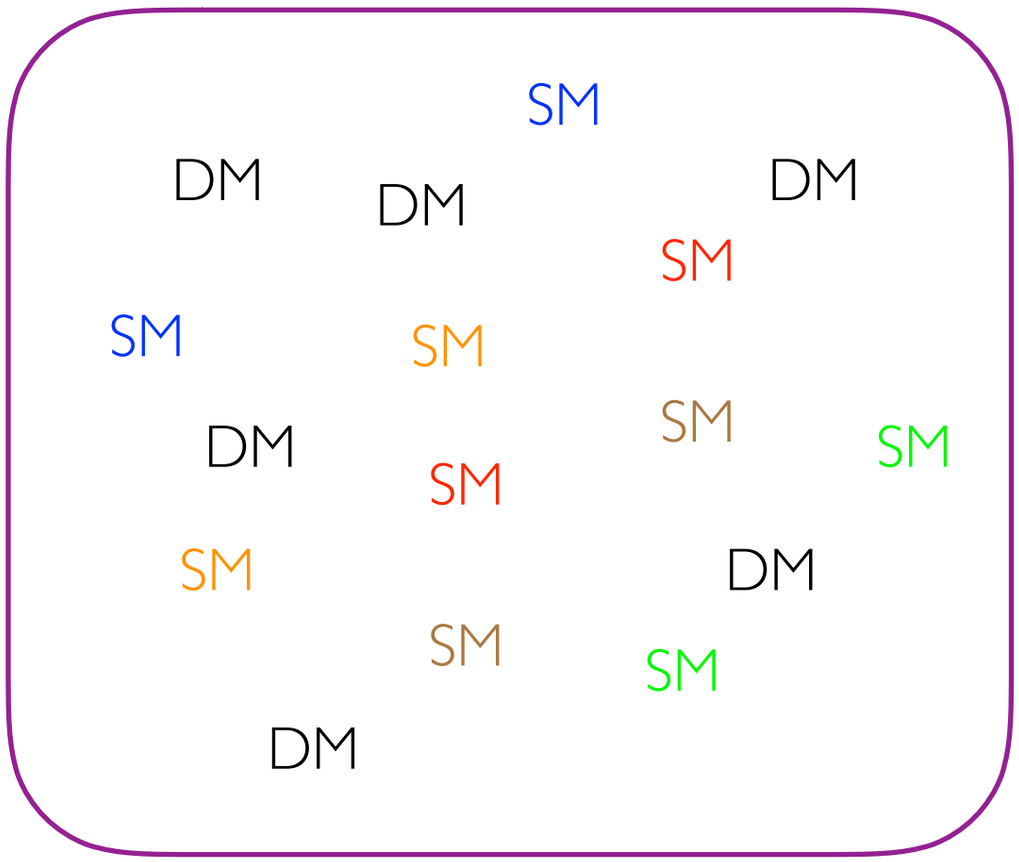
4. Summary

FREEZE-IN DARK MATTER

Expanding Universe

- coupling ~ O(0.1)

Thermal Plasma

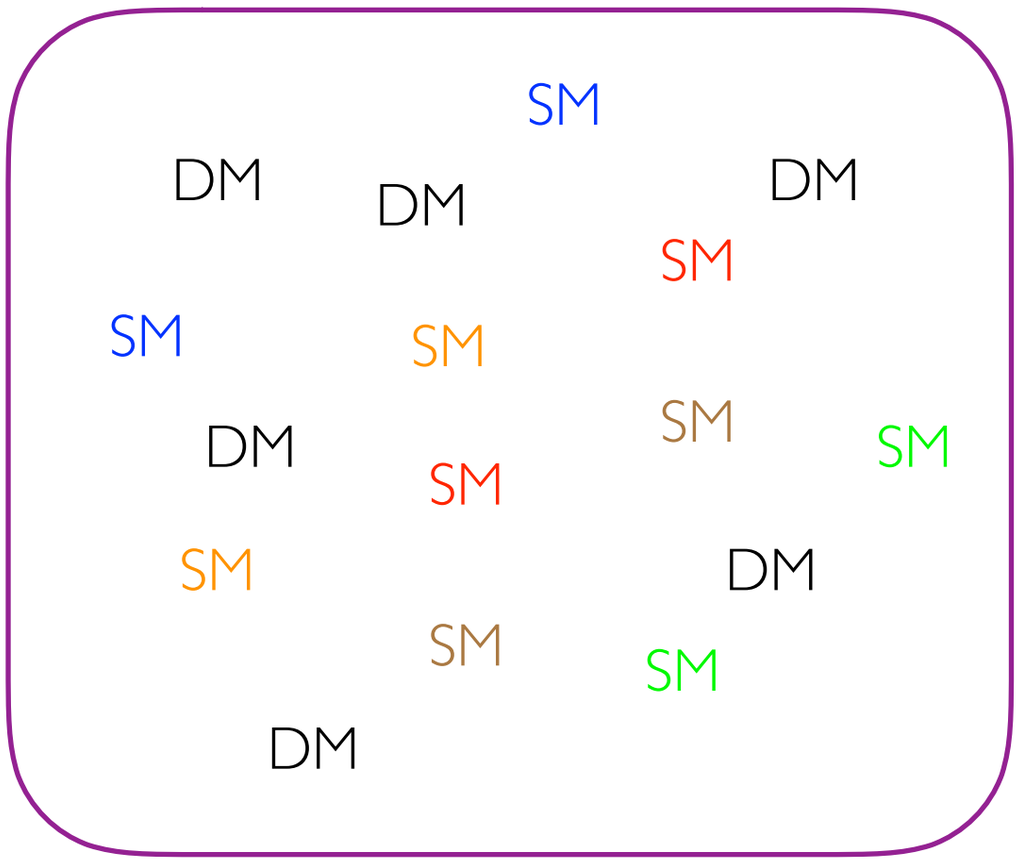


$$\mathrm{SM}+\mathrm{SM} \Leftrightarrow \mathrm{DM}+\mathrm{DM}$$

FREEZE-IN DARK MATTER

- coupling ~ O(0.1)

Thermal Plasma



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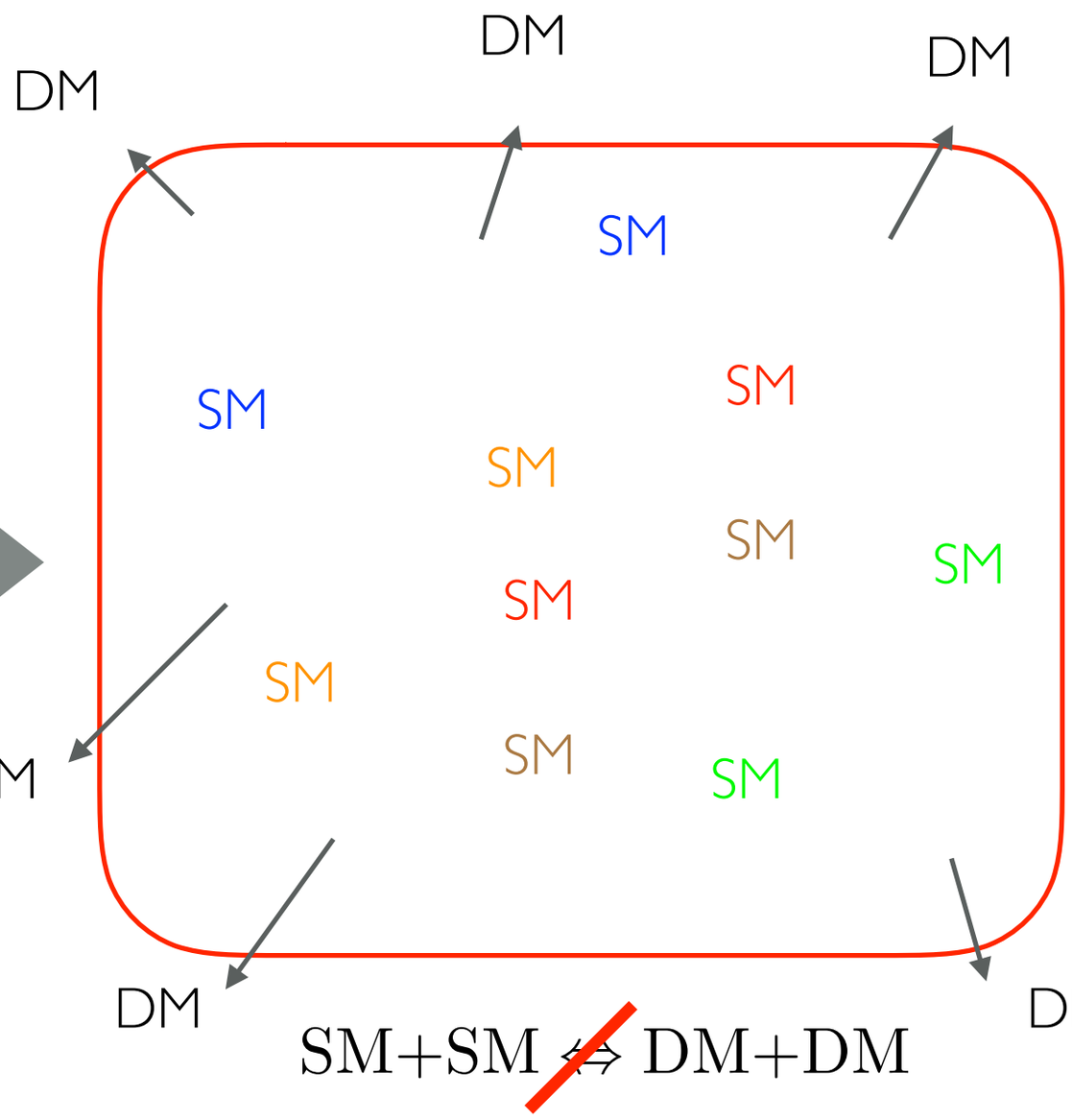
Expanding Universe

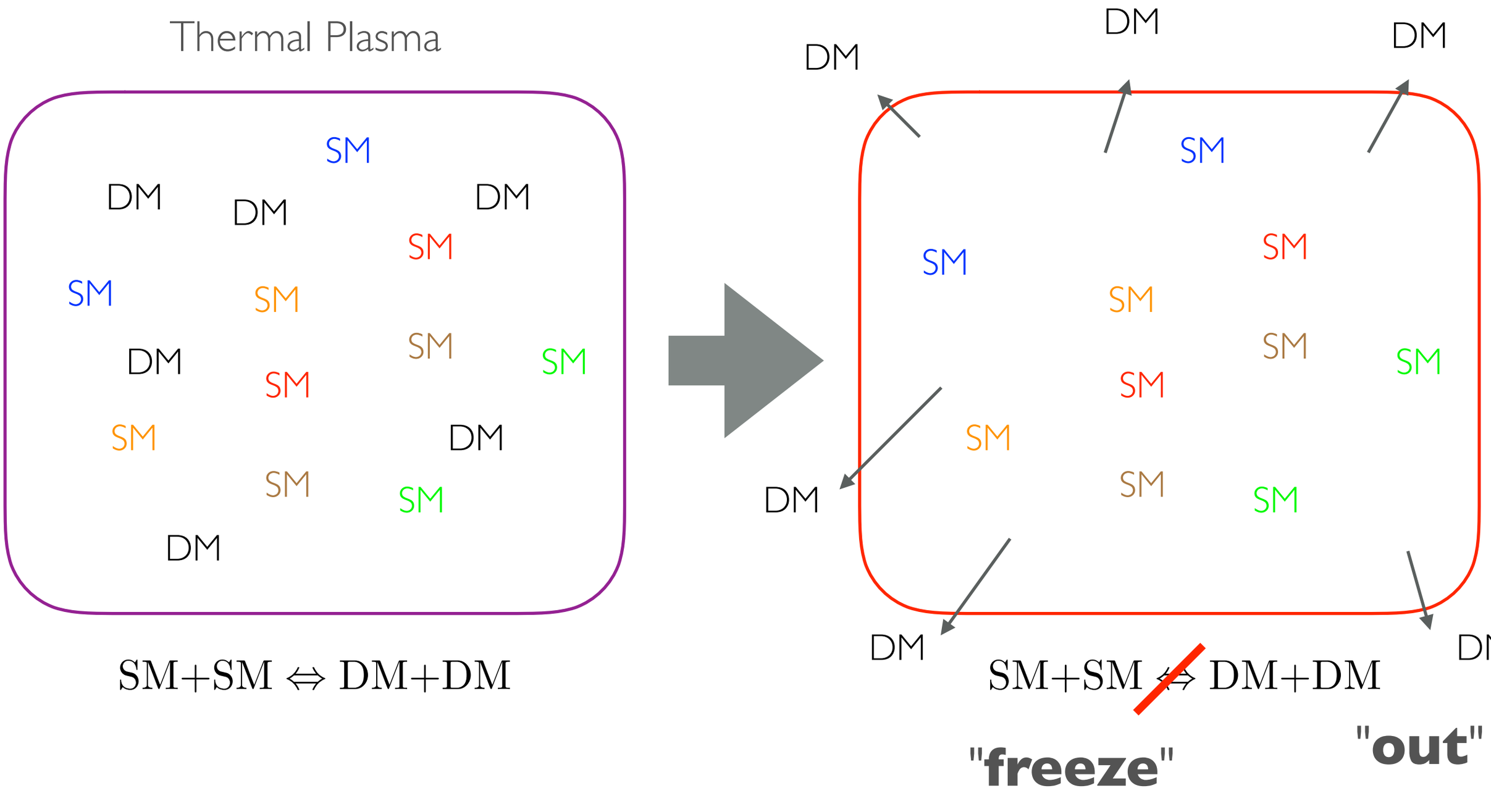


$$\mathrm{SM}+\mathrm{SM} \not\Leftrightarrow \mathrm{DM}+\mathrm{DM}$$

FREEZE-IN DARK MATTER

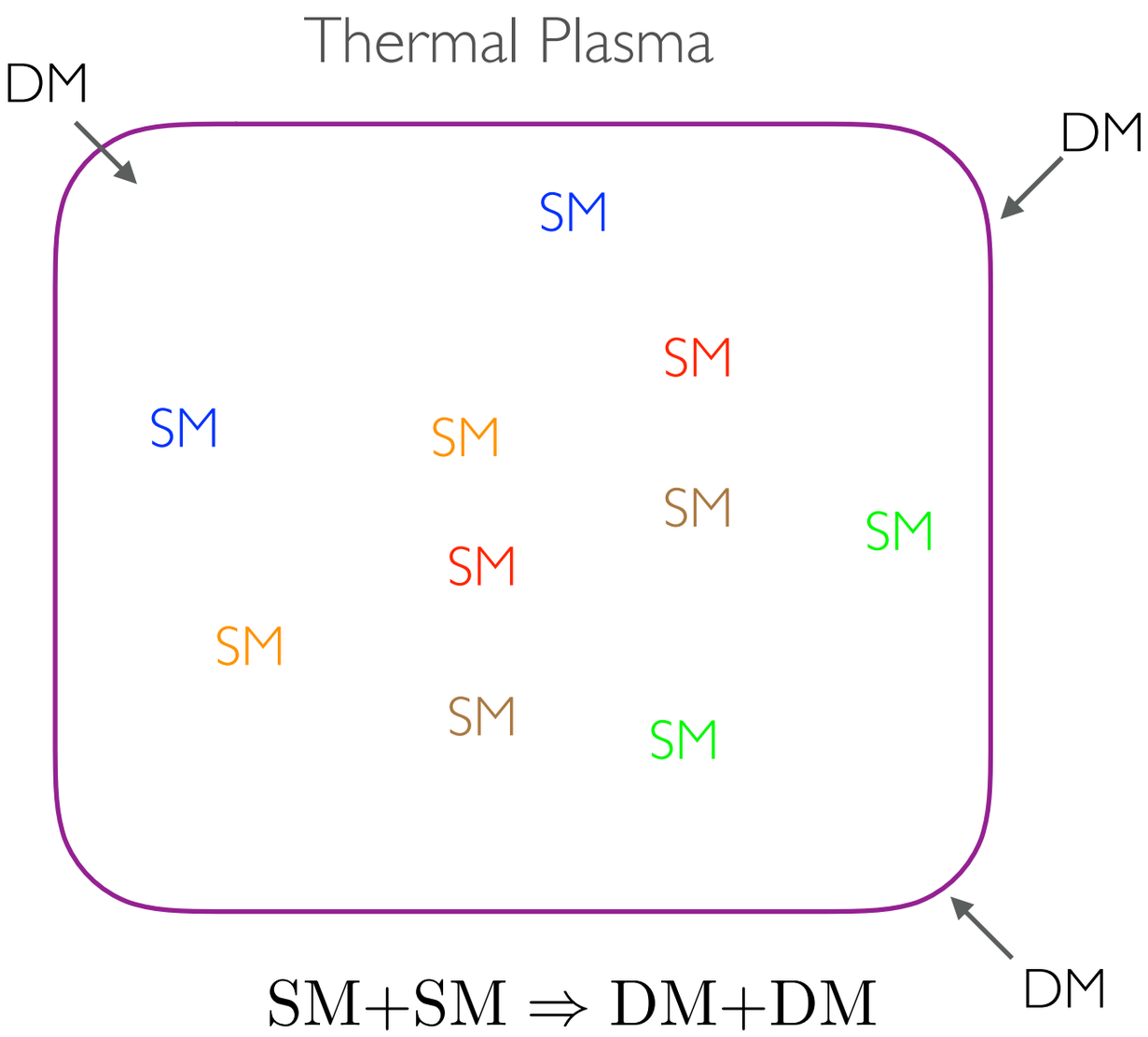
Expanding Universe

- coupling ~ O(0.1)



FREEZE-IN DARK MATTER

- coupling << 0.1



$$\mathrm{SM}+\mathrm{SM} \Rightarrow \mathrm{DM}+\mathrm{DM}$$

FREEZE-IN DARK MATTER

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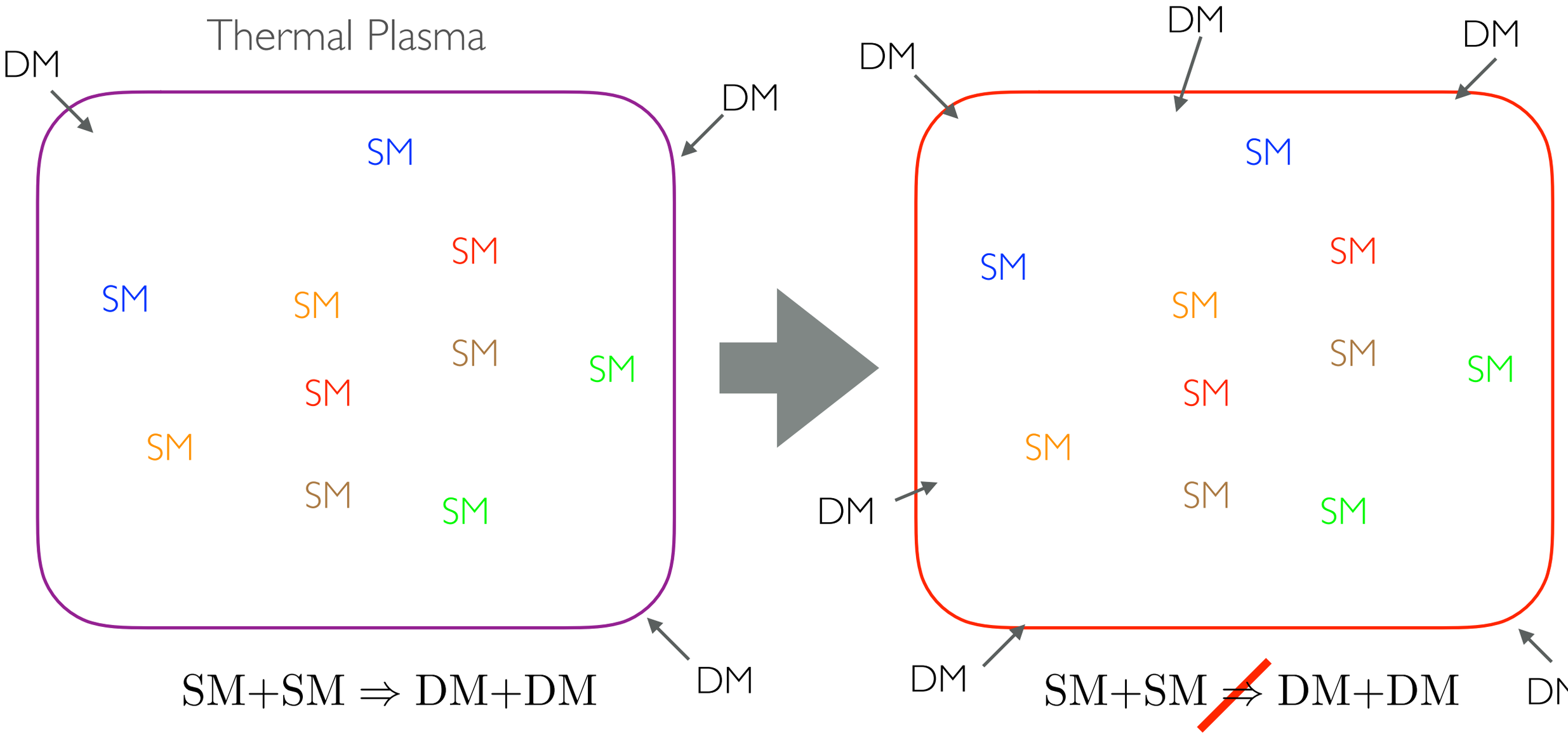

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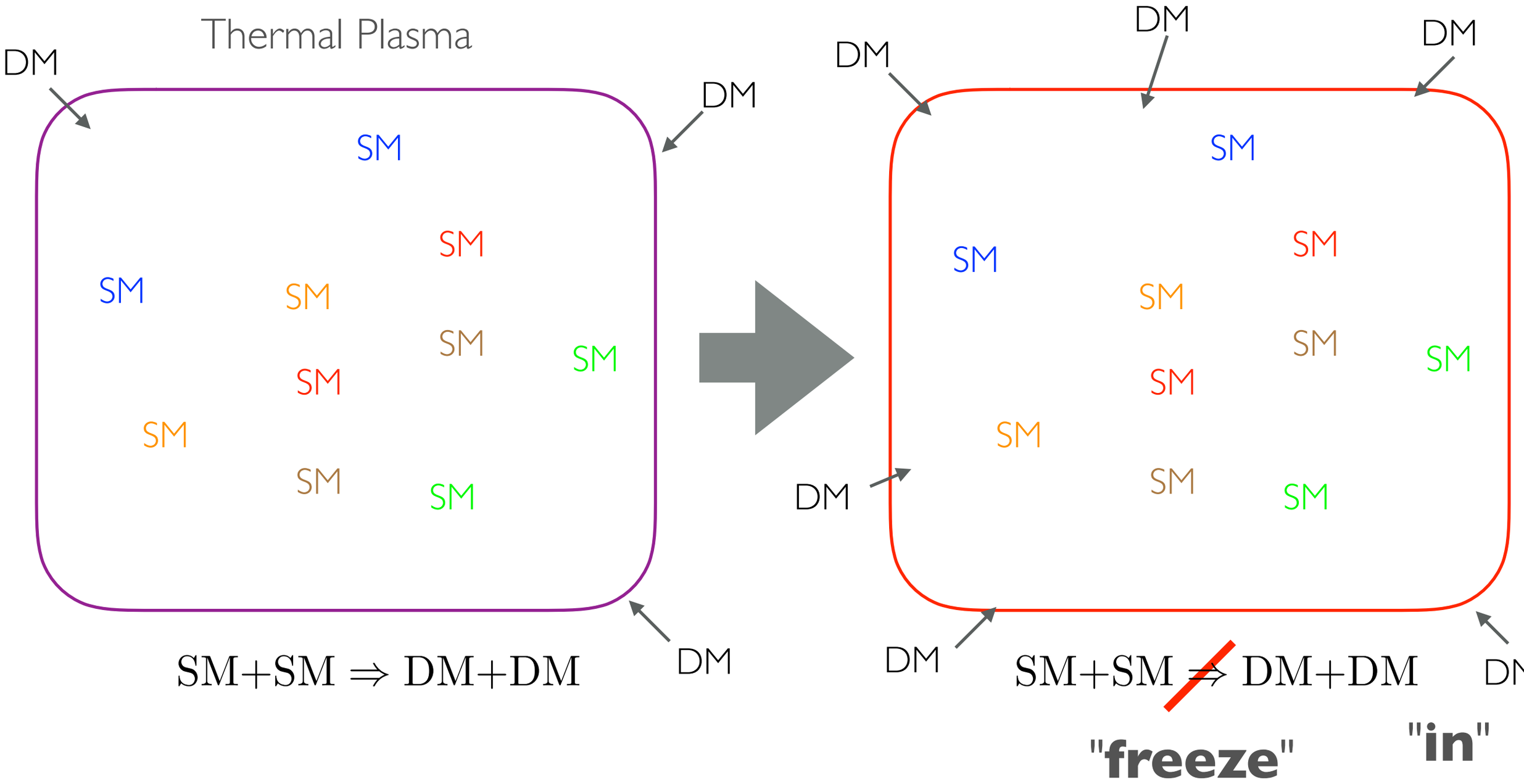
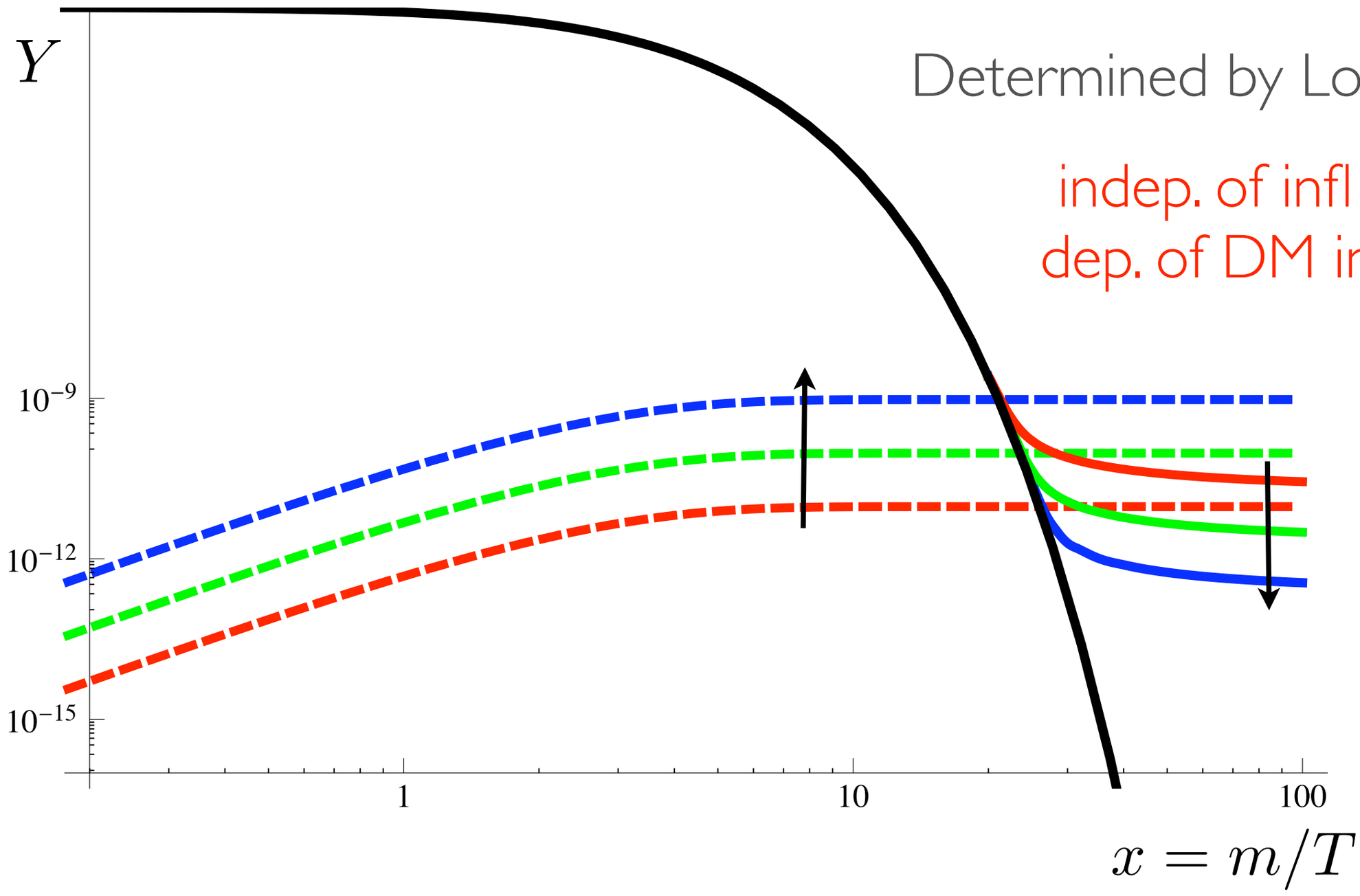


FREEZE-IN DARK MATTER



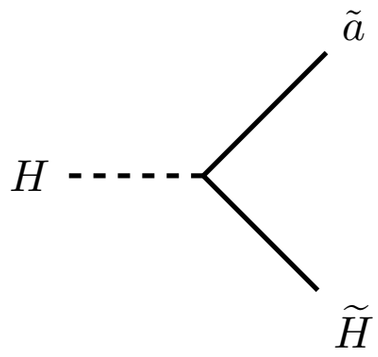
Determined by Low-T

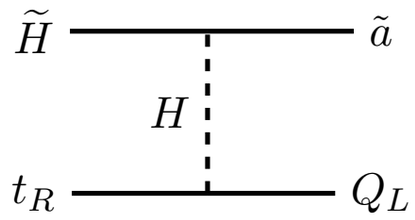
indep. of infl /
dep. of DM int.

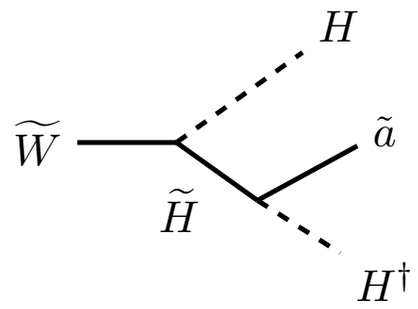
Hall, Jedamzik, March-Russell, West

FREEZE-IN AXINO PRODUCTION

KJB, Kamada, Liew, Yanagi (2017)





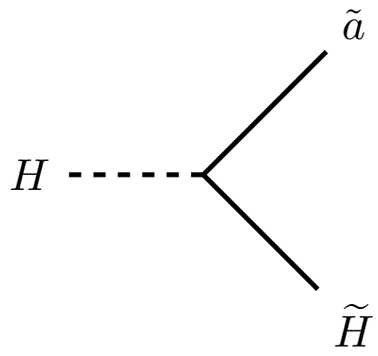


$$\propto \left(\frac{\mu}{f_a}\right)^2$$

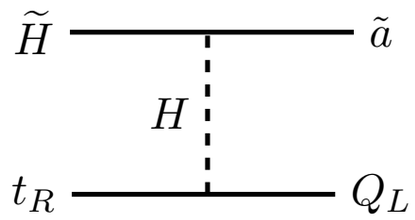
2-body decay 2-to-2 3-body decay

FREEZE-IN AXINO PRODUCTION

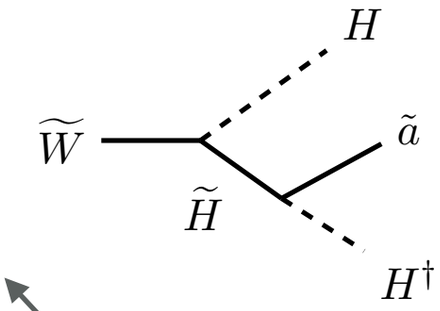
KJB, Kamada, Liew, Yanagi (2017)



2-body decay

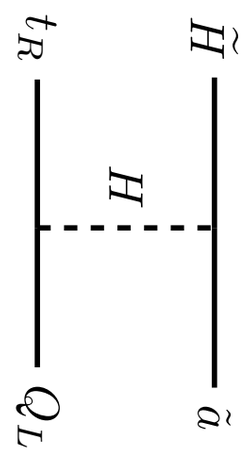


2-to-2



3-body decay

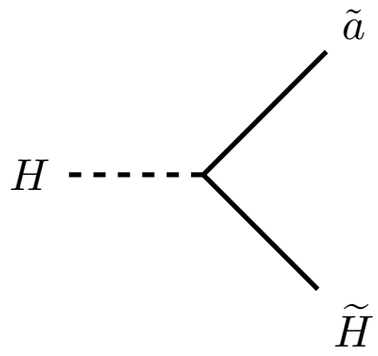
$$\propto \left(\frac{\mu}{f_a}\right)^2$$



s- & t-channel makes different dist.

FREEZE-IN AXINO PRODUCTION

KJB, Kamada, Liew, Yanagi (2017)



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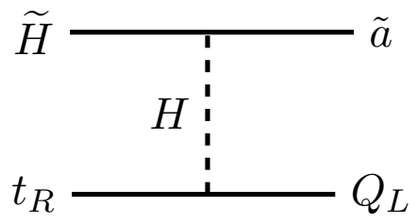

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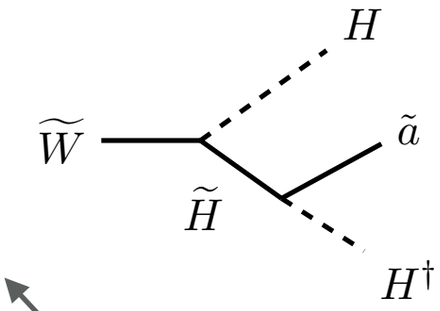

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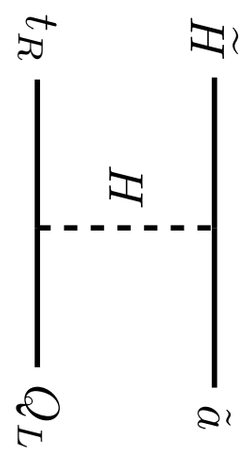
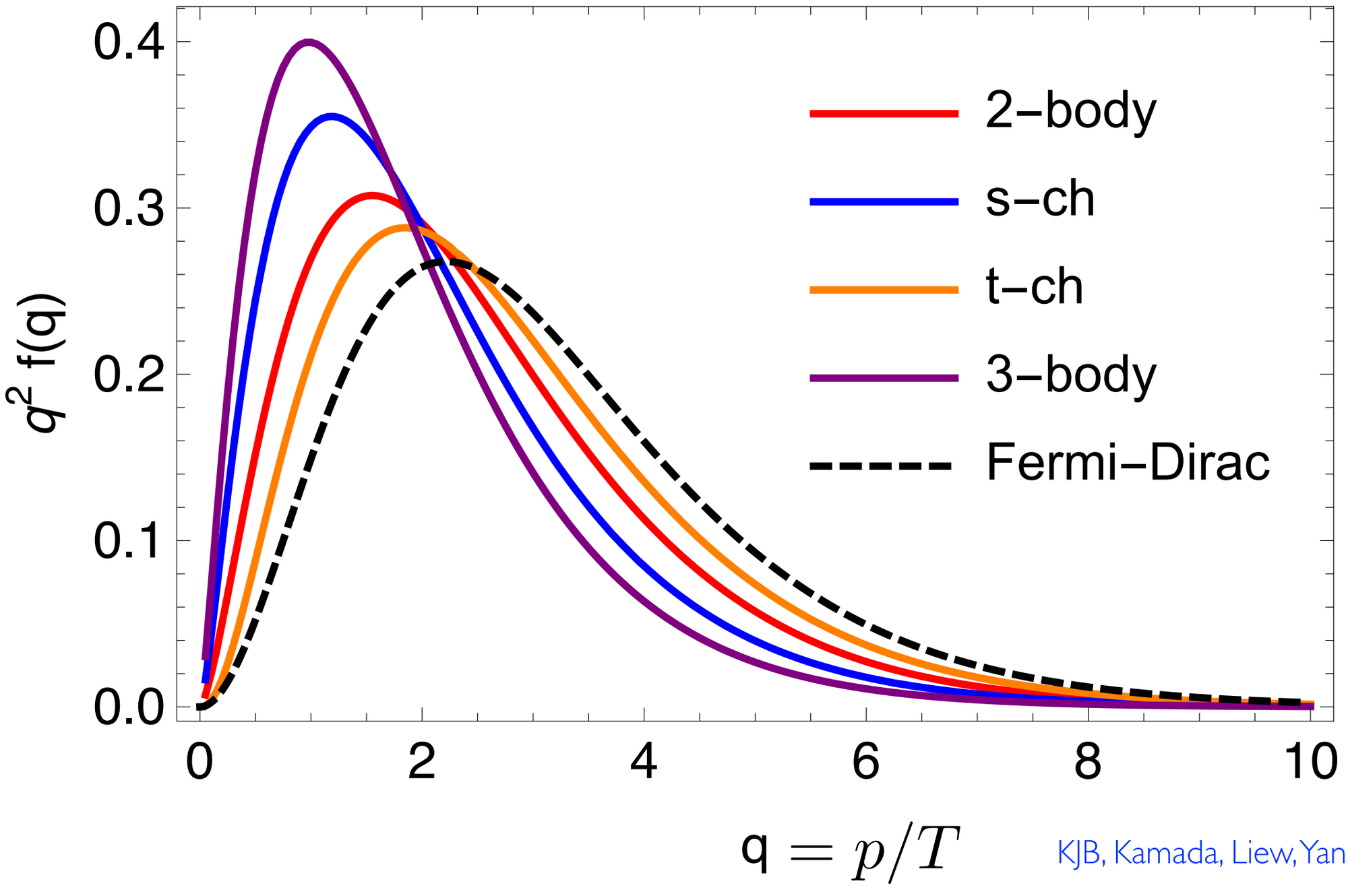


s- & t-channel makes different dist.

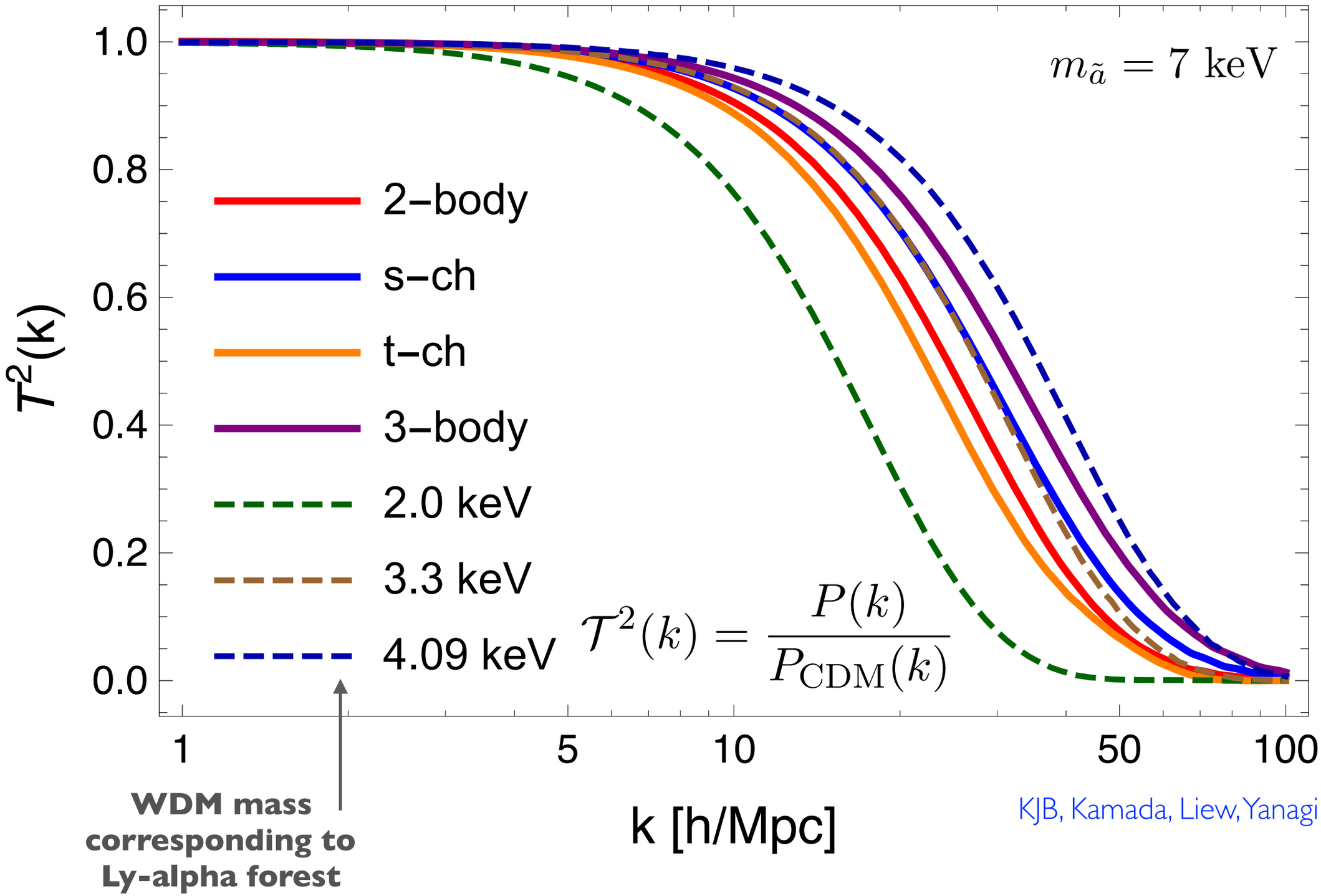
DM imprints its production processes on phase space dist.!

DISTRIBUTION



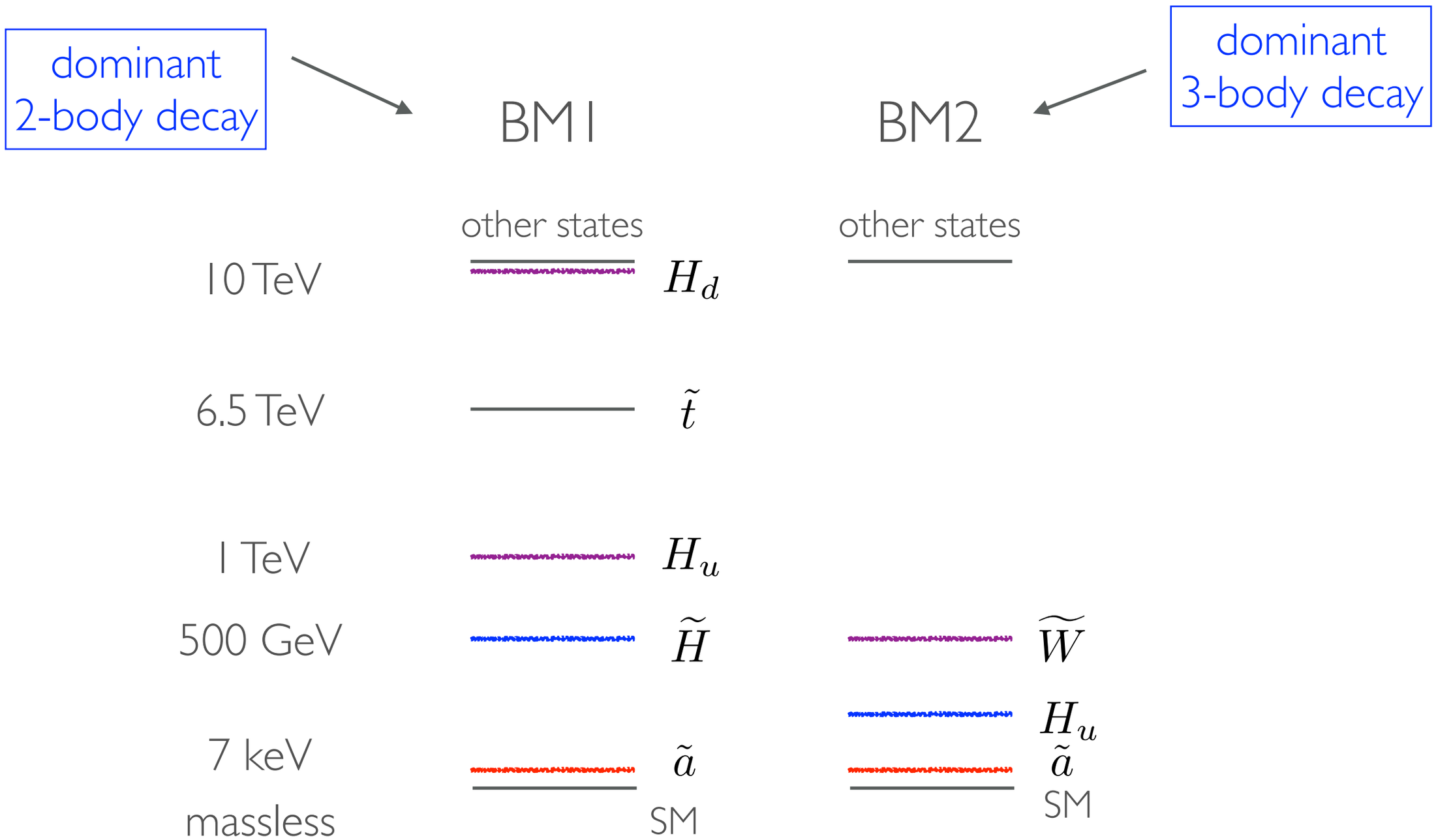
KJB, Kamada, Liew, Yanagi (2017)

MATTER POWER SPECTRUM



KJB, Kamada, Liew, Yanagi (2017)

BENCHMARK SCENARIOS



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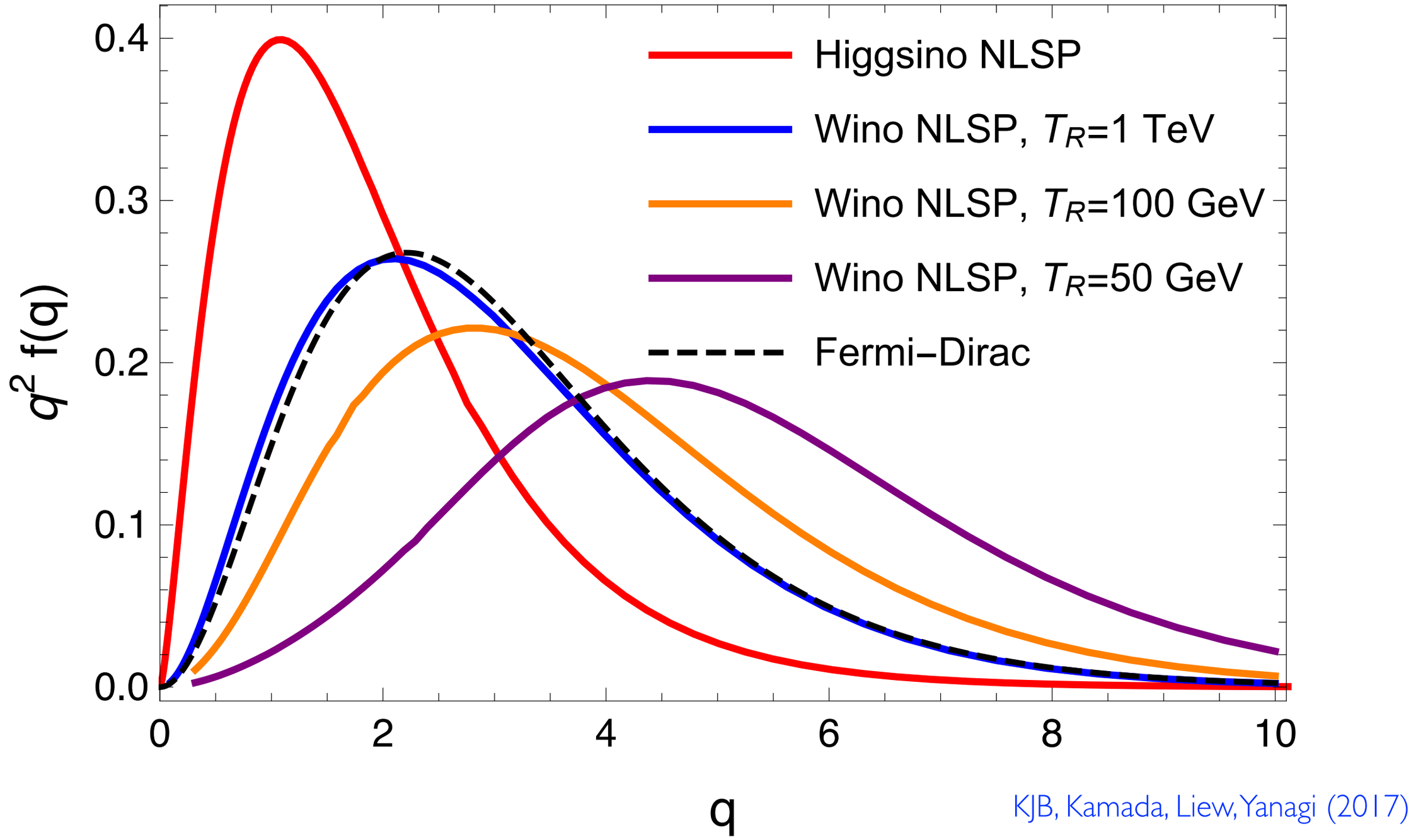
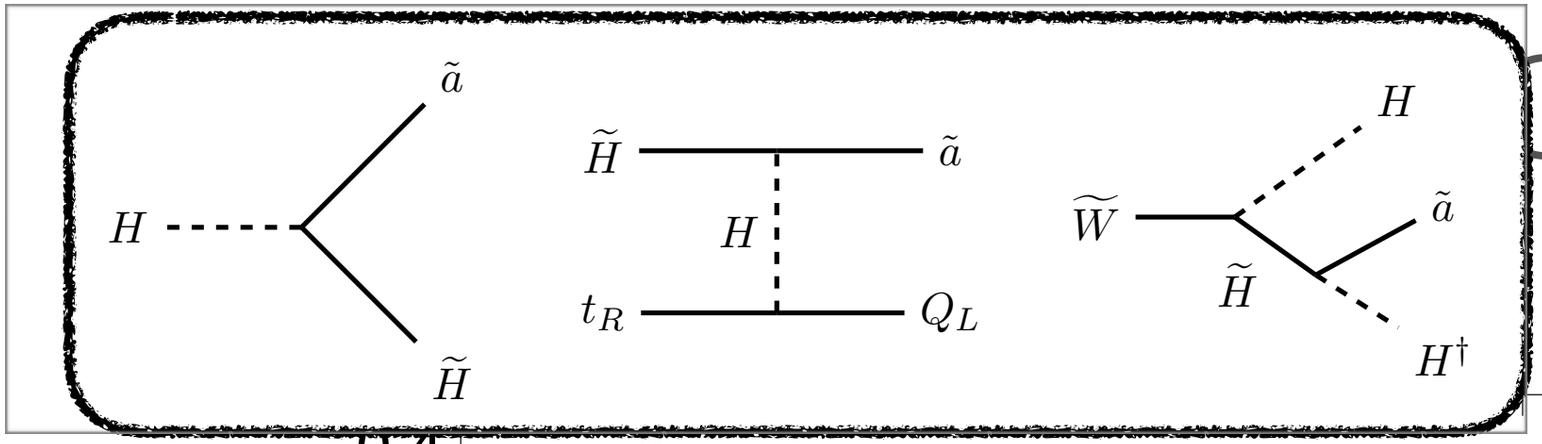
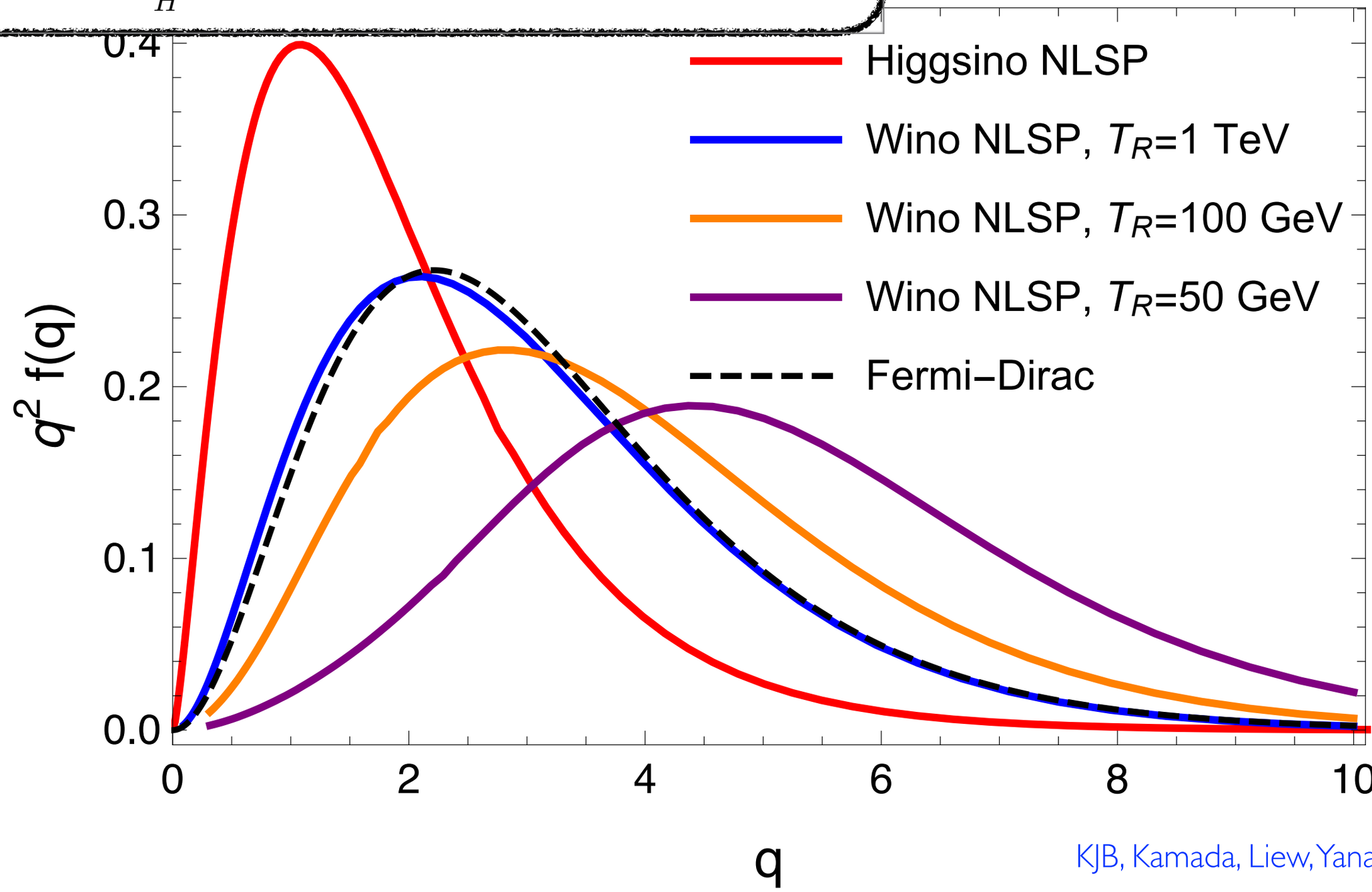


KJB, Kamada, Liew, Yanagi (2017)

ON





KJB, Kamada, Liew, Yanagi (2017)

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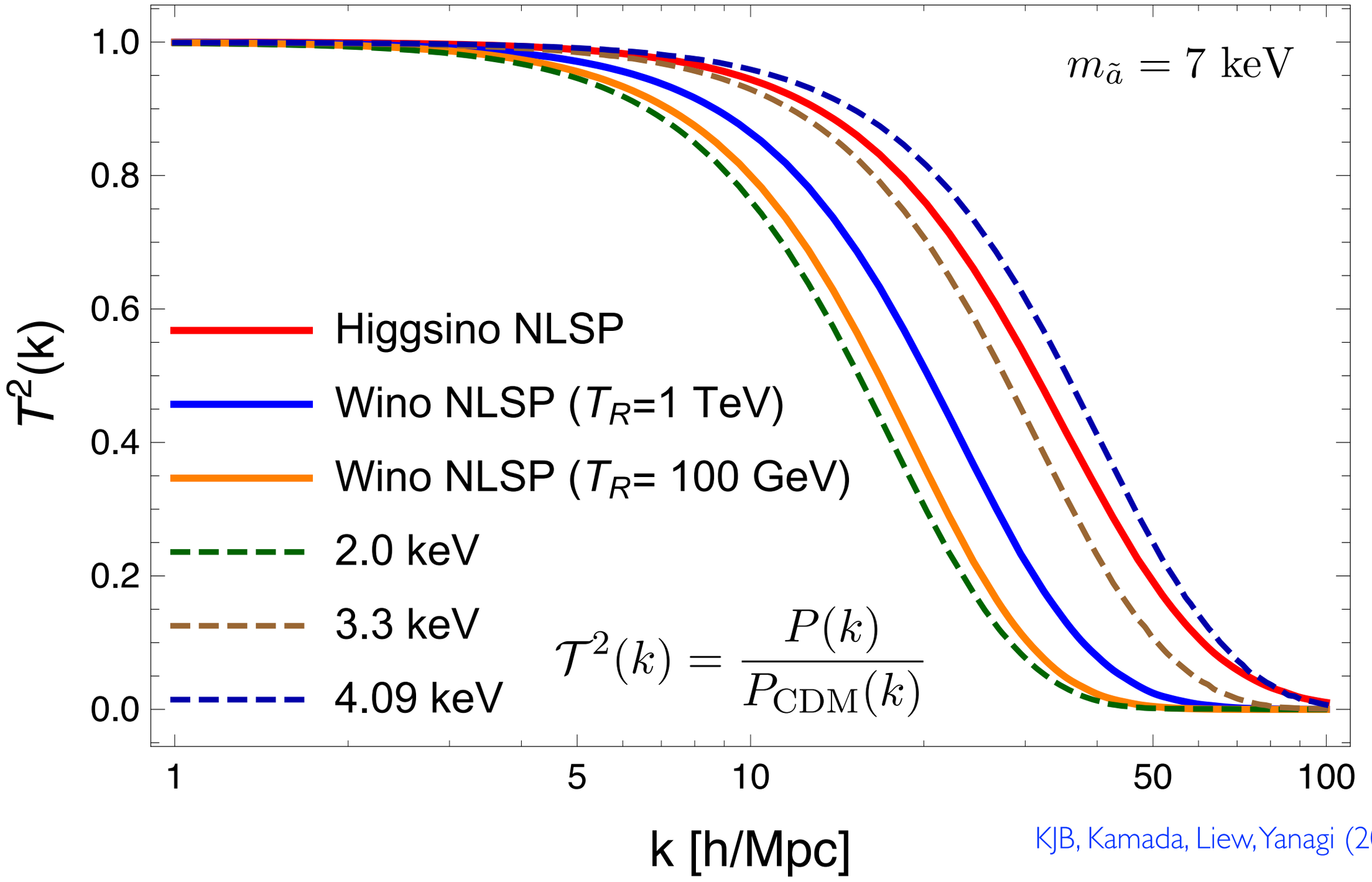
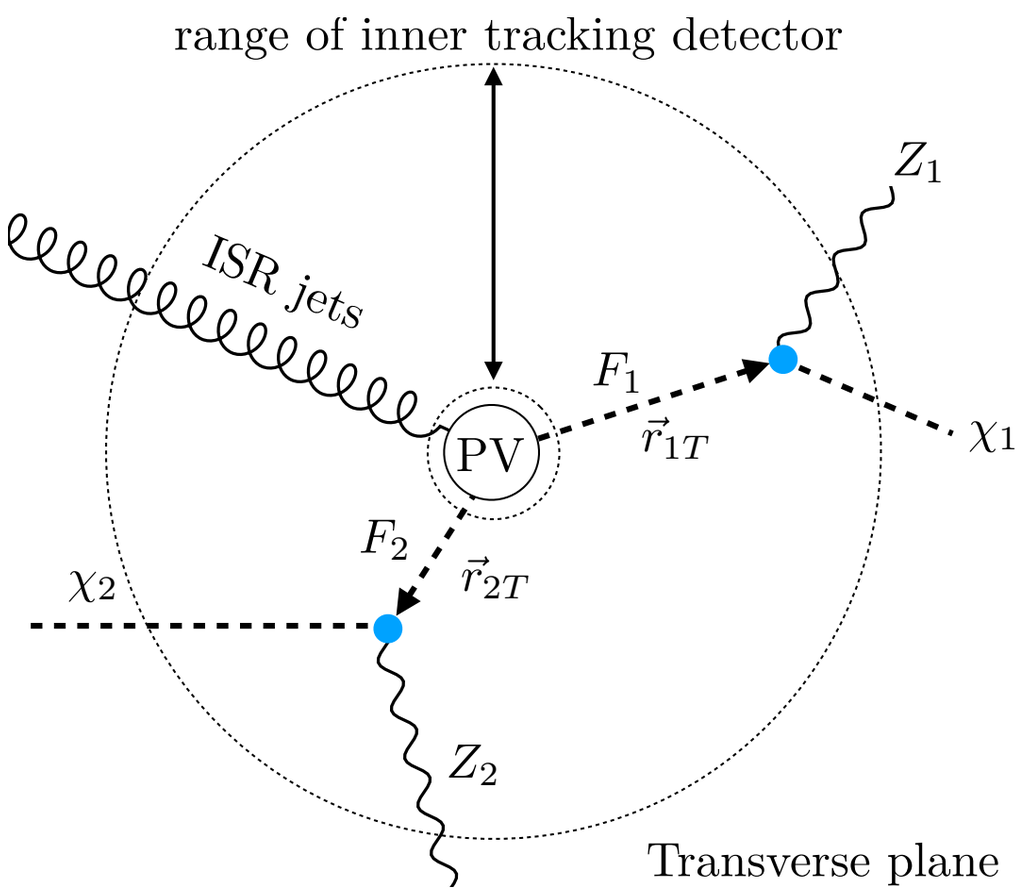
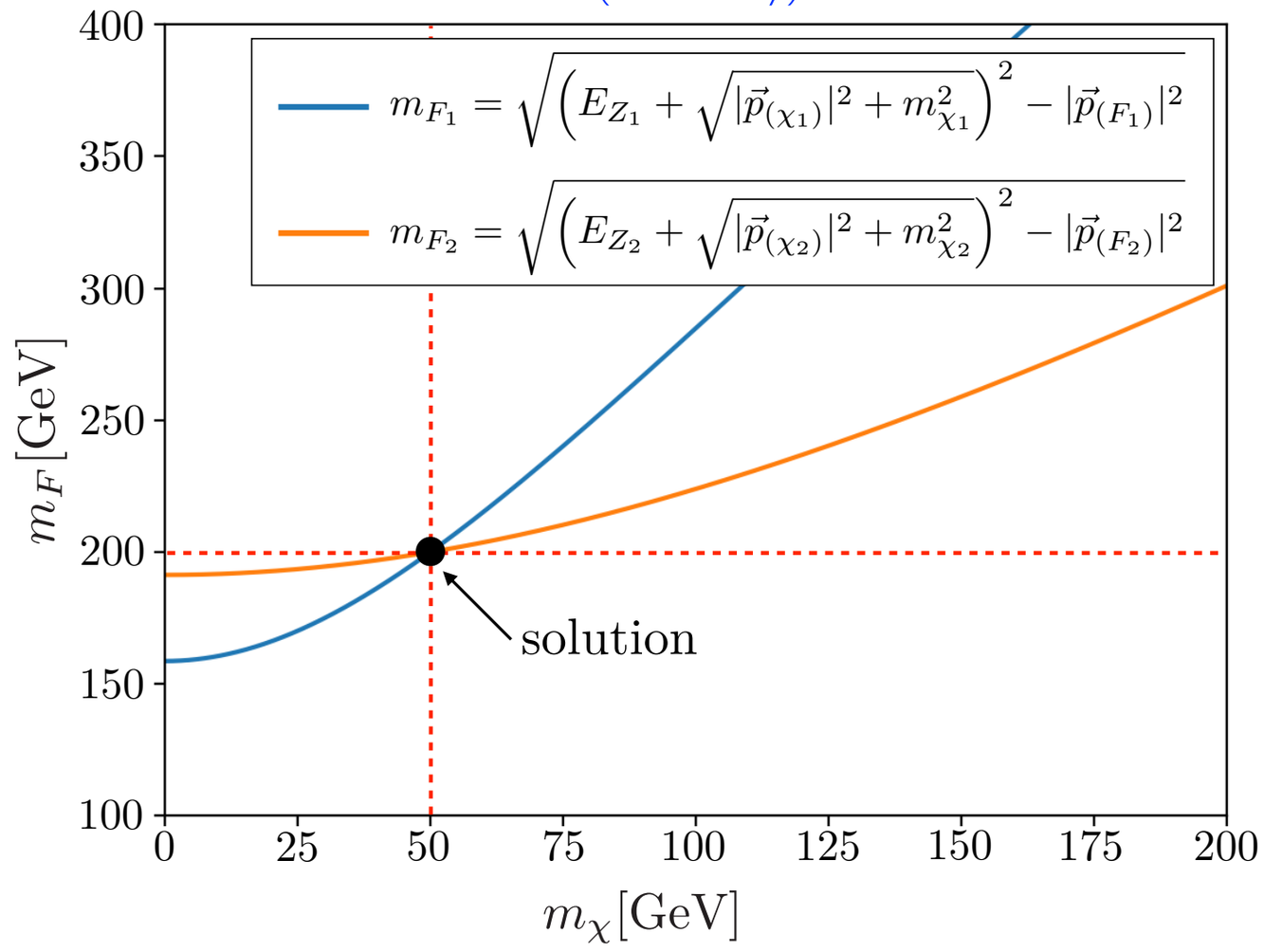


KJB, Kamada, Liew, Yanagi (2017)

LONG-LIVED PARTICLE SEARCH

KJB, Park, Zhang, 2001.02412
(Yesterday)





- Event-by-event mass reconstruction is possible
- extracting mass spectrum related to freeze-in processes

→ examining DM phase space dist. at collider!

OUTLINE

1. Introduction

2. Light Axino Dark Matter

3. **Decaying Axino Dark Matter**

4. Summary

HEAVY AXINO DM

Heavy axino: produced via either freeze-out or freeze-in

$\longrightarrow$ Cold Dark Matter

Axino model has more structure...

Axino mass ~ SUSY breaking

accompanied by *Gravitino*

*In previous case, we assume gravitino is much heavier, then decoupled

But in simple SUGRA, axino mass ~ gravitino mass

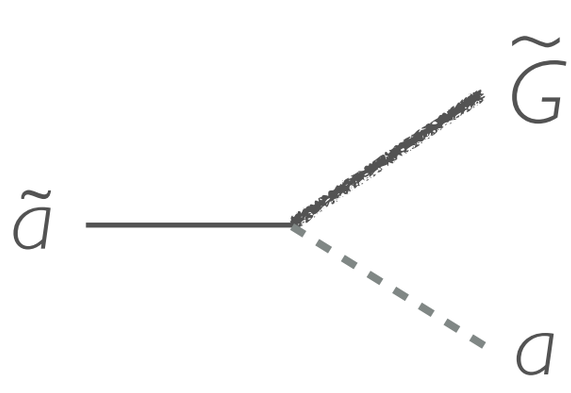
What if axino mass > gravitino mass?

AXINO-GRAVITINO

Axino-Gravitino interaction,

$$\mathcal{L}_{3/2} = -\frac{1}{2M_{\rm pl}} \partial_\nu a \, \bar{\psi}_\mu \, \gamma^\nu \gamma^\mu i\gamma_5 \, \tilde{a} \, ,$$

mediates ***axino decay***

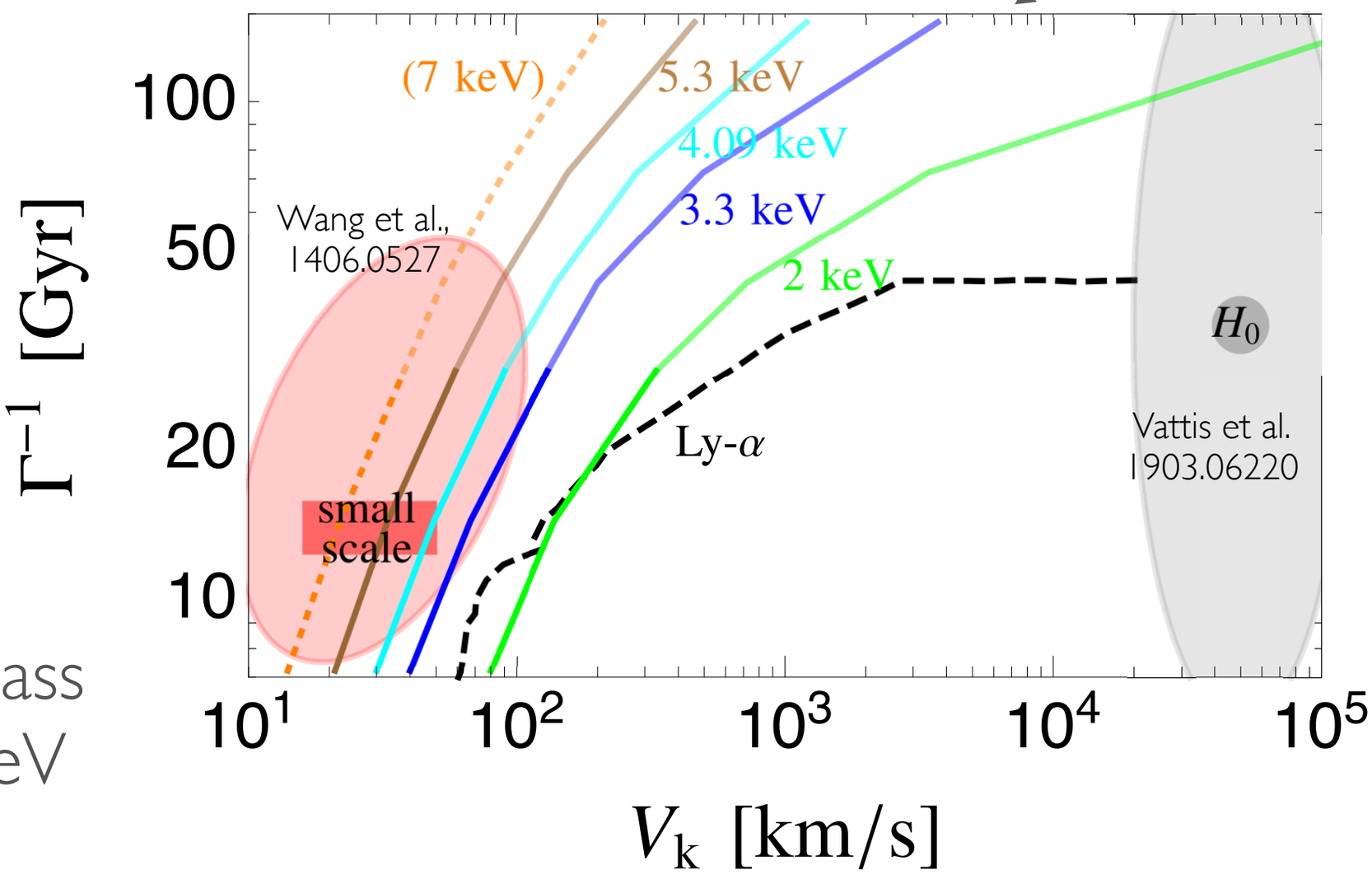


$$\begin{aligned} \Gamma_{\tilde{a}}^{-1} &= \frac{96\pi m_{3/2}^2 M_{\rm pl}^2}{m_{\tilde{a}}^5} \left(1 - \frac{m_{3/2}}{m_{\tilde{a}}}\right)^{-2} \left(1 - \frac{m_{3/2}^2}{m_{\tilde{a}}^2}\right)^{-3} \\ &\simeq 10\,{\rm Gyr} \left(\frac{700\,{\rm TeV}}{m}\right)^3 \left(\frac{20\,{\rm km/s}}{V_{\rm k}}\right)^5 . \end{aligned}$$

Axino lifetime ~ age of the universe!

DECAYING AXINO DM

Axino lifetime ~ age of the universe



axino mass ~700 TeV

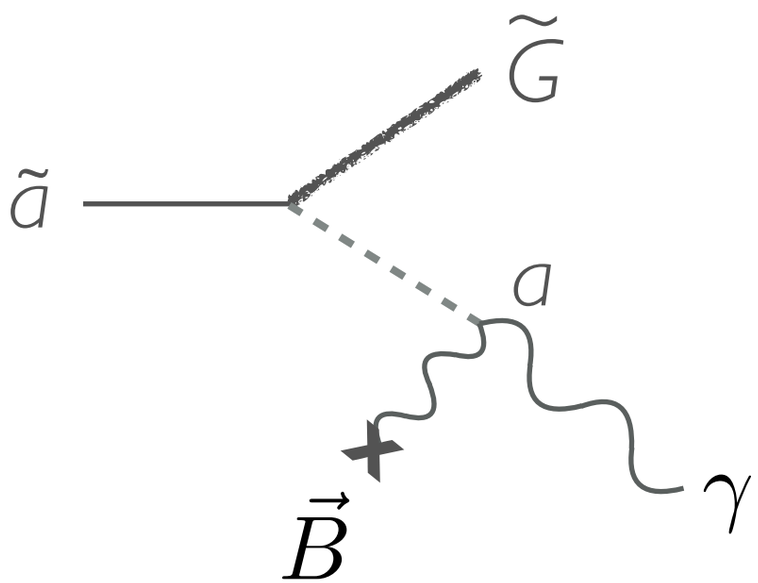
KJB, Kamada, Kim (19)

axino mass ~1 GeV

KJB, Kamada, Kim, in preparation

$$V_k \sim \frac{\Delta m}{m}$$

SIGNAL FROM AXION



Galactic magnetic field

~few μG

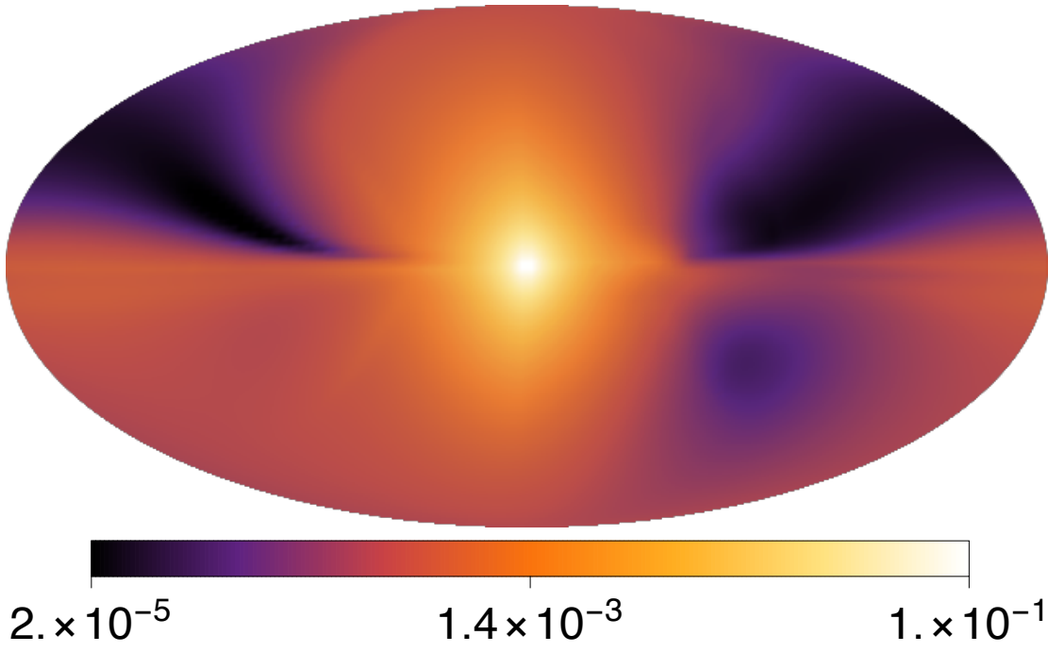
KJB, Kamada, Kim (19)

$$P_{a\gamma}(s,\Omega) \simeq 2\times 10^{-7}\left|\frac{B_T(s,\Omega)}{\mu\mathrm{G}}\right|^2\left(\frac{10^{-8}\,\mathrm{eV}}{m_a}\right)^4 \times\left(\frac{g_{a\gamma}}{10^{-13}\,\mathrm{GeV}^{-1}}\right)^2\left(\frac{E_\gamma}{47\,\mathrm{GeV}}\right)^2,$$

$$E_\gamma \simeq \Delta m$$

Signal Morphology: convolution of $B_T(s,\Omega)$ and $\rho_{\mathrm{dm}}(s,\Omega)$

$$m_a^2/E_a \gg g_{a\gamma}|B_T|$$



$E_\gamma = 47\,\mathrm{GeV}$ $g_{a\gamma} = 10^{-13}\,\mathrm{GeV}^{-1}$

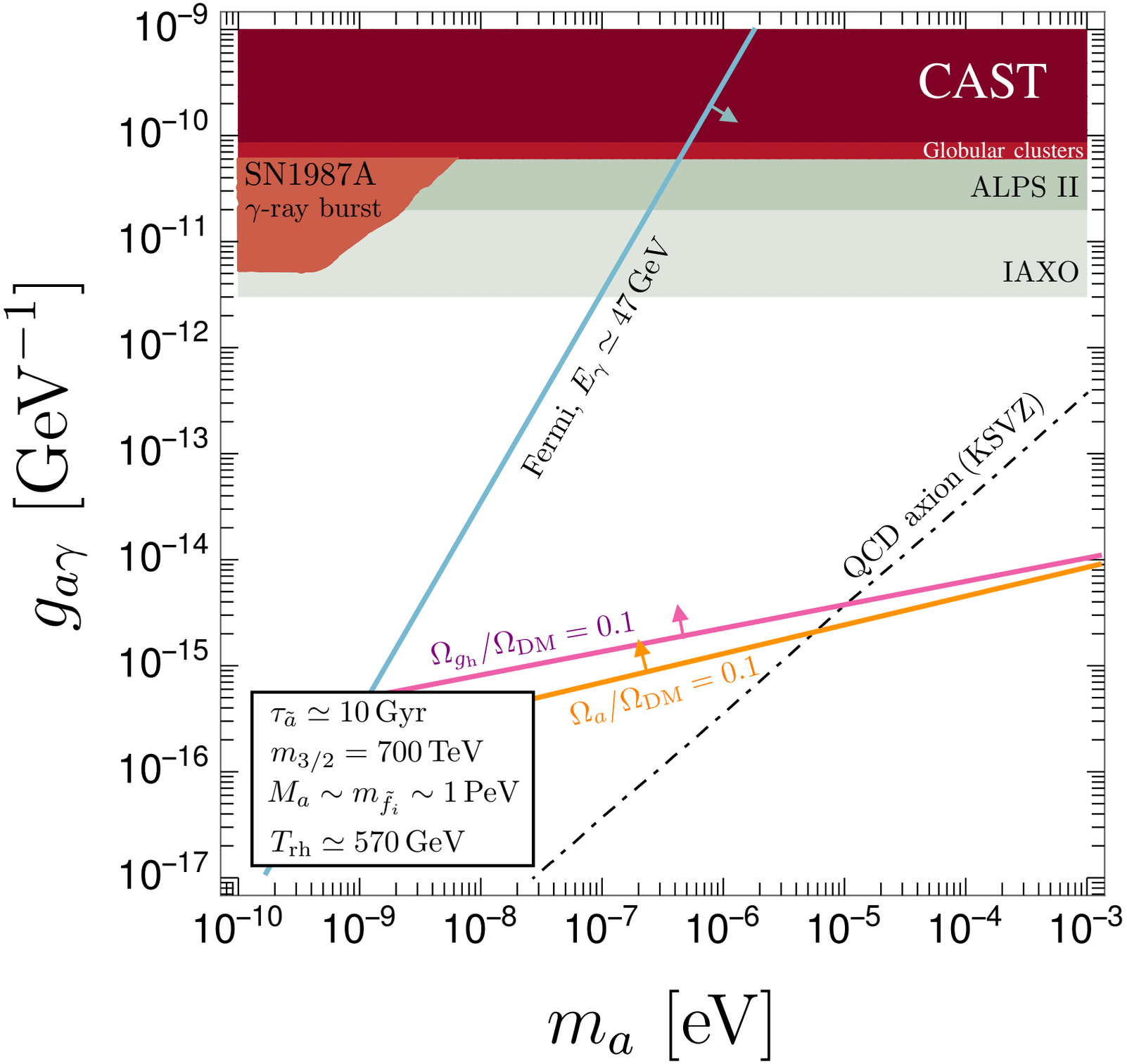
$\tau_{\tilde{a}} \sim 3\times10^{17}\ \mathrm{s}$ $m_a = 10^{-8}\,\mathrm{eV}$

Magnetic field profile from Jansson & Farrar,
Astrophys. J., vol. 757, p. 14, 2012

SIGNAL FROM AXION

KJB, Kamada, Kim, in preparation

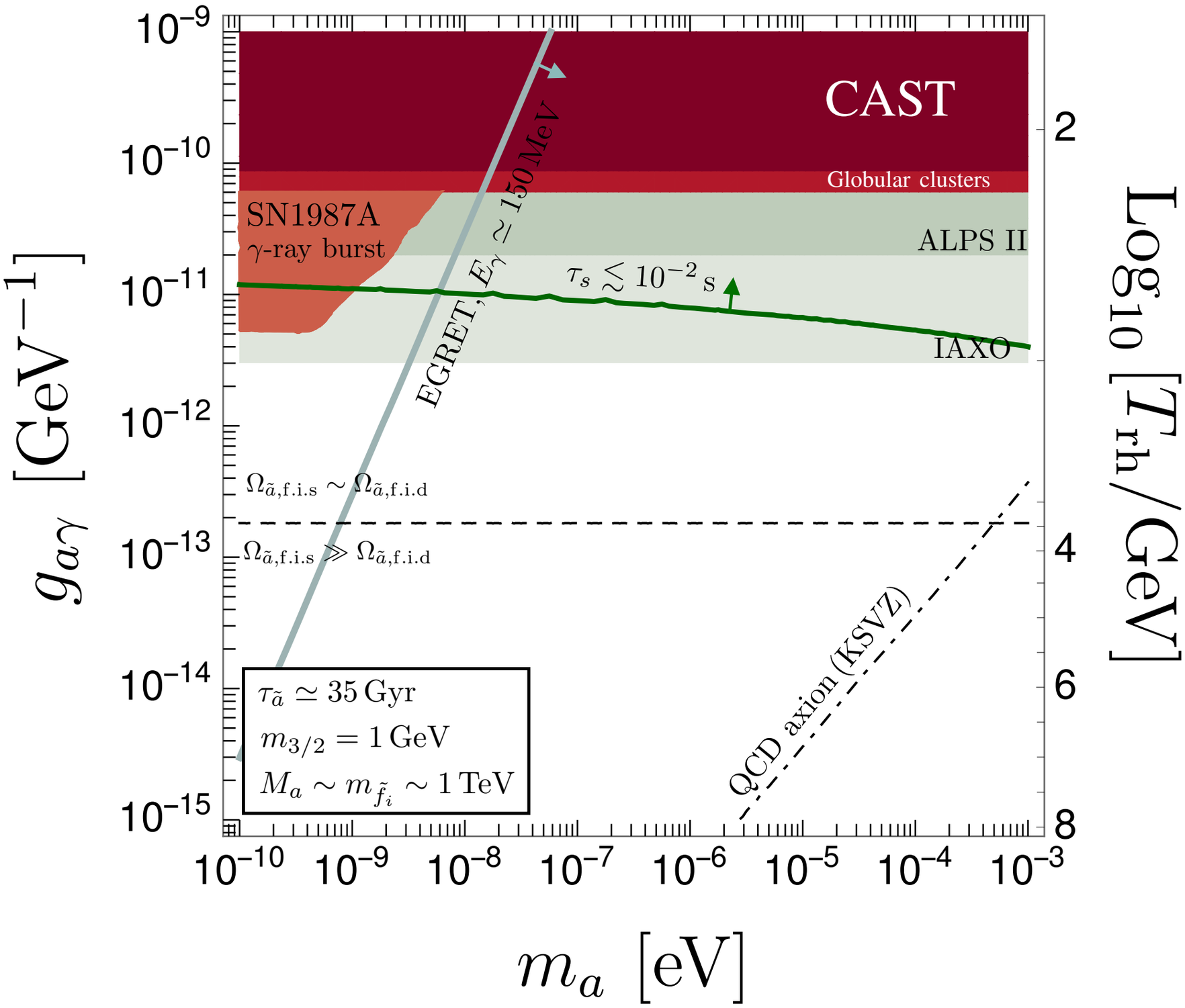
Small-scale issues



SIGNAL FROM AXION

KJB, Kamada, Kim, in preparation

H_0 tension



SUMMARY

- Departure from WIMP: lower coupling, various mass region, unstable particle
- Axino inherits properties of axion, but fermion and massive; good candidate for an alternative to WIMP
- I presented, 2 different scenarios
    - Axino mass is ~keV, produced via freeze-in process;
      leading to non-thermal nature and impact on small-scale structure
      long-lived particle at the LHC
    - Axino mass is > GeV. Axino is CDM, but decaying;
      leading to late-time "warm" behavior and thus
      impact on small-scale / altering H_0 evolution

      (these regions does not coincide, unfortunately.)

      axion-photon conversion by Galactic magnetic field