Probing Non-standard Cosmology Through Sub-earth Halos

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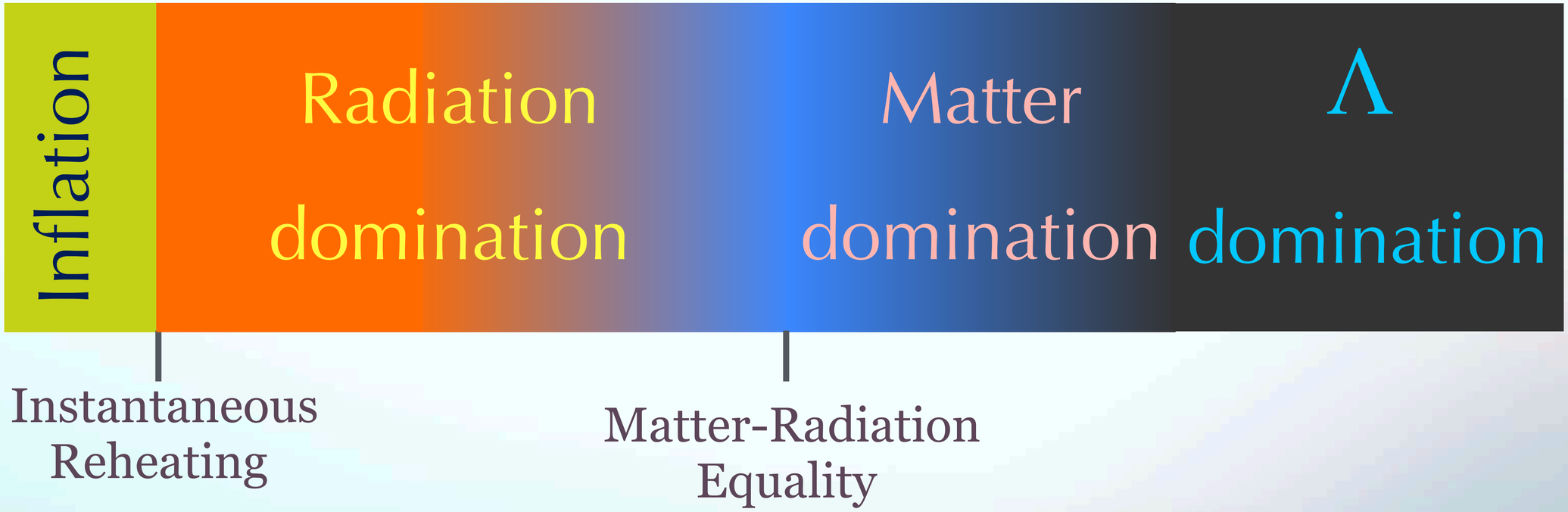
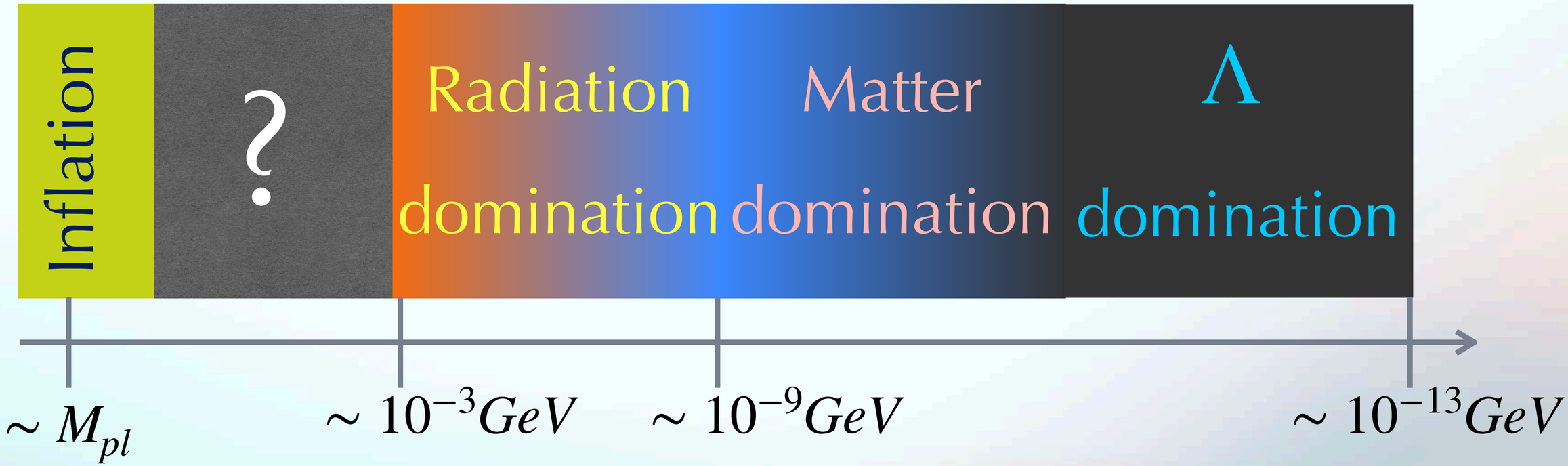
Standard Cosmology



Universe was **radiation dominated** at the time of **Big-Bang Nucleosynthesis**

(Non-)Standard Cosmology



Was the Universe **radiation dominated** before **Big-Bang Nucleosynthesis**?

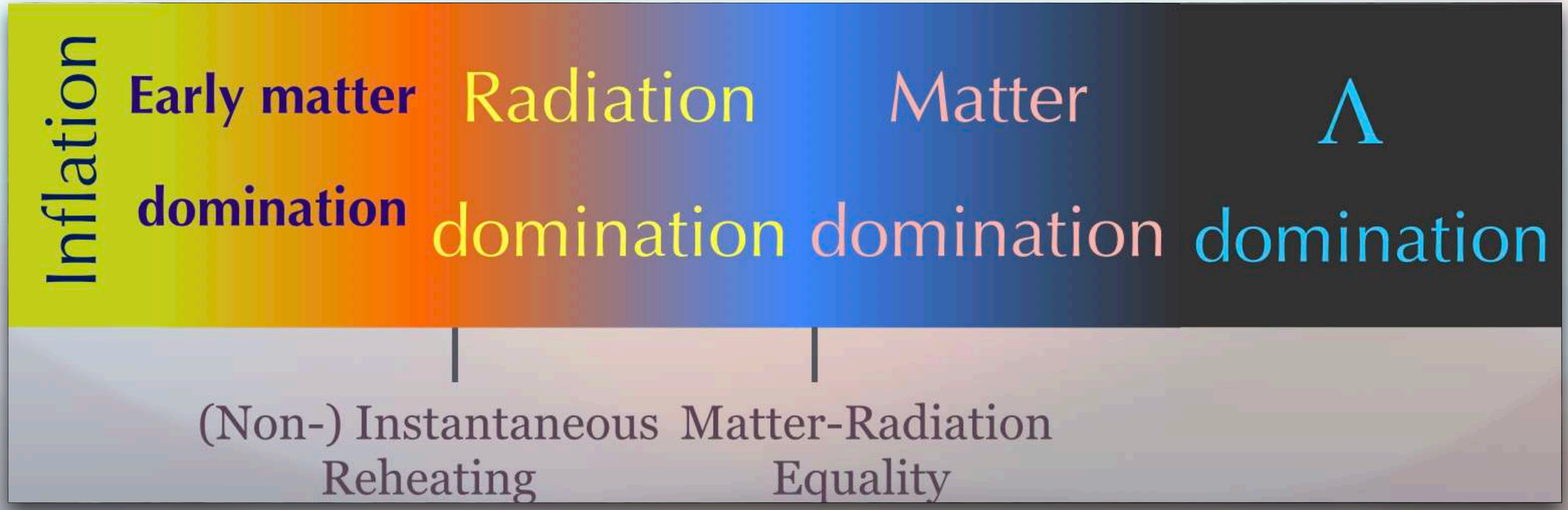
Not necessarily!

Non-Standard Cosmology

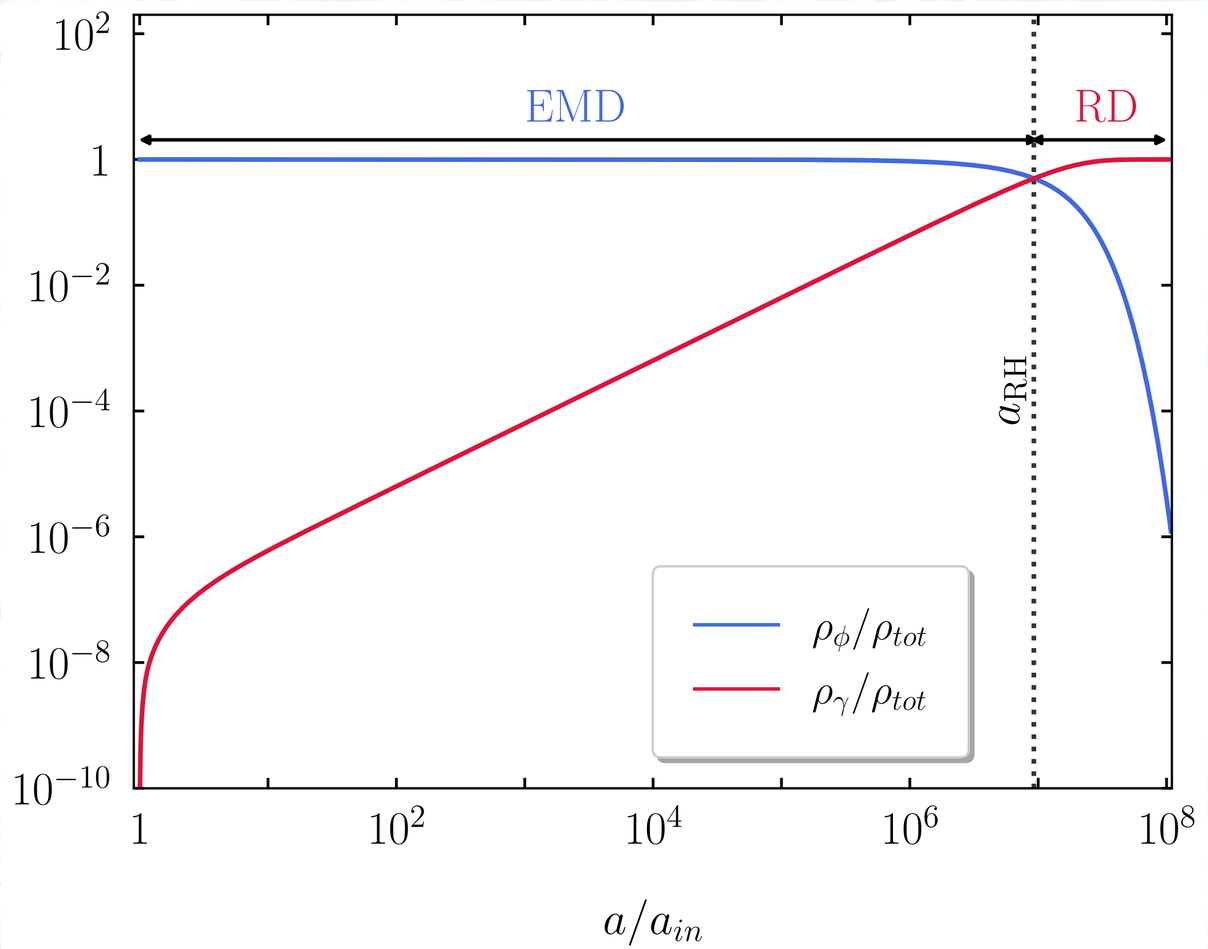
Meta-stable scalar field dominates the energy density after inflation

Moduli, Curvaton, Inflaton, Dilaton, ...

These meta-stable fields could instigate an early matter-dominated epoch



Early matter dominated epoch



Meta-stable field must decay before the start of BBN (~3 MeV)

Dissipation rate of ϕ:

Perturbative decay: $\Gamma_\phi \sim const\ .$

Field dependent: $\Gamma_\phi \sim \phi^k$

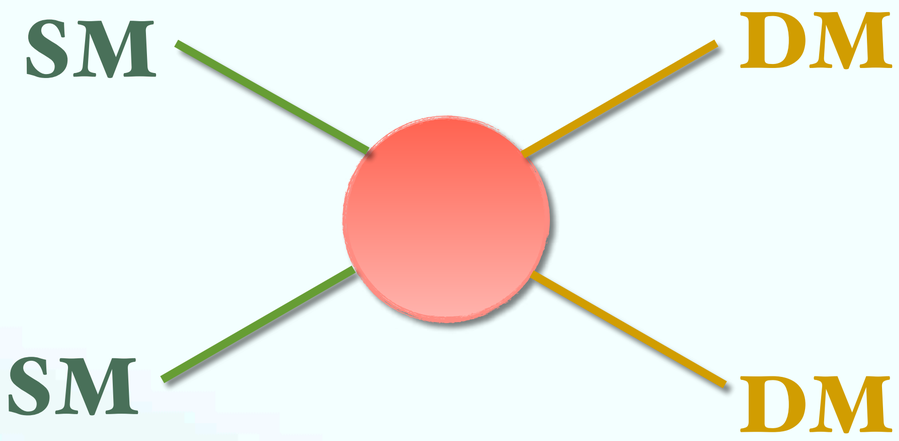
Thermally dominated: $\Gamma_\phi \sim T^m$

Scherrer, Turner '85; Shtanov et al. '95; Kofman et al. '97; Garcia et al. '12; Mukaida et al. 1208.3399, 1212.4985; Drewes, 1406.6243.....

Looking into the physics of the universe during reheating experimentally is extremely challenging!

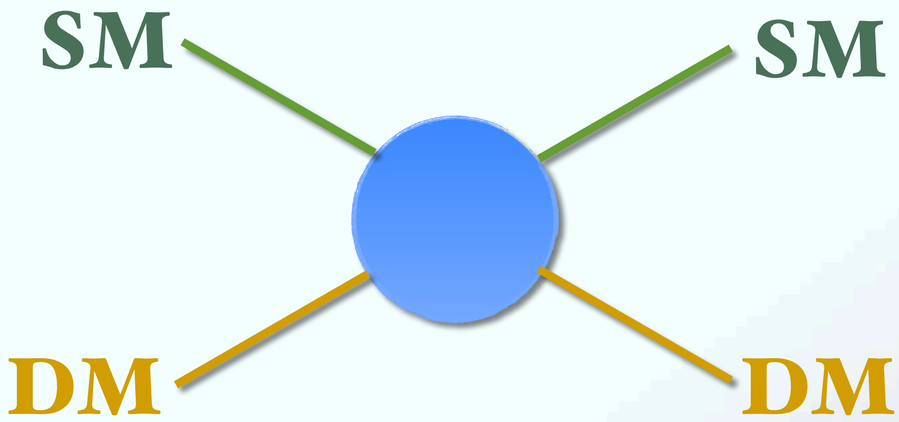
What are the probes?

Thermal decoupling of DM



T_{FO}

Chemical equilibrium



T_{kds}

Kinetic equilibrium

$1/T$

Chemical decoupling followed by a kinetic decoupling : $T_{FO} > T_{kds}$

DM starts free-streaming after kinetic decoupling : $T < T_{kds}$

Traces of EMDE

Kinetic decoupling in (non-) standard cosmology

Fokker-Planck Equation:

$$\frac{1}{T_\chi}\frac{dT_\chi}{d\ln a} + 2\left[1 + \frac{\gamma_{el}(a)}{H(a)}\right] = 2\frac{\gamma_{el}(a)}{H(a)}\frac{T(a)}{T_\chi(a)}$$

$$\gamma_{el}(a) \ll H(a)$$

$$\gamma_{el}(a)T(a) \not\ll H(a)T_\chi(a)$$

$$T_\chi(a) = C_1\left(\frac{a}{a_{dec}}\right)^{-q} + C_2\left(\frac{a}{a_{dec}}\right)^{-2}$$

Momentum transfer rate in elastic scattering

$$\gamma_{el} \sim \begin{cases} T^4 & s-wave \\ T^6 & p-wave \end{cases}$$

Visinelli et al.'15, Waldstein et al. '16

Evolution of DM temperature

Standard Radiation dominated cosmology:

$$T \sim a^{-1}, H \sim T^2$$

$$T_\chi \sim a^{-2}$$

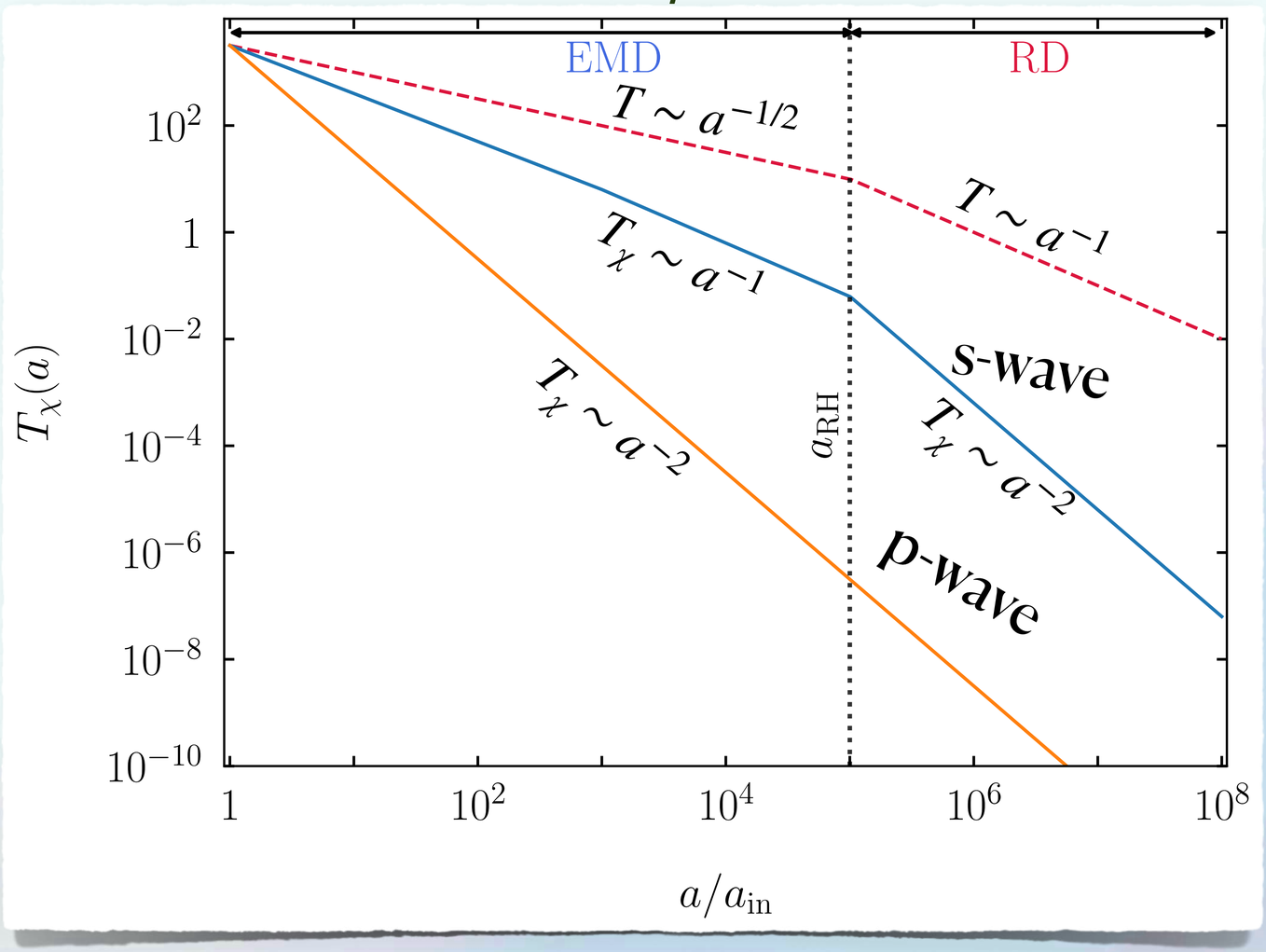
Fully decoupled

Early matter dominated epoch: $\Gamma_\phi \sim const.$

$$T \sim a^{-3/8}, H \sim T^4$$

$$T_\chi \sim a^{-9/8}$$ (p-wave)

$\Gamma_\phi \sim T$



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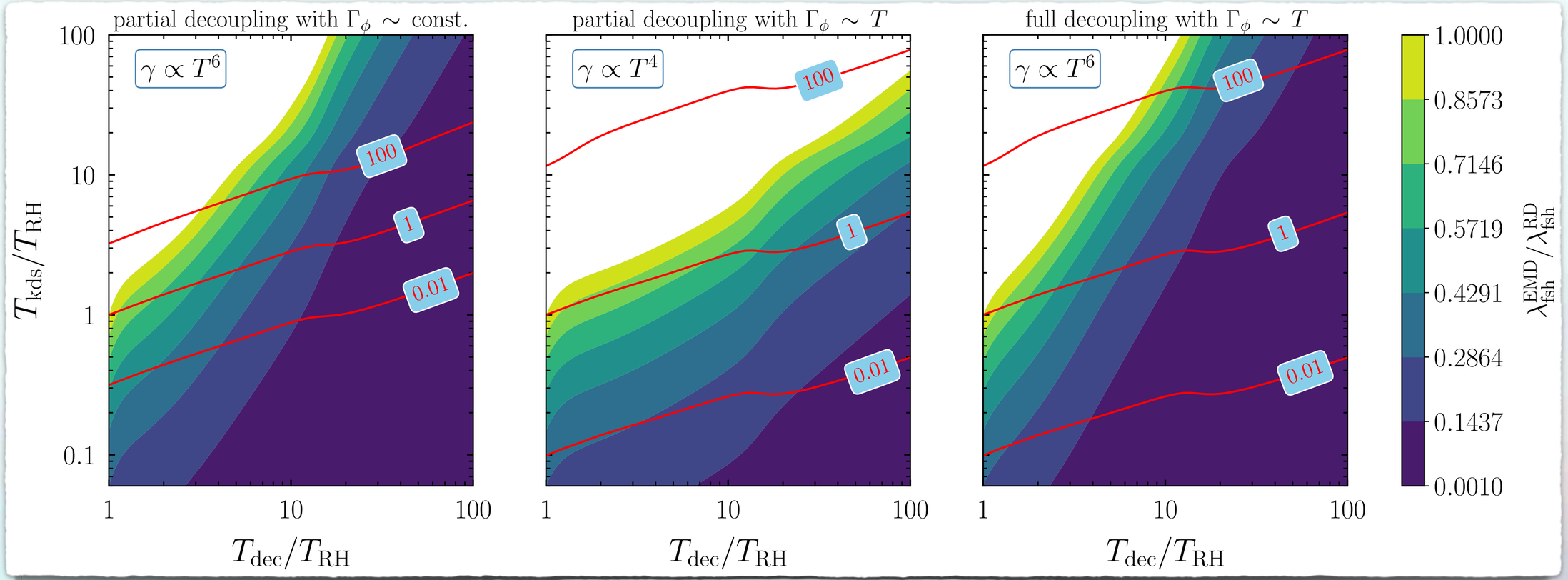
Impact on free-streaming horizon



$\Gamma_\phi \sim const.$

p-wave : partial decoupling

$\Gamma_\phi \sim T$

s-wave : partial decoupling

$\Gamma_\phi \sim T$

p-wave : full decoupling

Free-streaming horizon reduces if the DM decouples (partially / fully) during EMDE

Caveat: Chemical and Kinetic decoupling is governed by same interaction

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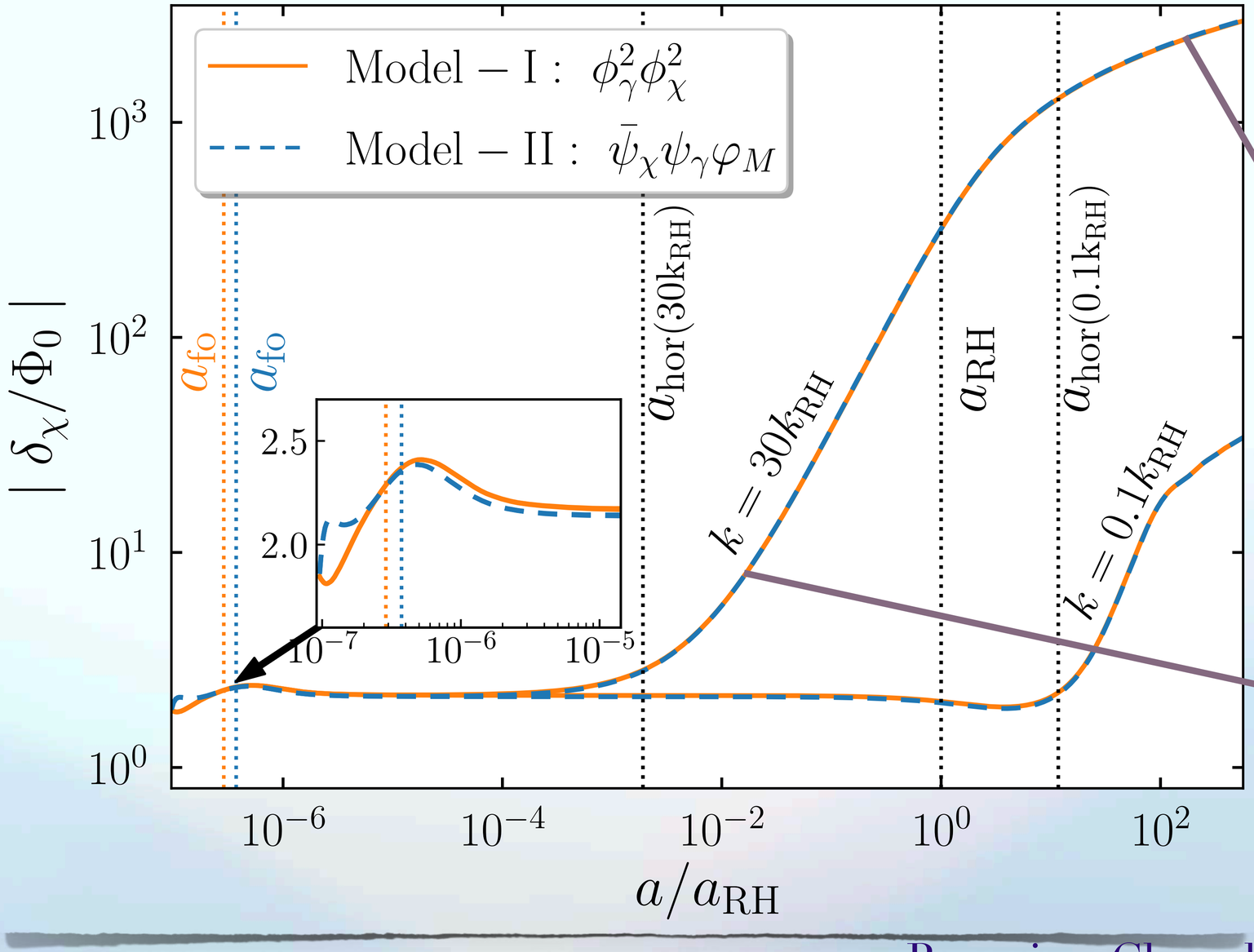
Growth of perturbations during EMDE

Modes inside the horizon during EMDE grow linearly till the end of reheating



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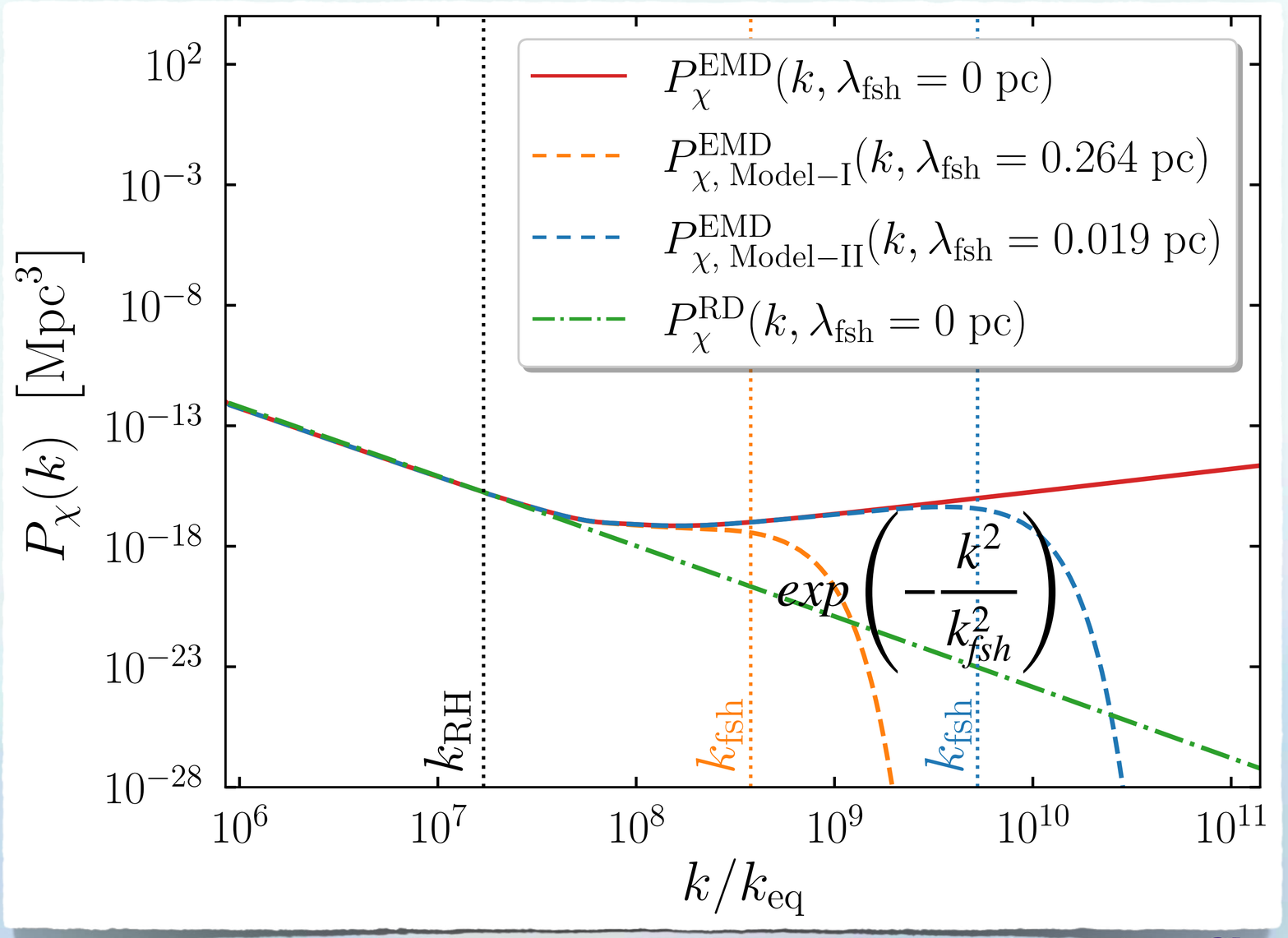
Enhancement in power spectrum



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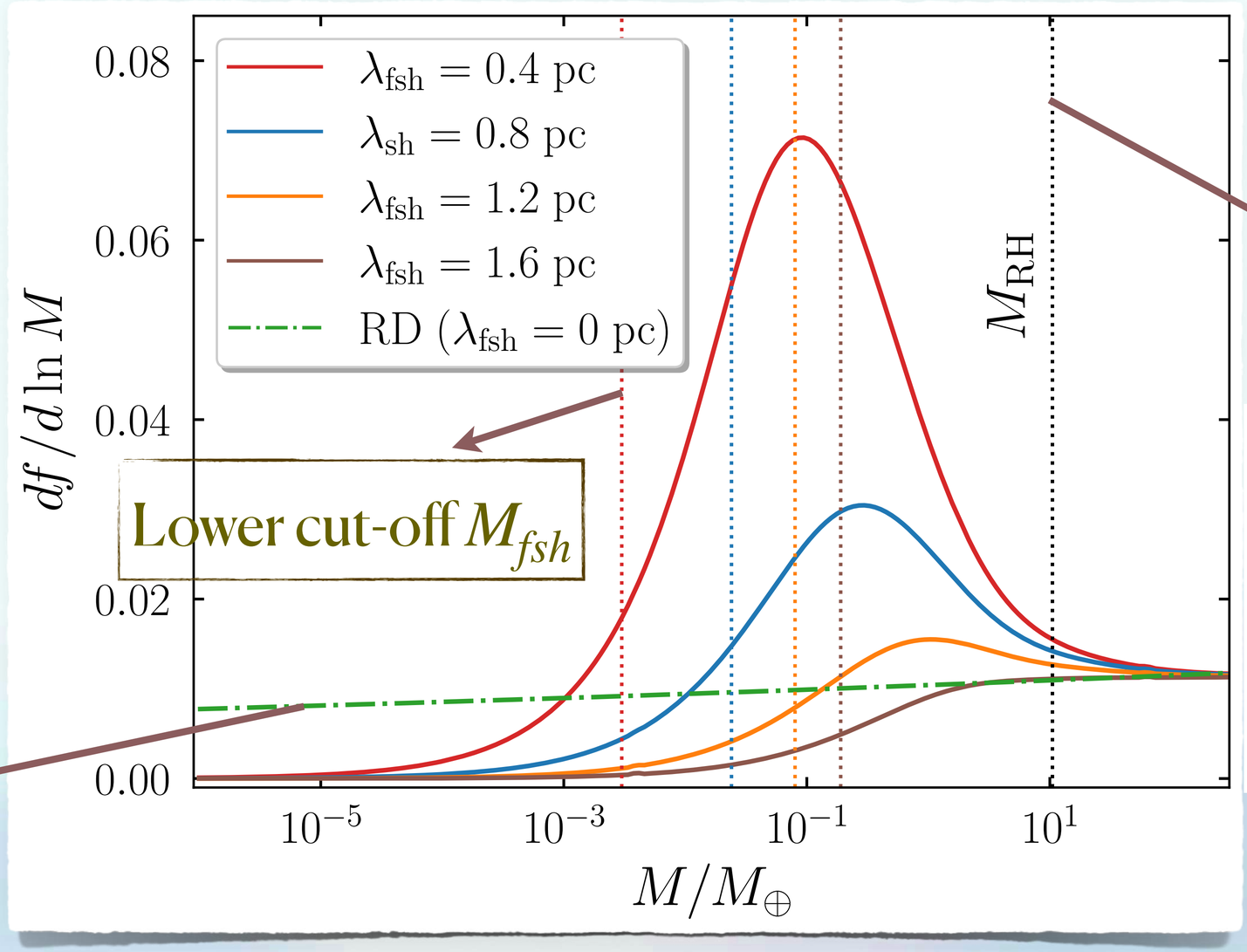
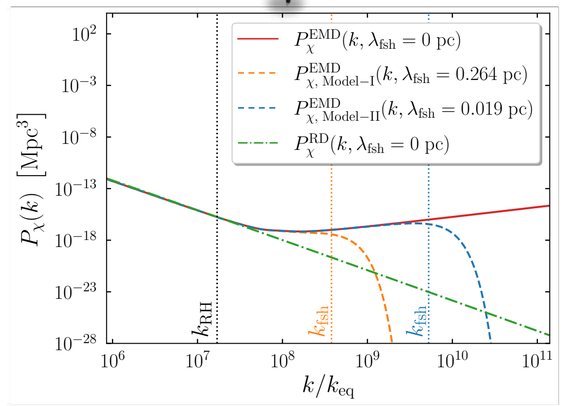
Boost in sub-earth mass halo population



Lower cut-off M_{fsh}

Upper cut-off M_{RH}



Free-streaming horizon above which EMDE shows no boost

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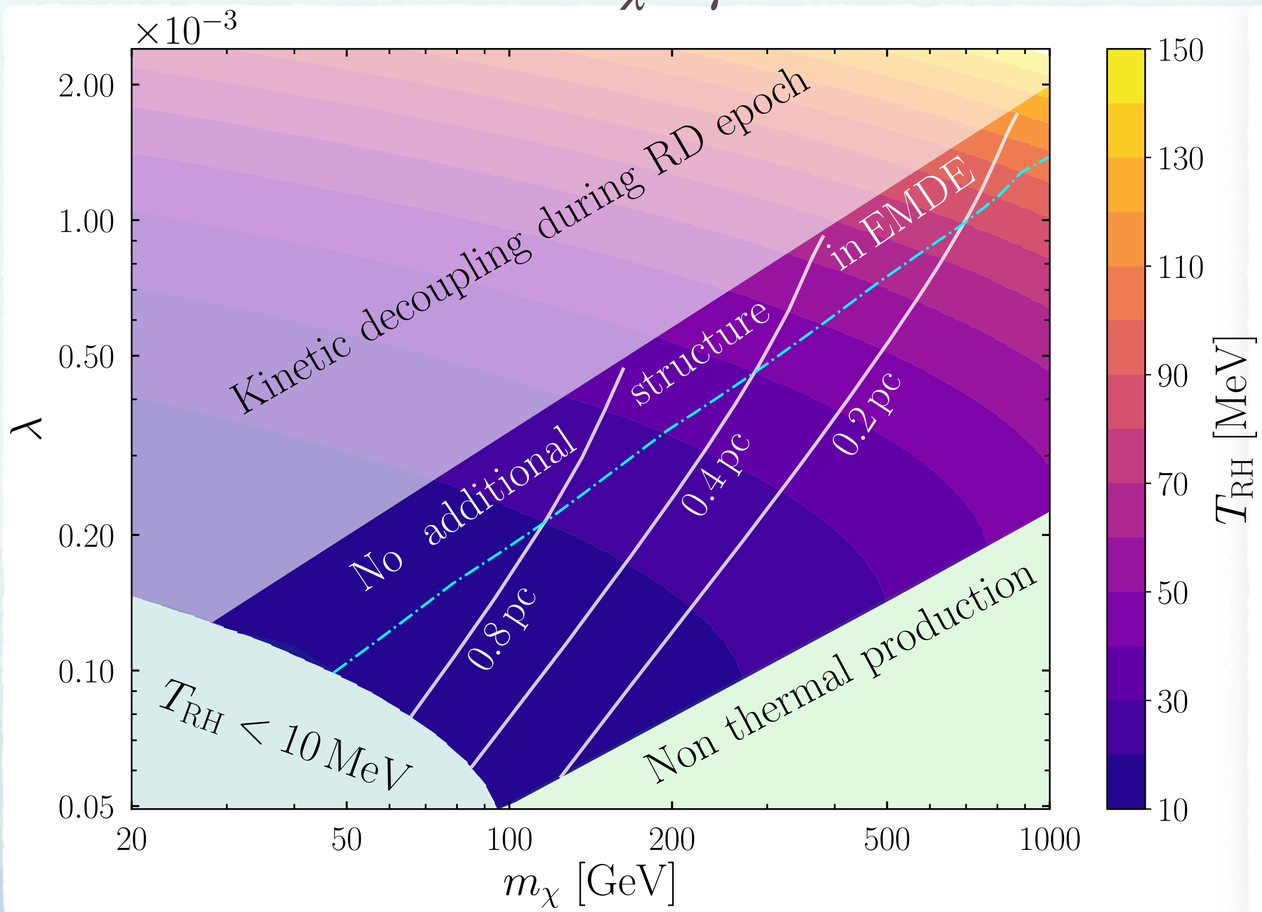
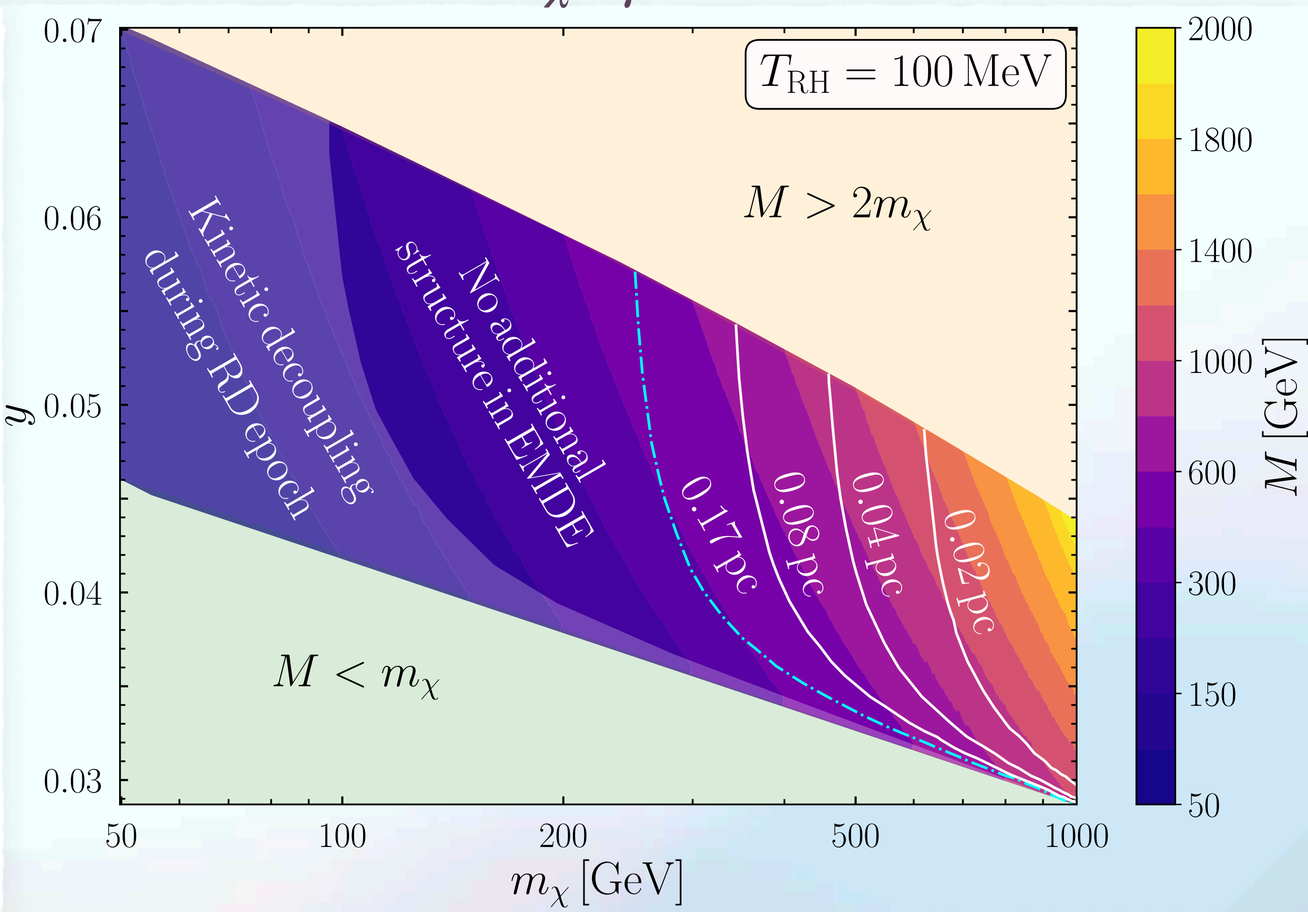
Connection between Particle Physics and Cosmology

$\mathscr{L} \supset \lambda \phi_\chi^2 \phi_\gamma^2$



$\mathscr{L} \supset y \bar{\psi}_\chi \psi_\gamma \phi_M$



s-wave elastic scattering ($\gamma_{el} \sim T^4$)

Partial decoupling during EMDE

p-wave elastic scattering ($\gamma_{el} \sim T^6$)

Full decoupling during EMDE

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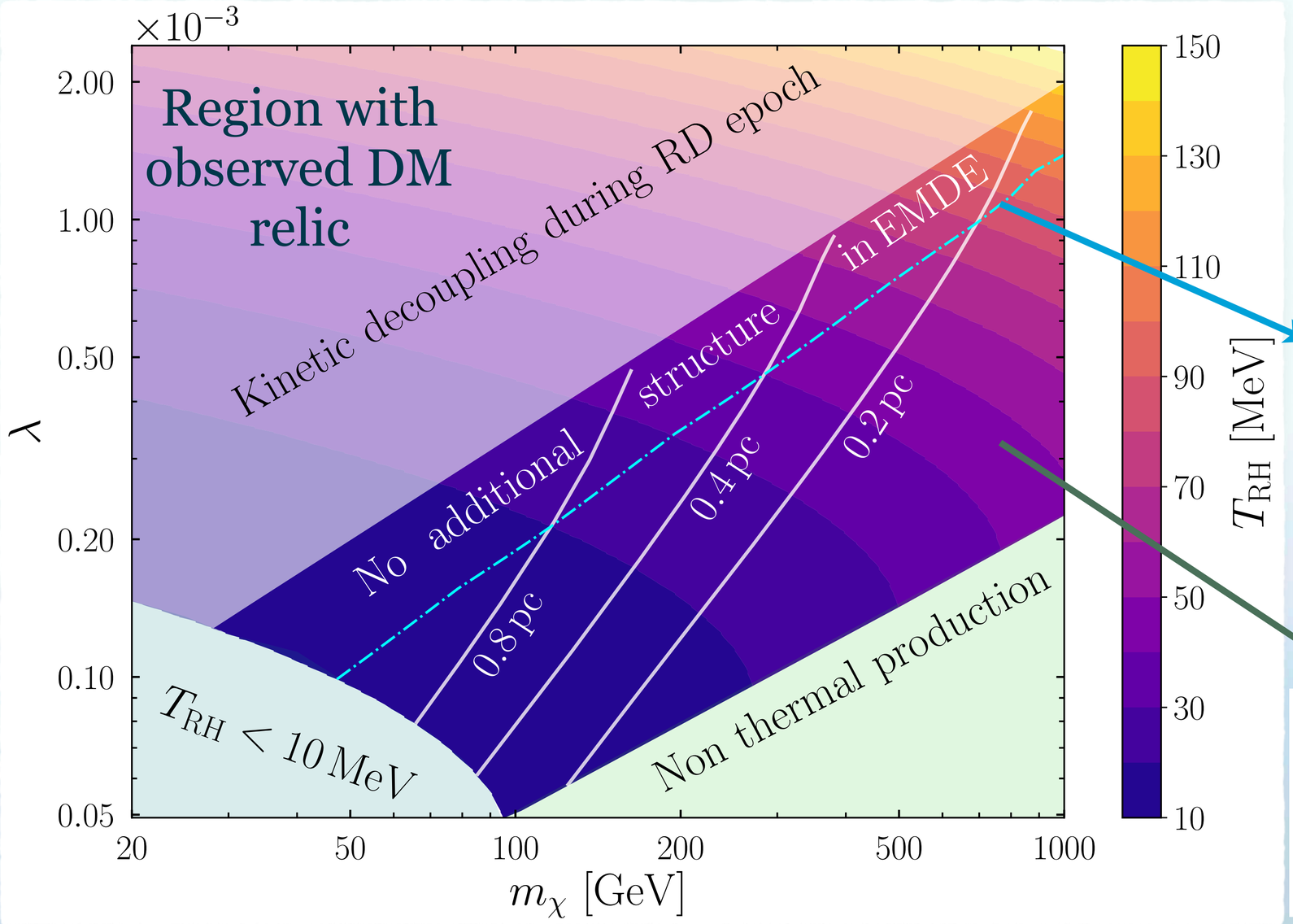
Model I



Cut-off free streaming horizon

Partial decoupling during EMDE

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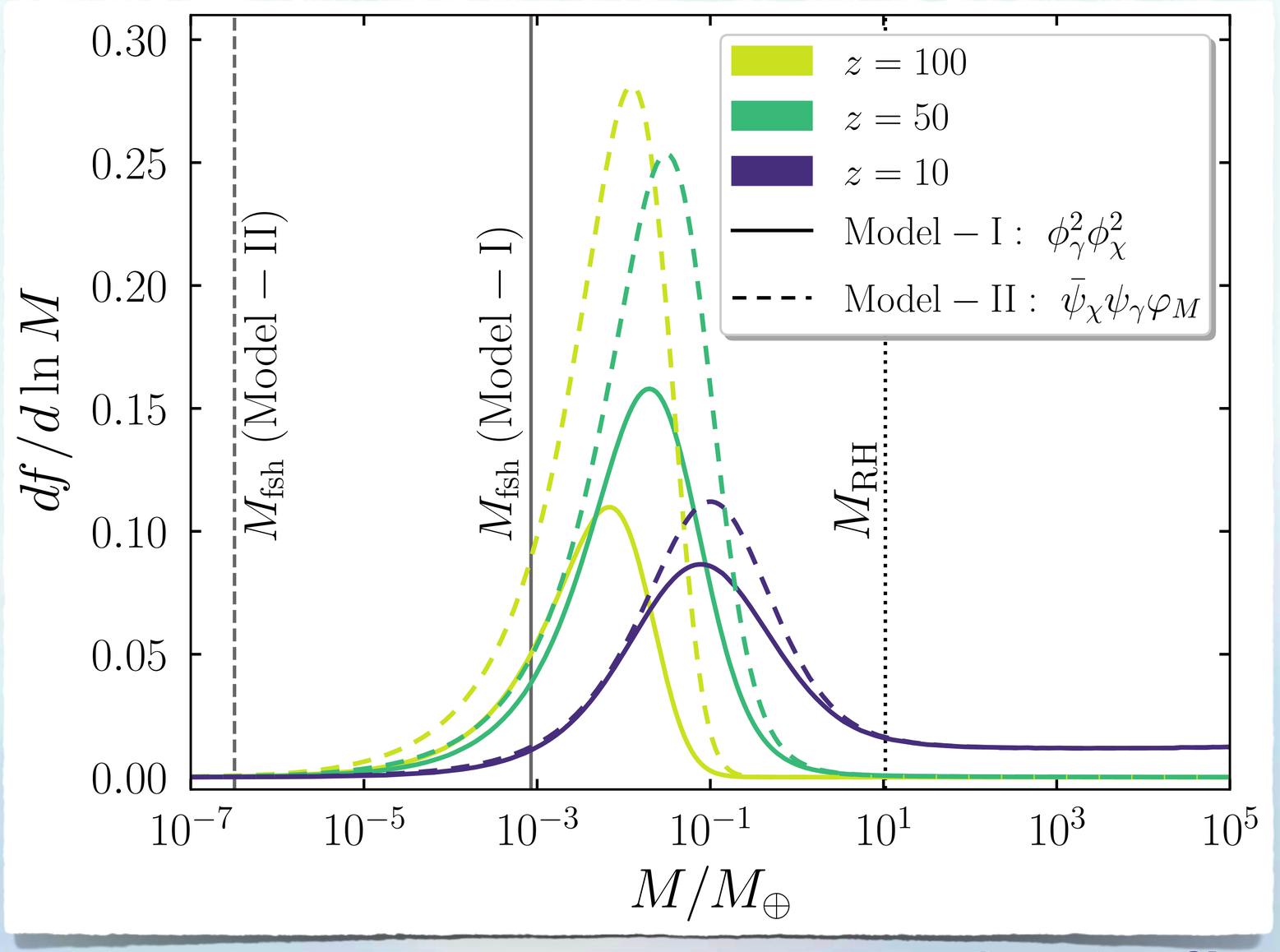
Comparison between Model I & II

Lower mass halos due to additional cooling in Model II



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TAKEAWAYS

A pre-BBN early matter dominated epoch

- Dilutes the number density of DM
  - Requires smaller $\langle \sigma v \rangle$ for DM freeze-out
- Matter perturbations grow linearly
  - Enhancement in sub-earth halo population
- DM goes through additional cooling
  - Reduced free-streaming horizon

Boost in the annihilation signal of DM

Thank you for your attention