

IRN Terascale Heidelberg 2026

WIMPs and FIMPs in the Inert Doublet Model

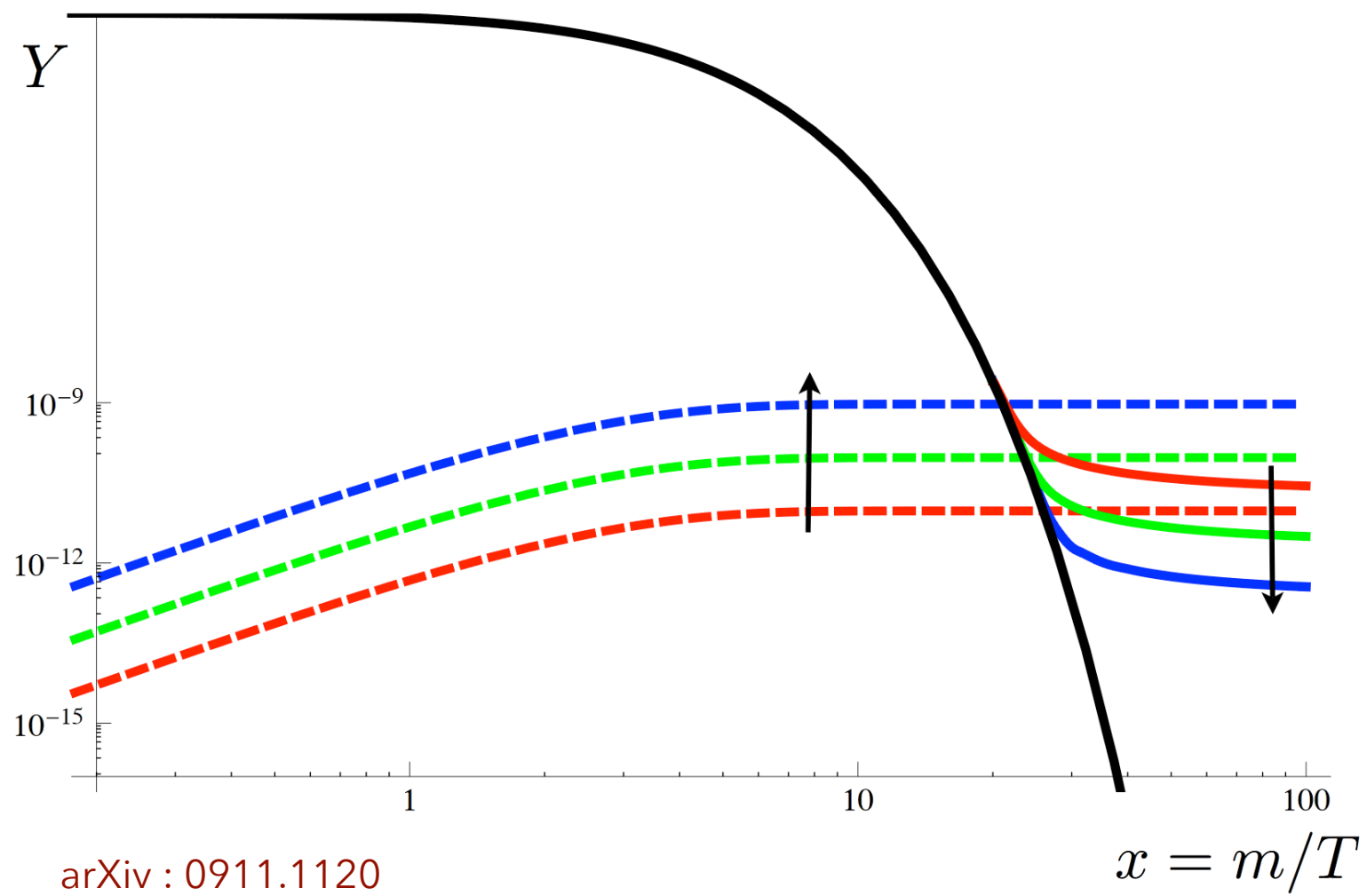
Thomas Reggio

Laboratoire de physique de Clermont Auvergne - LPCA

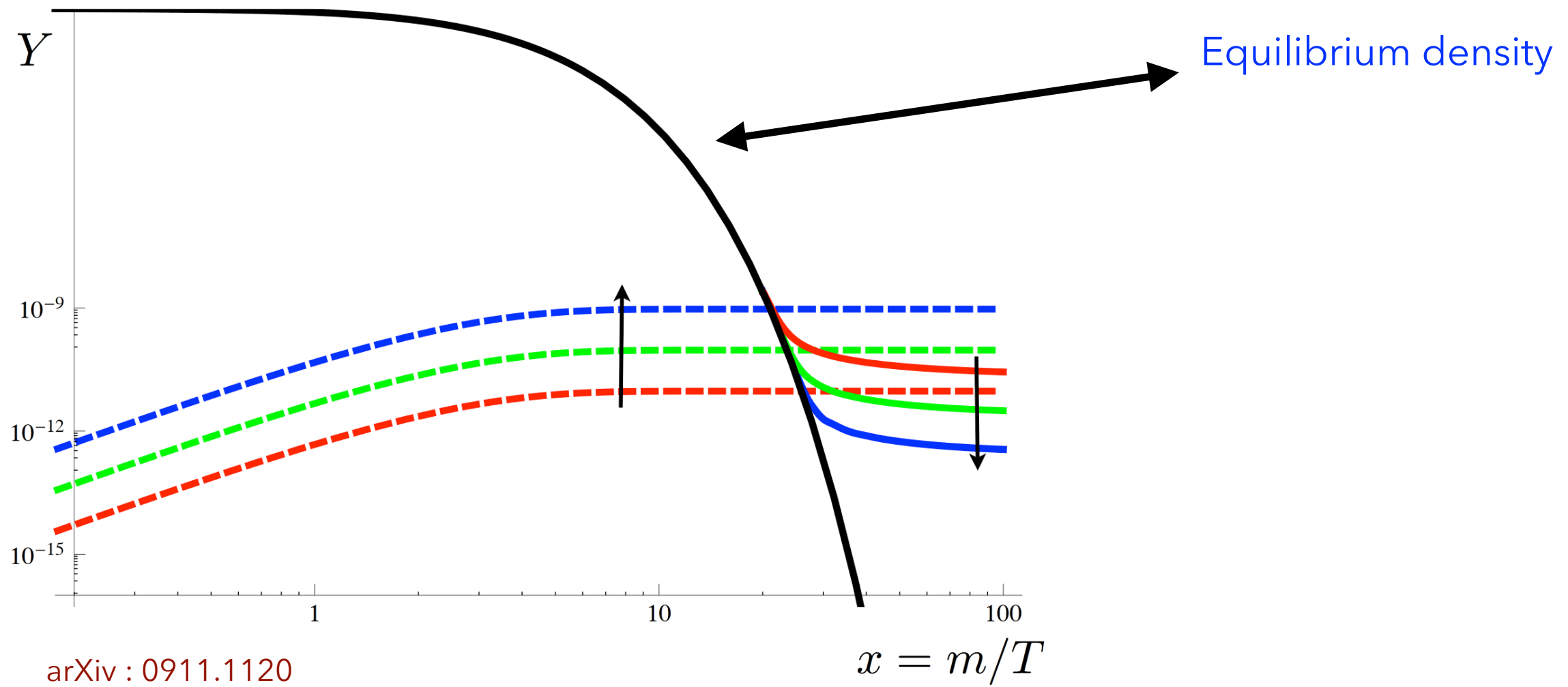
Work in progress with G.Bélanger, N. Bernal, A. Goudelis.



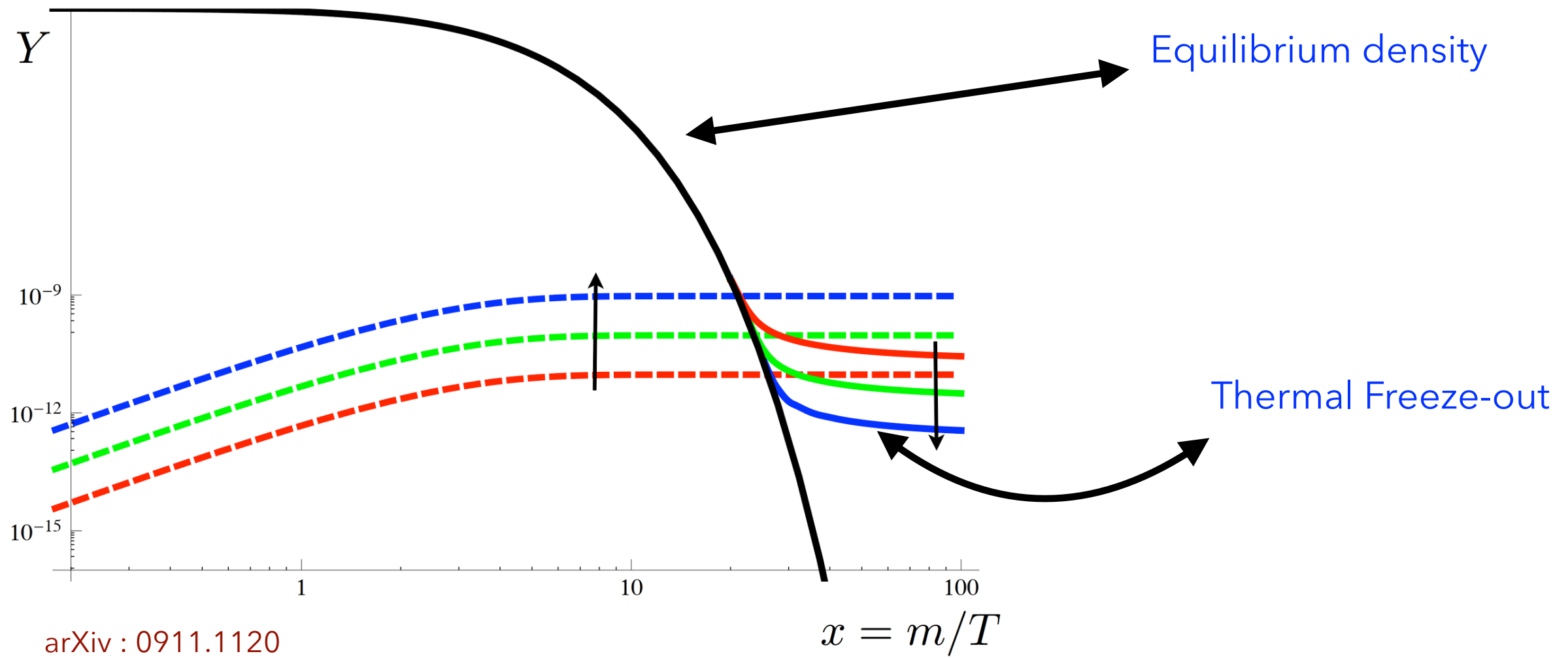
Freeze-out vs freeze-in



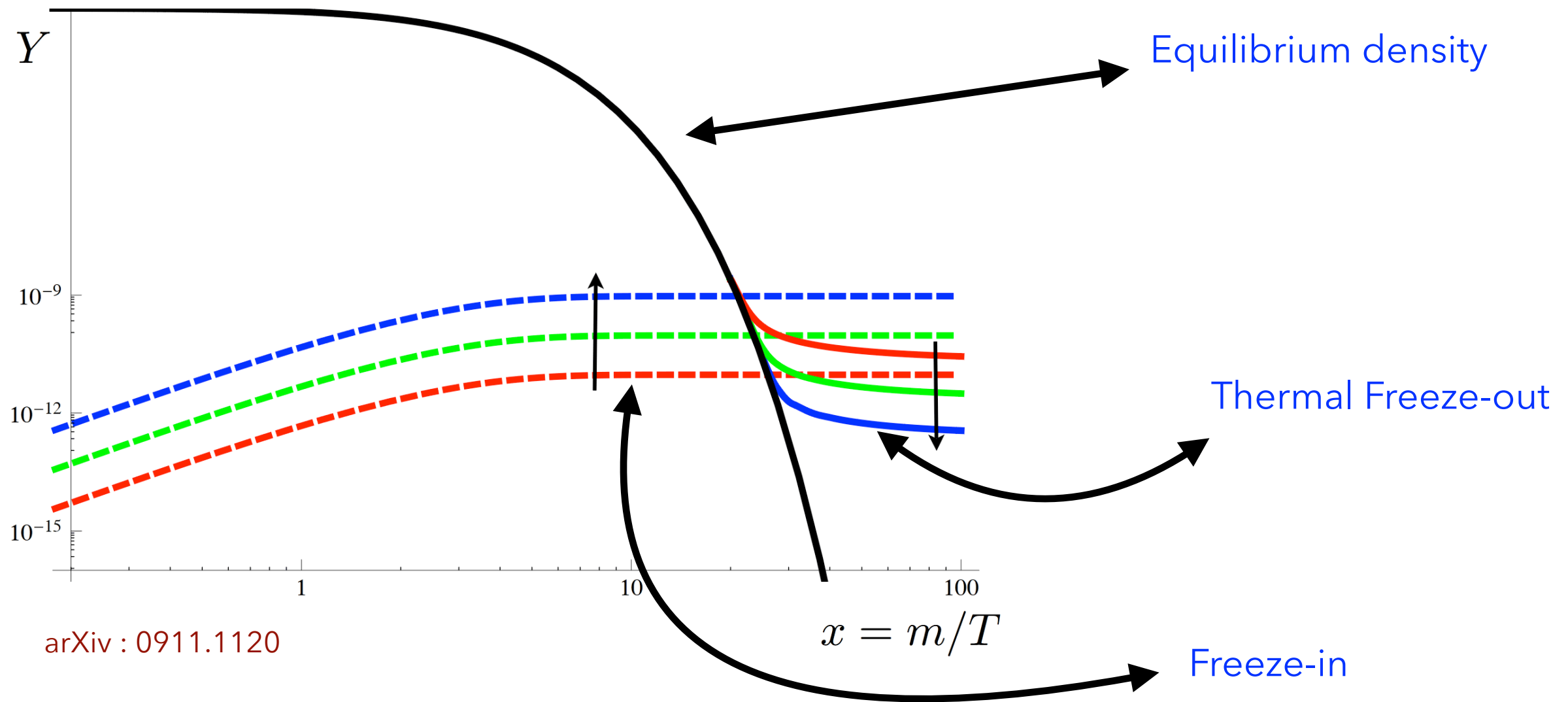
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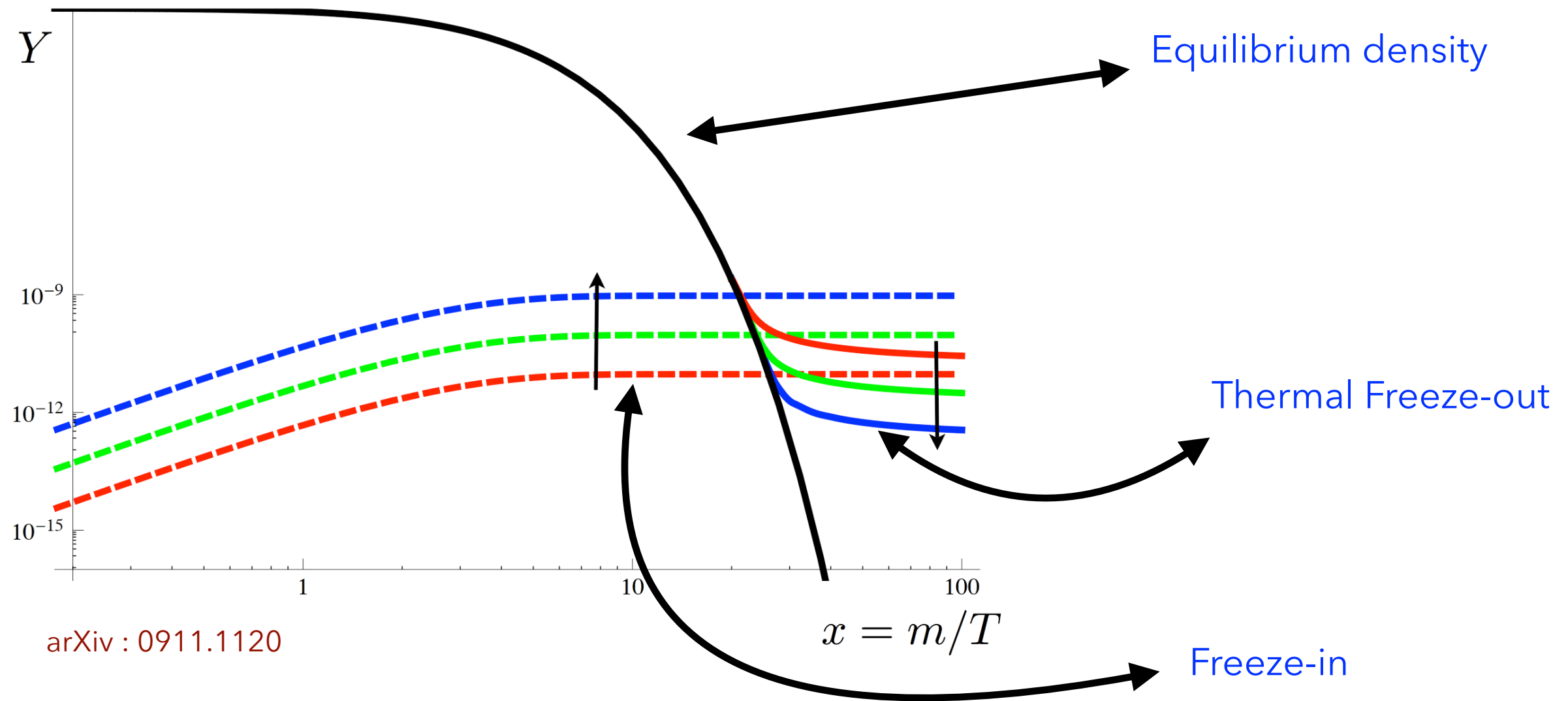
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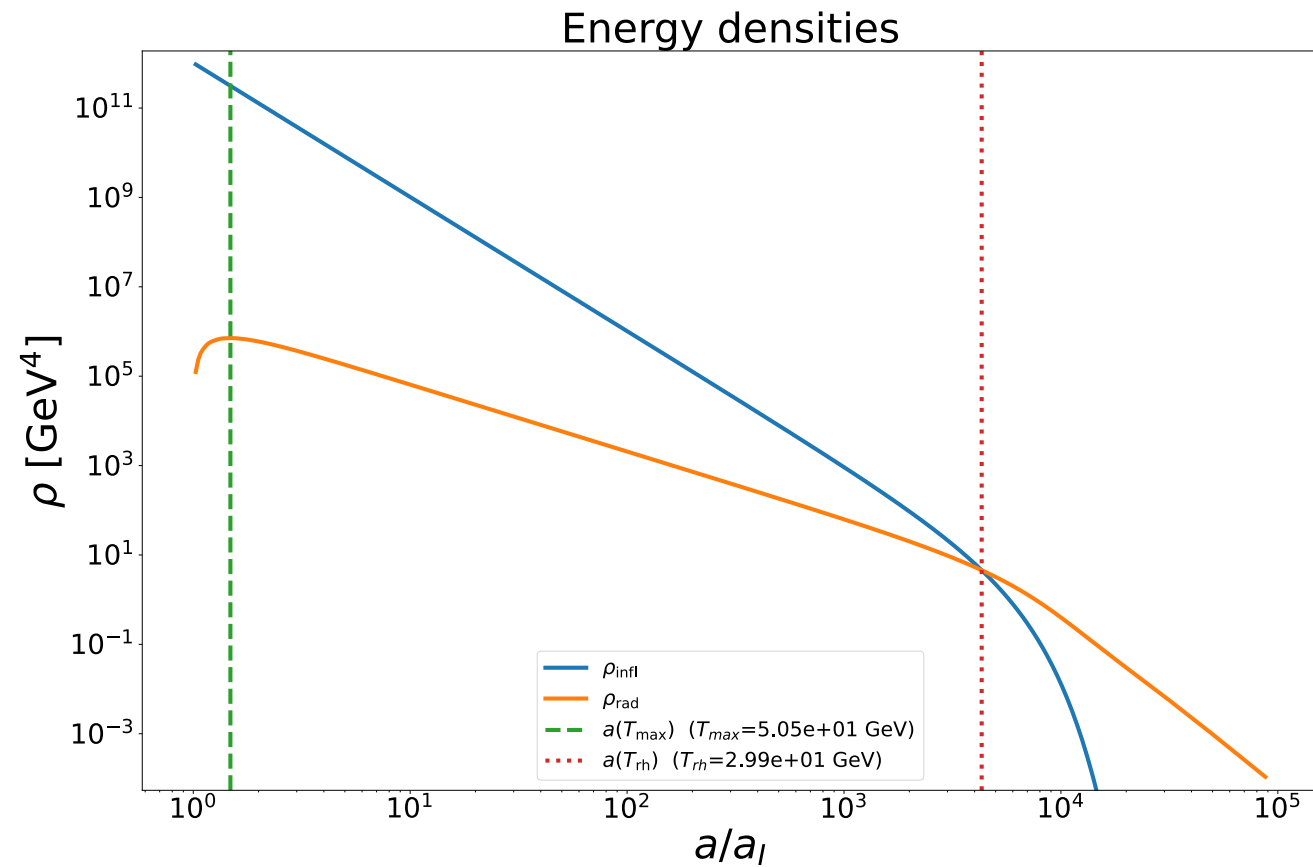
- Freeze-out is typically associated with strongly coupled models to establish equilibrium
- Freeze-in with feebly coupled ones to avoid it

Reheating

Reheating is the period of the universe after inflation and before RD, where inflatons and radiation coexist.

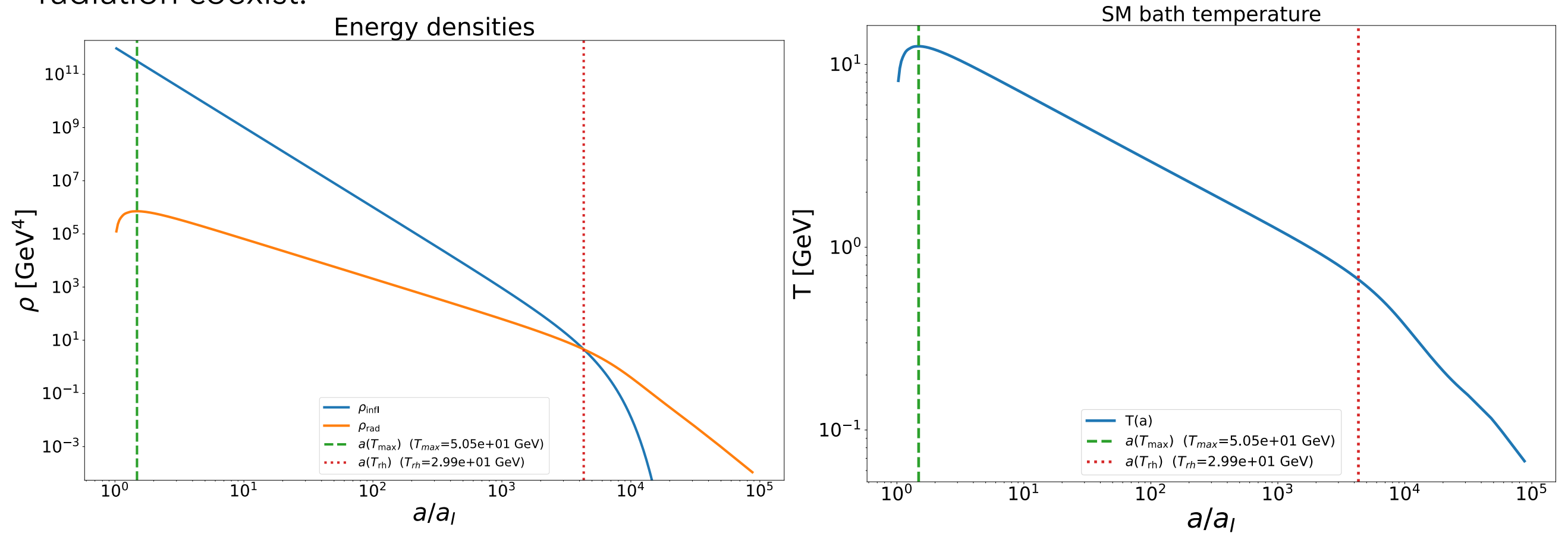
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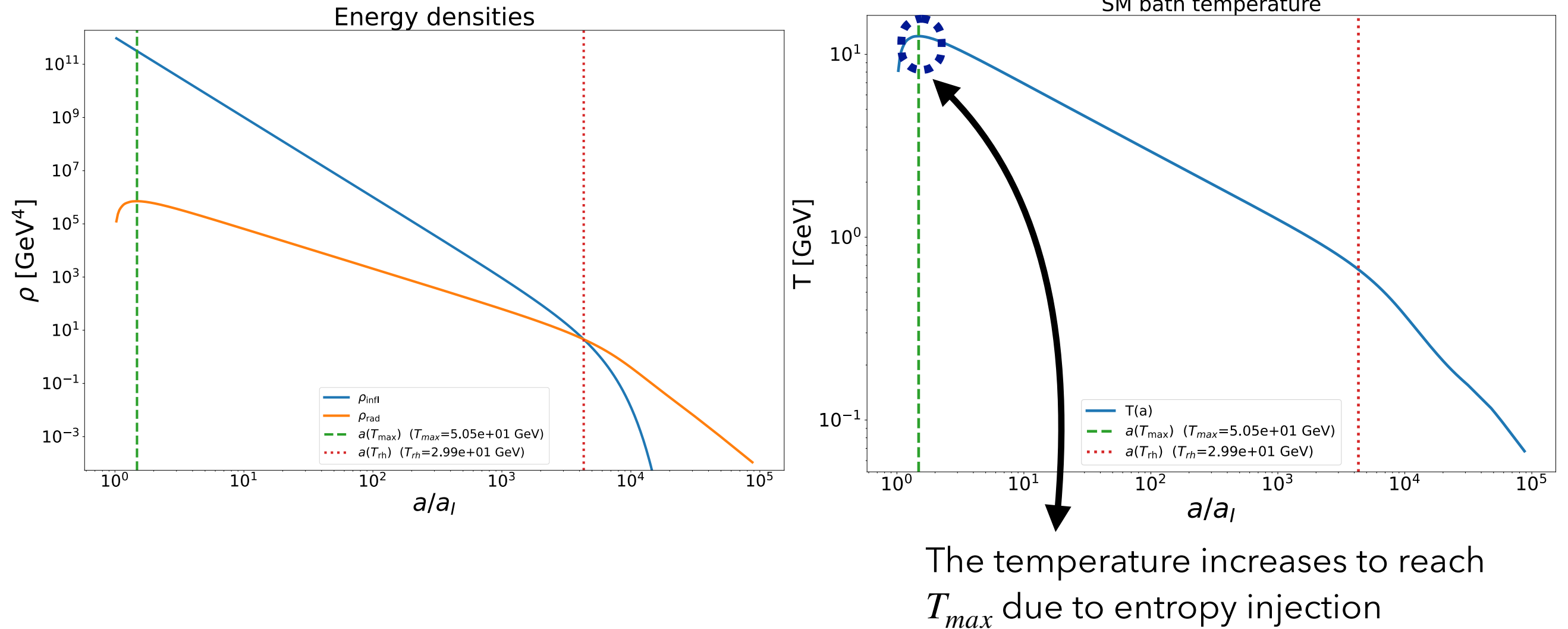
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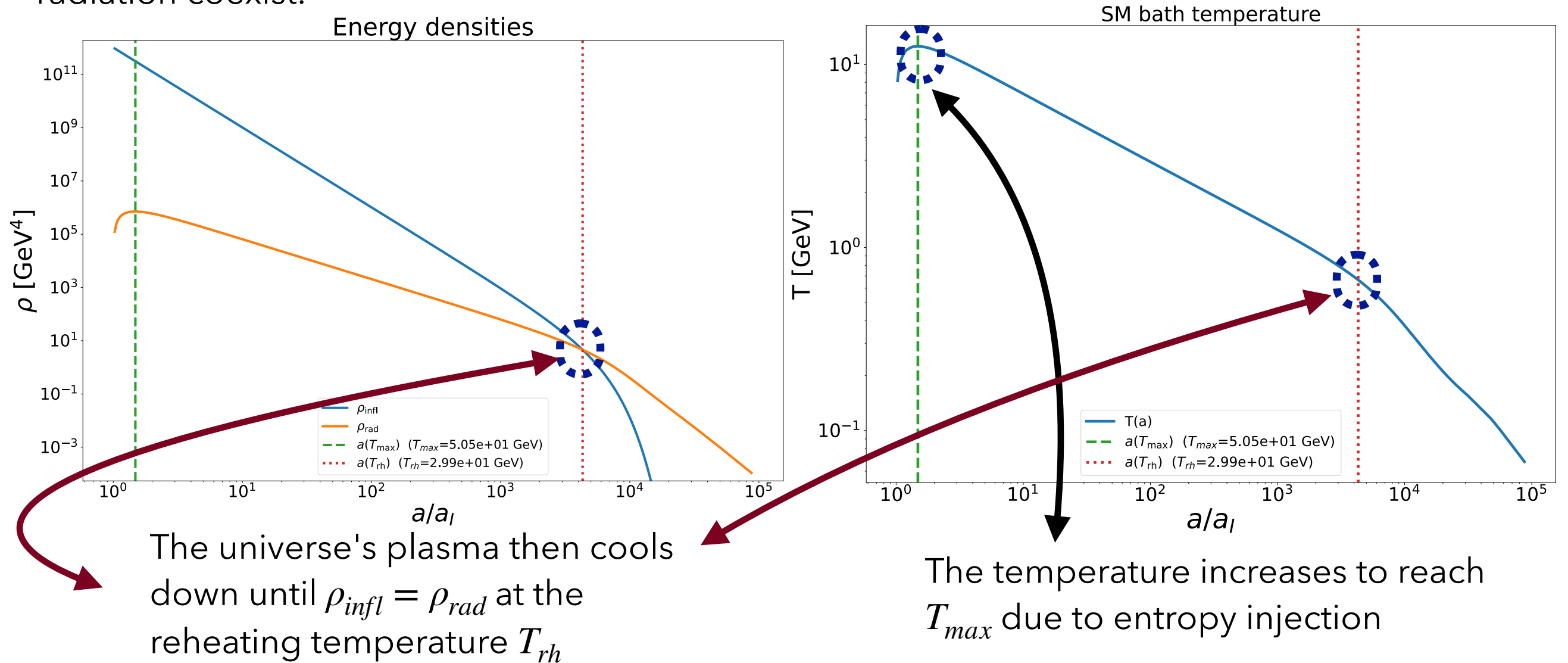
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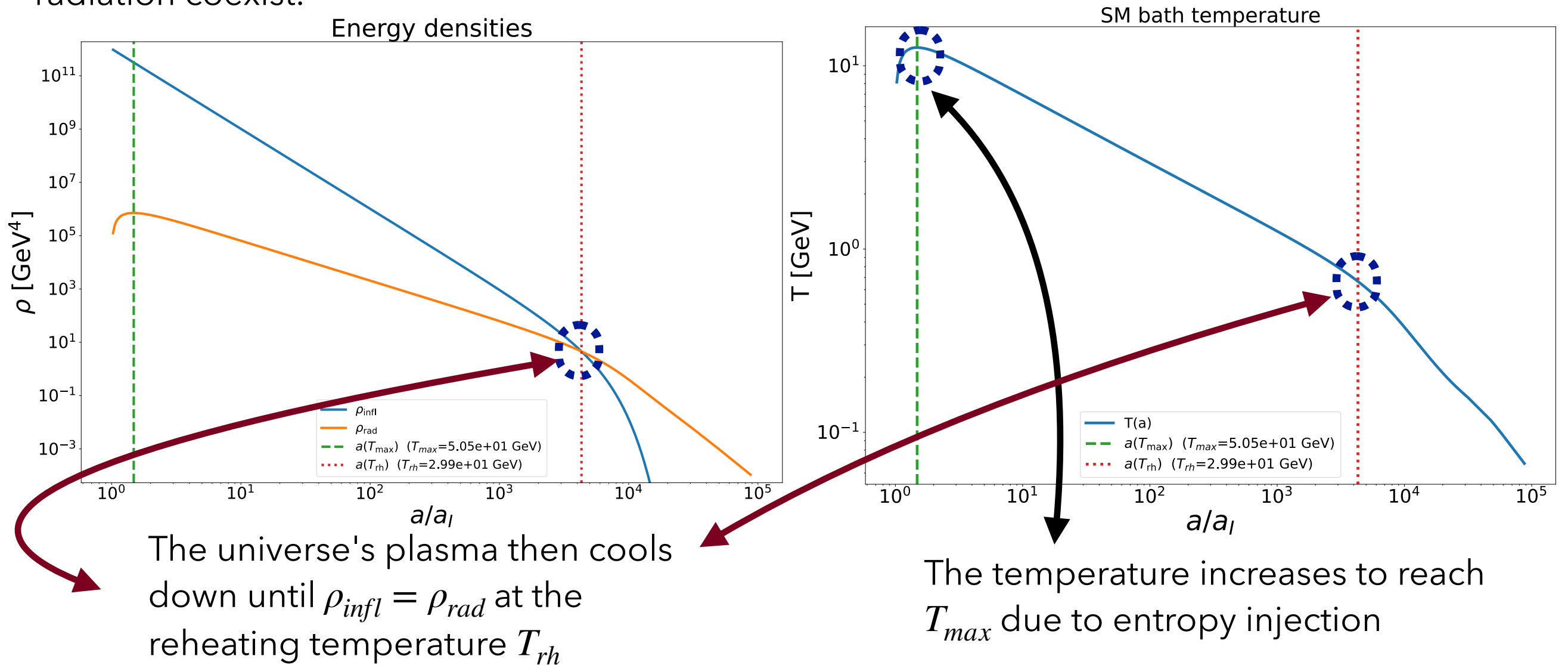
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Common cosmological assumption for DM production:

- The universe (instantaneously) reheated to a very high temperature (higher than all scales in the micro model)
- Dark matter production happened after reheating, during RD

Freeze-in at stronger coupling

Consider the case of freeze-in through scattering processes, the solution of the Boltzmann equation is

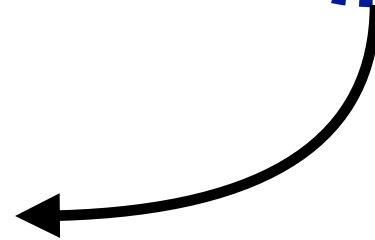
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But what if this is small? ie. Boltzmann suppression $\propto e^{-\frac{m_\chi}{T}}$ at
the beginning of RD

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Natural questions: What if WIMPs themselves freeze-in due to low T_{rh} ? What is the impact of a finite reheating time?

The Inert Doublet Model

An extension of the Standard Model by a complex, $SU(2)_L$ doublet, scalar field Φ , odd under a $\mathbb{Z}_2$ symmetry. Then only the scalar potential of the SM Lagrangian is modified and reads

$$V_0 = \mu_1^2 |H|^2 + \mu_2^2 |\Phi|^2 + \lambda_1 |H|^4 + \lambda_2 |\Phi|^4 + \lambda_3 |H|^2 |\Phi|^2 + \lambda_4 |H^\dagger \Phi|^2 + \frac{\lambda_5}{2} [(H^\dagger \Phi)^2 + \text{H.c.}]$$

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After EWSB, the SM Higgs doublet H and the inert doublet can be expanded as

$$H = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}} (v + h + iG^0) \end{pmatrix}, \quad \Phi = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}} (H^0 + iA^0) \end{pmatrix}$$

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That can be traded for more physically intuitive ones

$$\{m_{H^0}, m_{A^0}, m_{H^\pm}, \lambda_L, \lambda_2\}$$

Dark matter candidates: H^0 or A^0 . Identical phenomenology, stick to H^0 for simplicity.

Constraints on the IDM

The IDM is subject to multiple constraints :

Constraints on the IDM

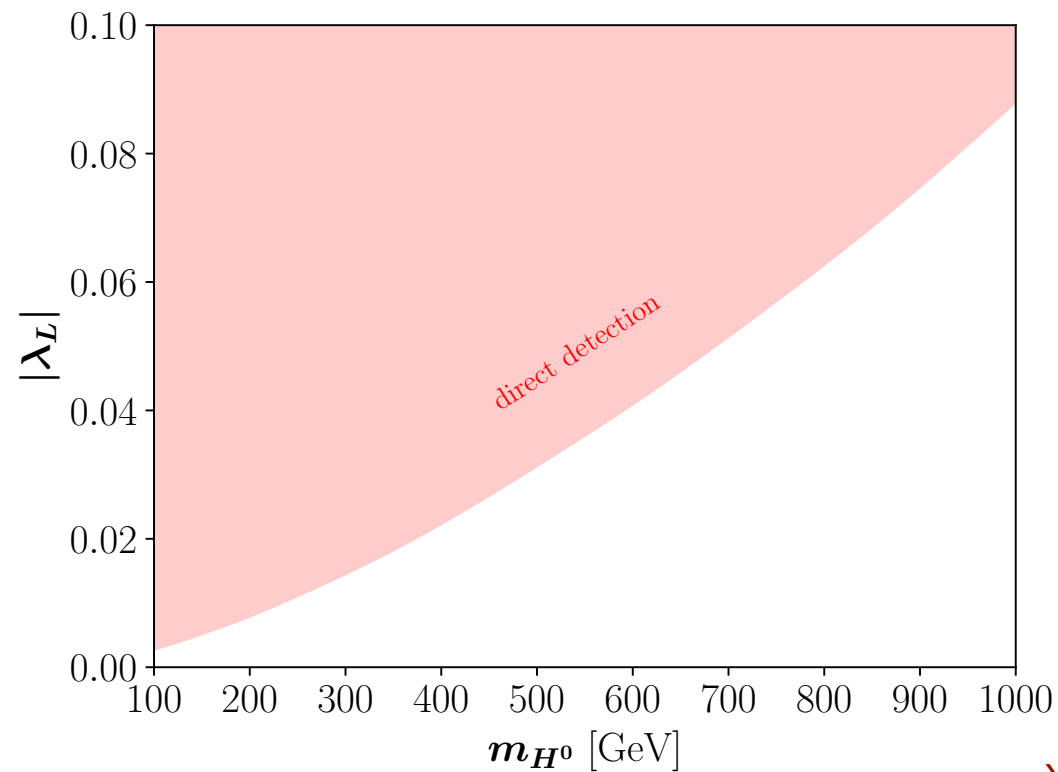
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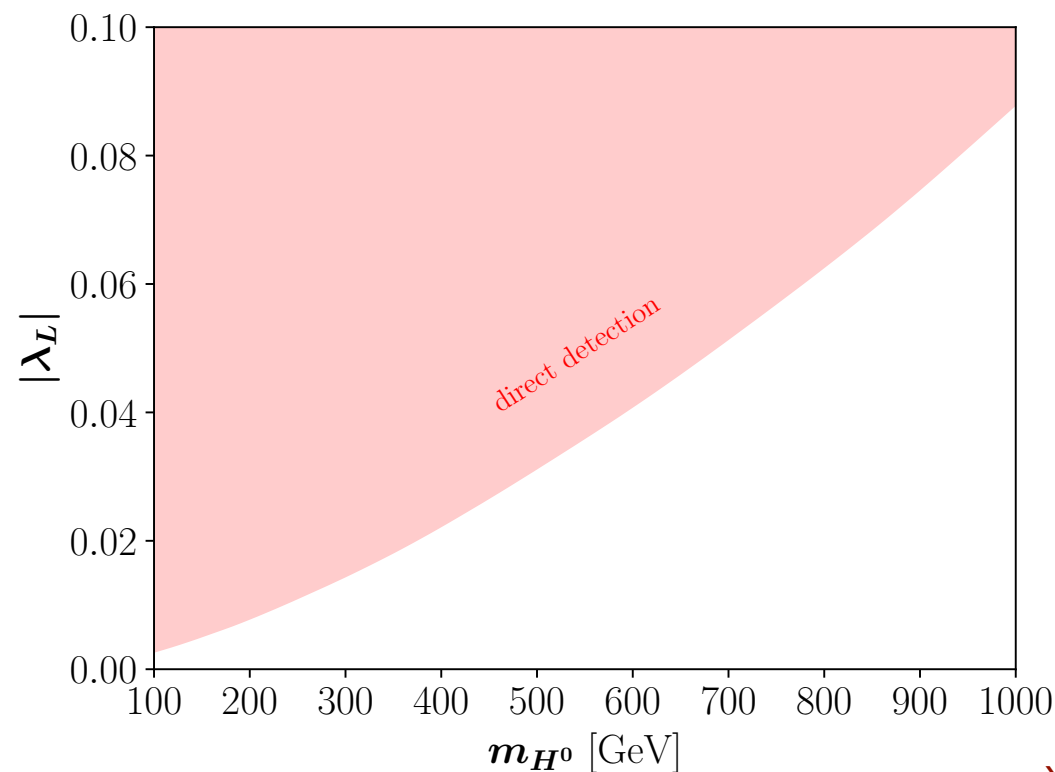
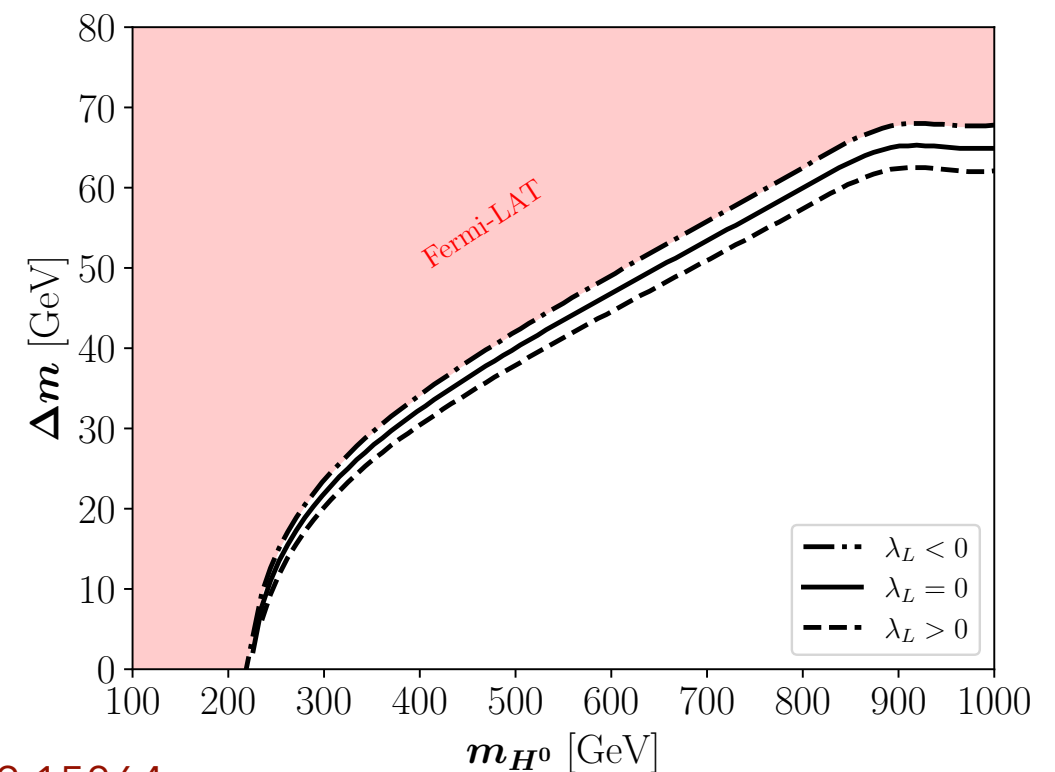


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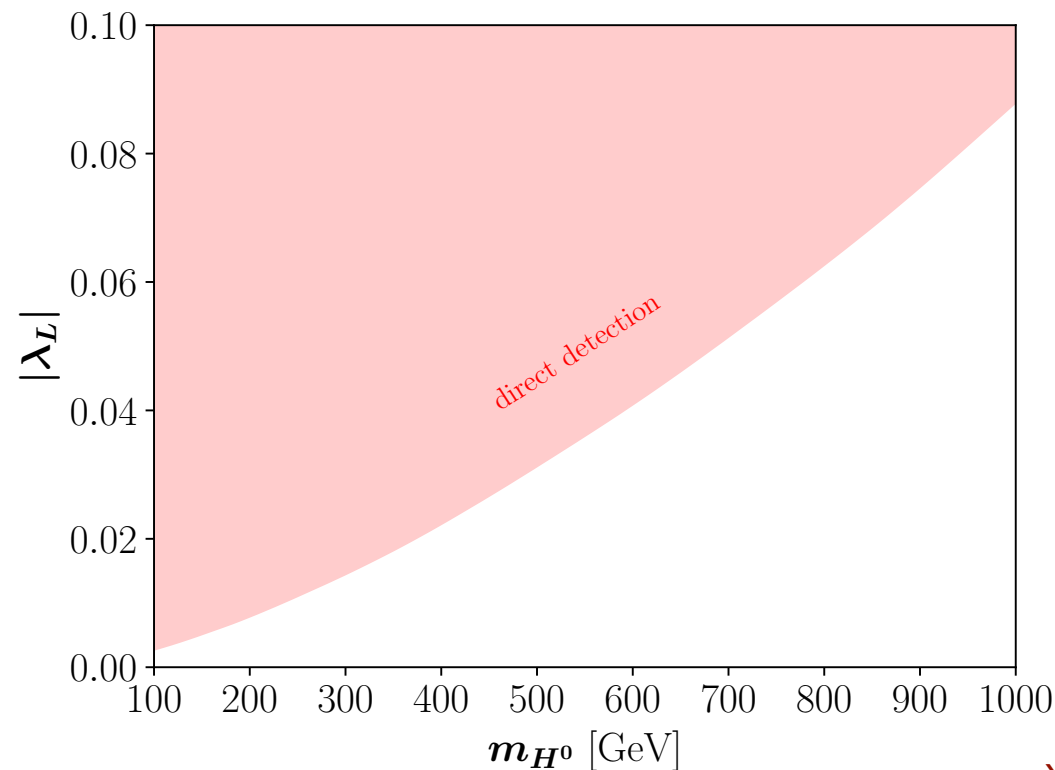
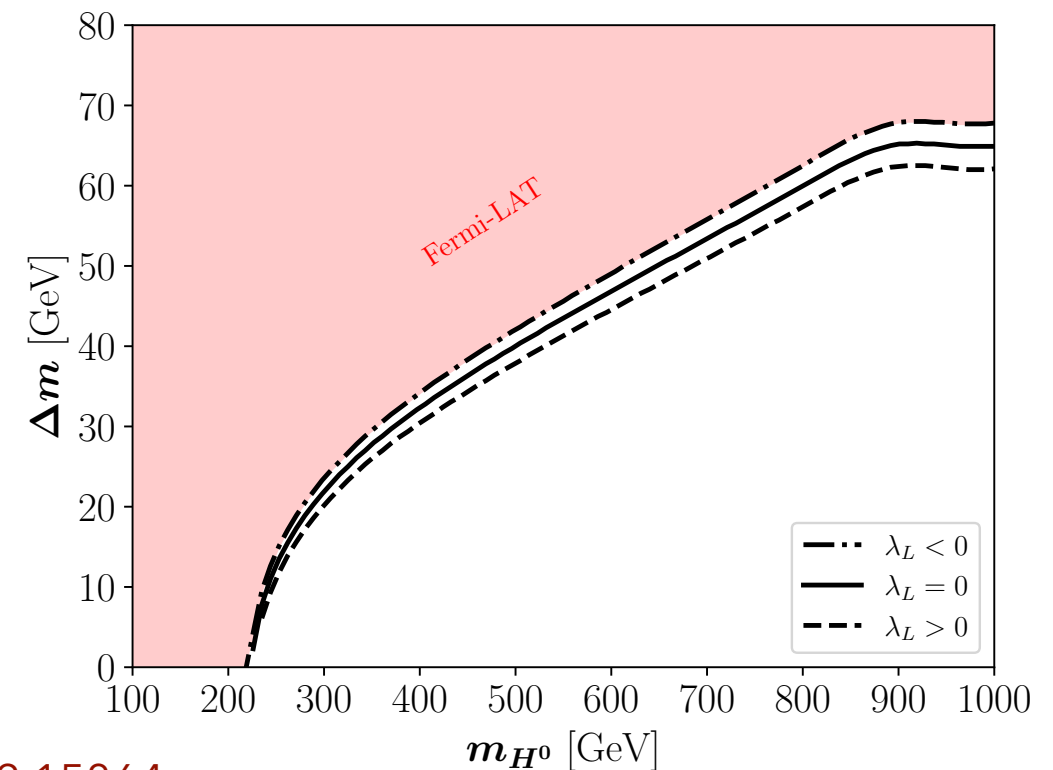


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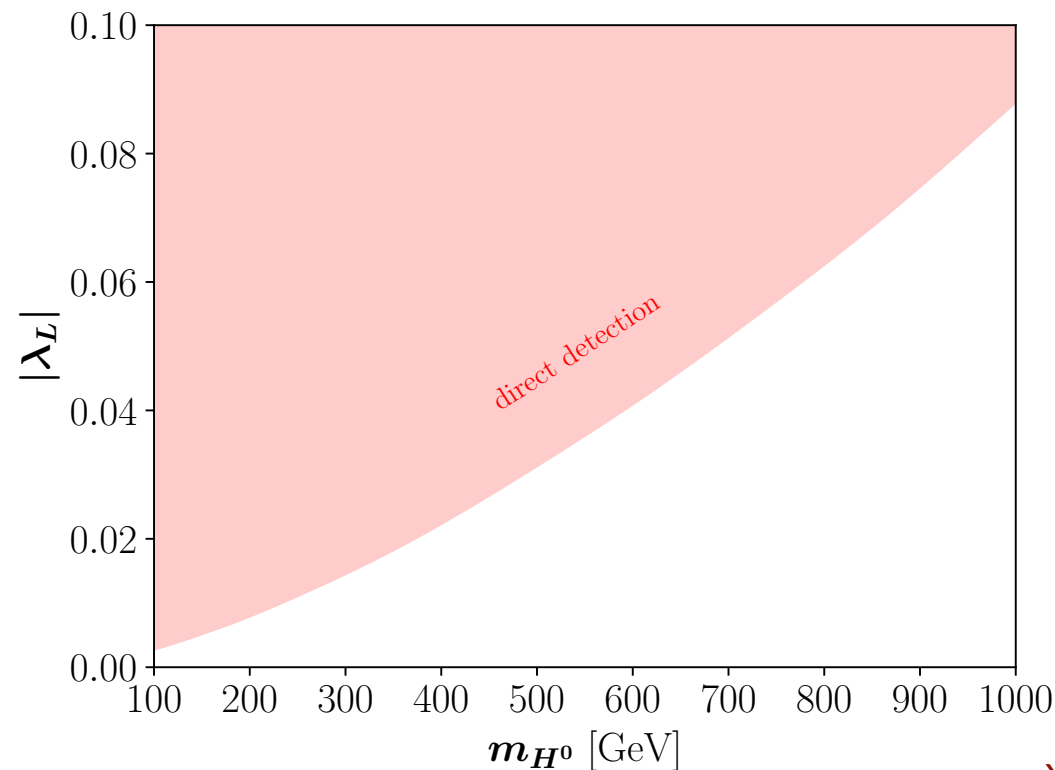
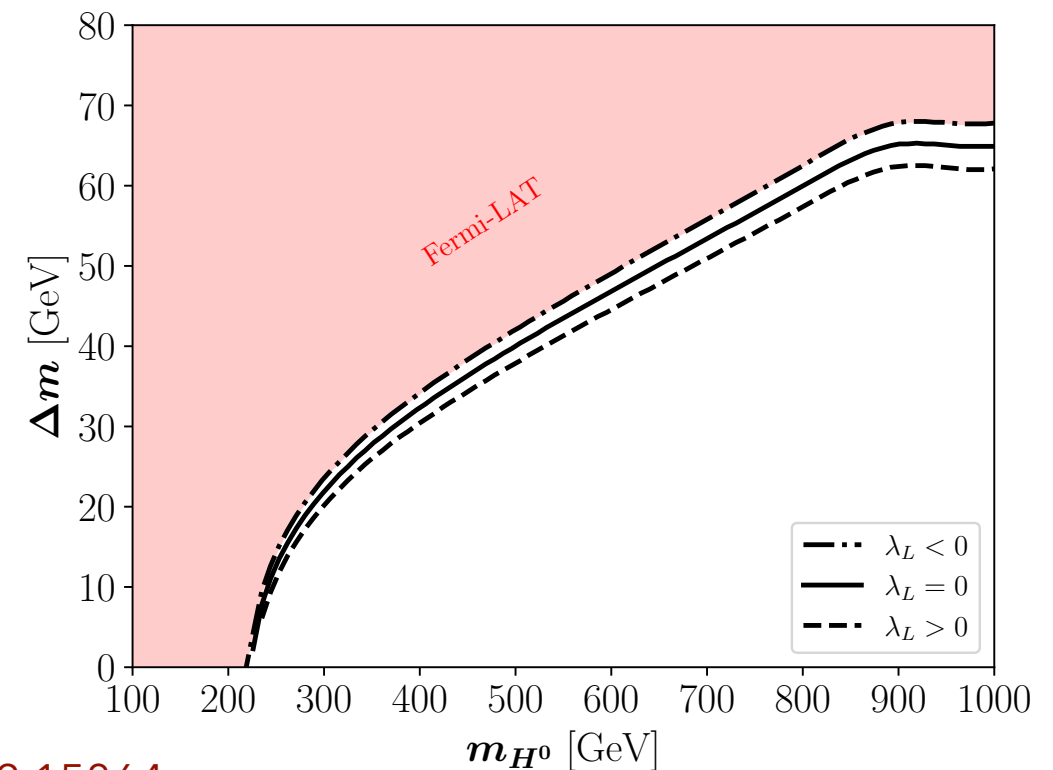


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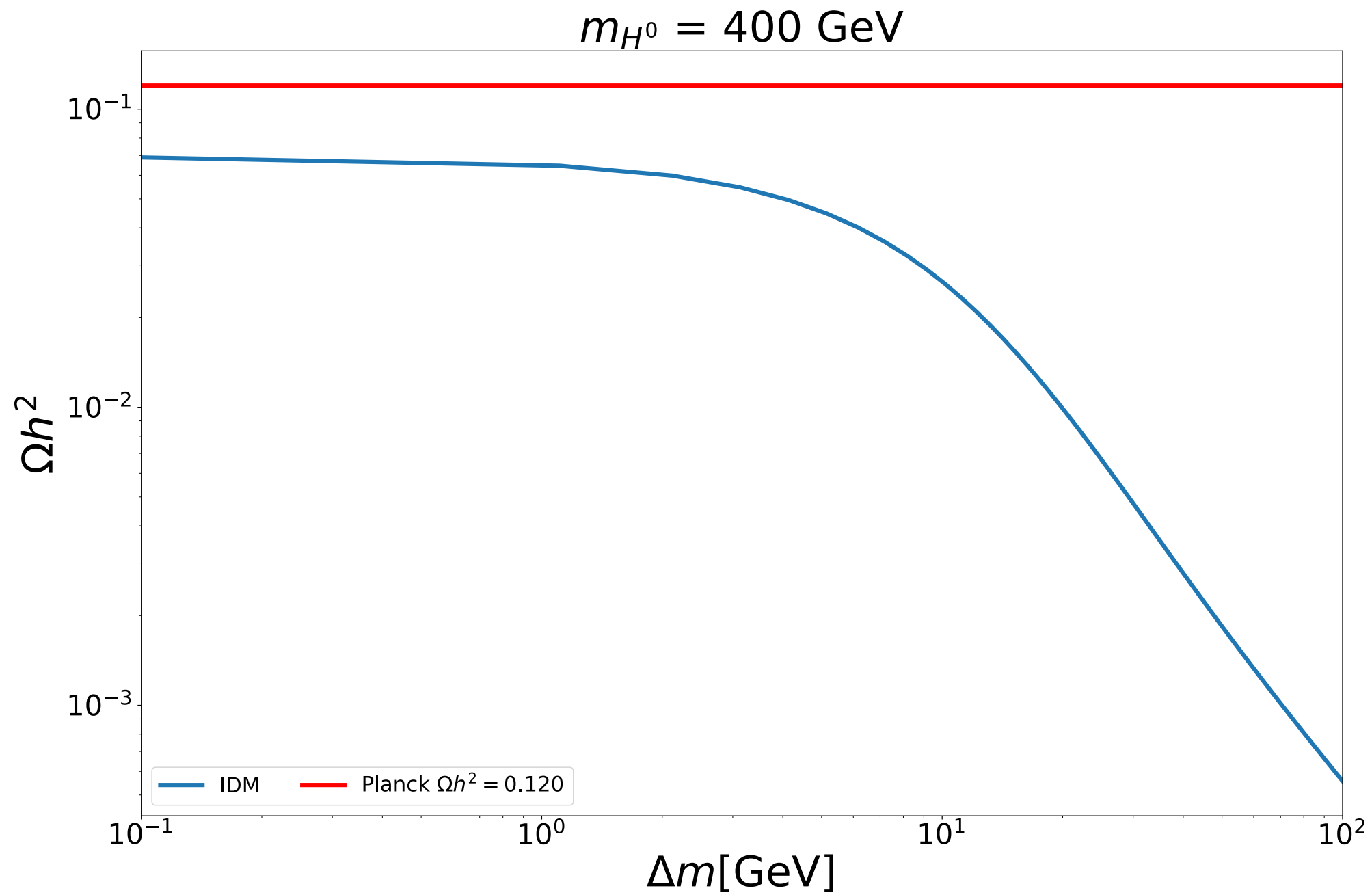
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- $m_{H^0} \gtrsim 500$ GeV from relic + DD

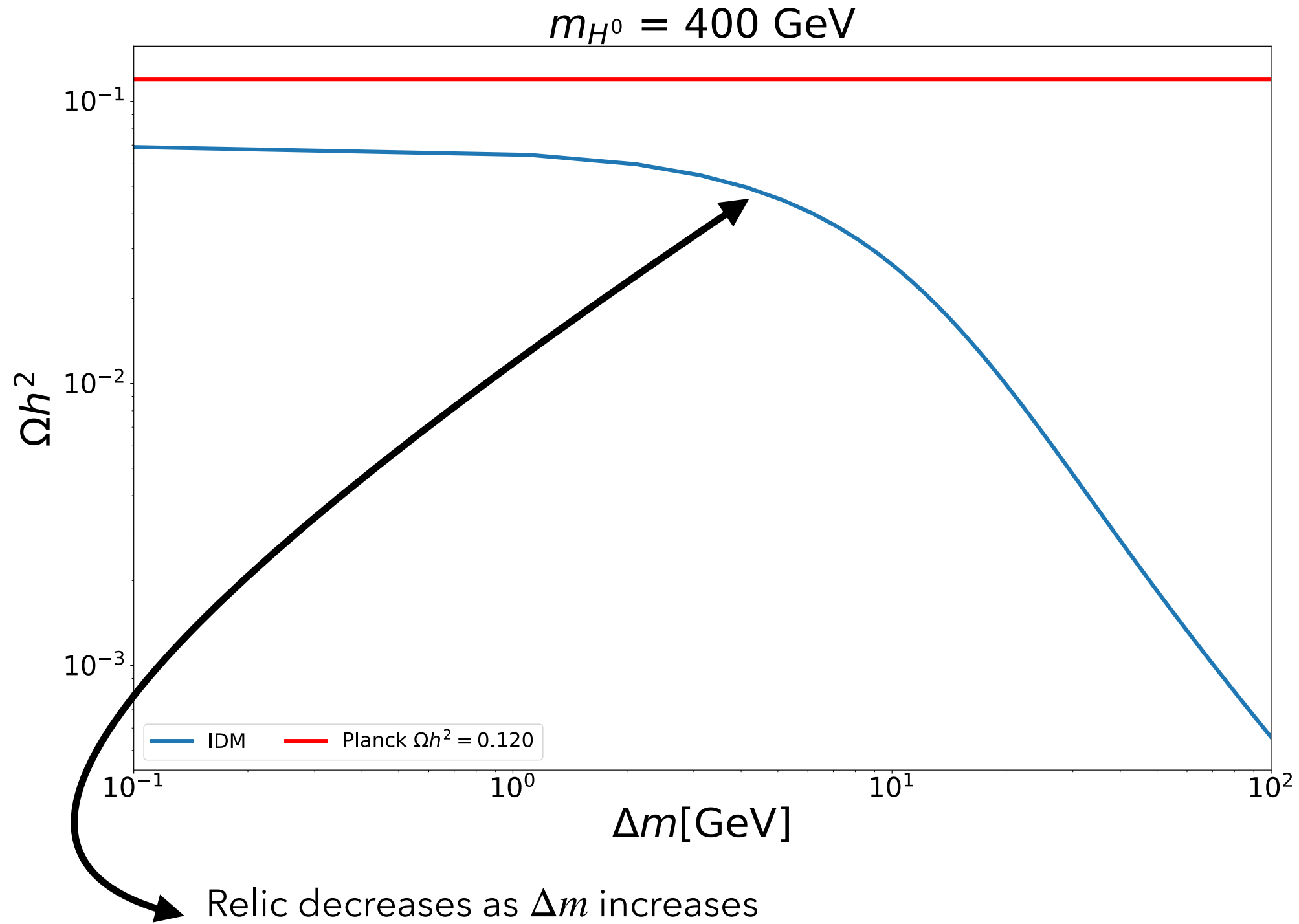


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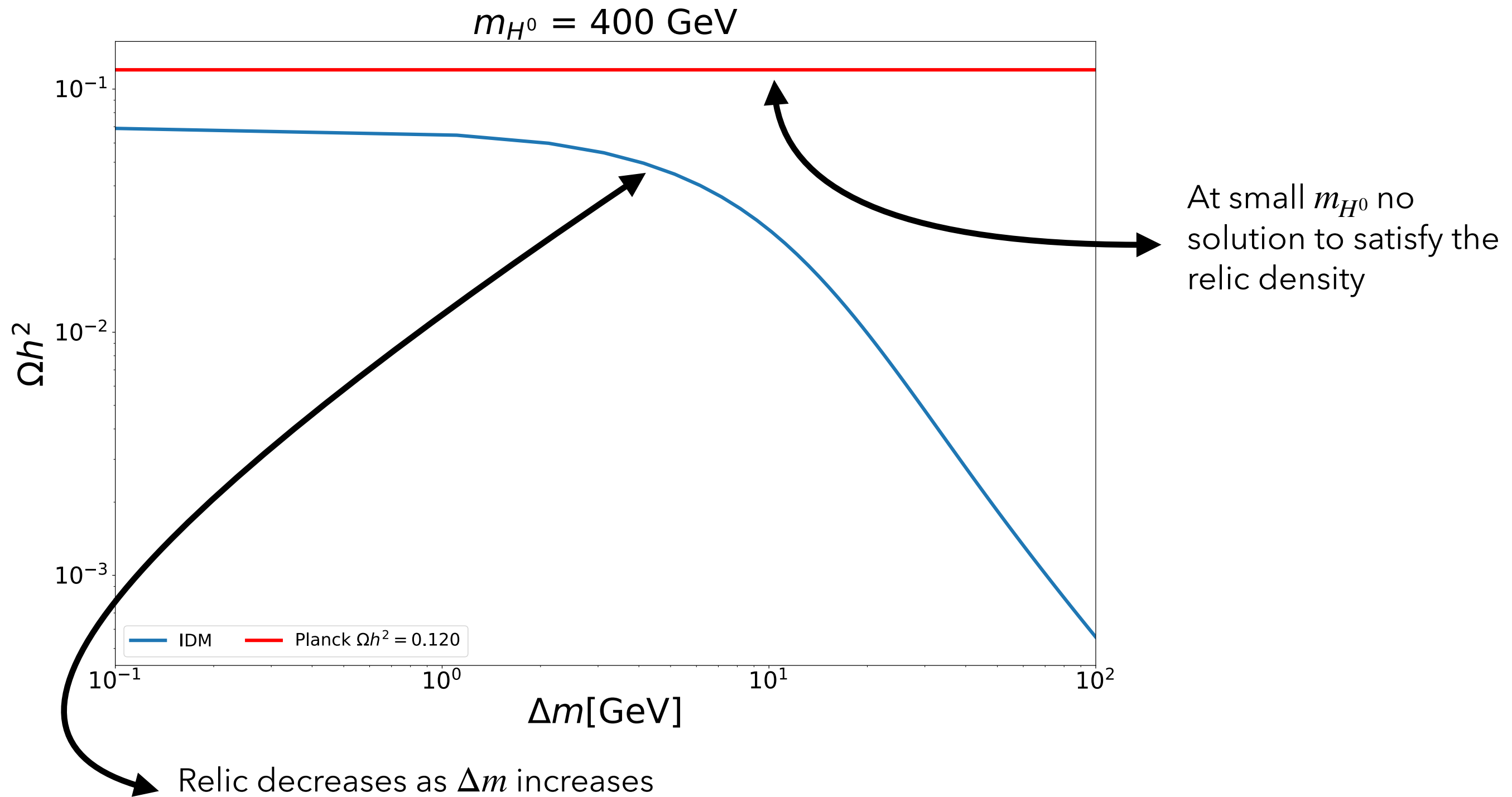
Relic density with thermal freeze-out



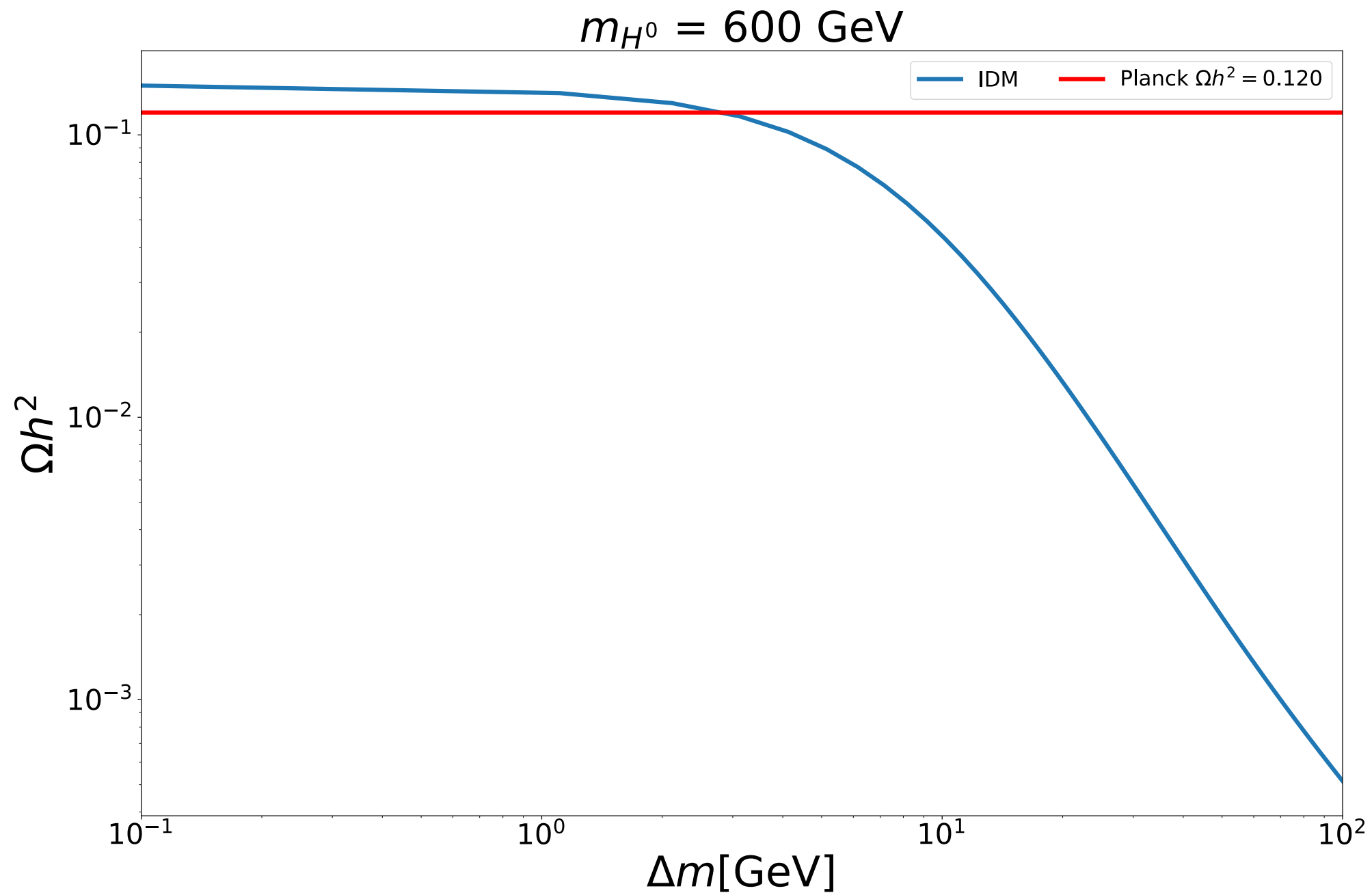
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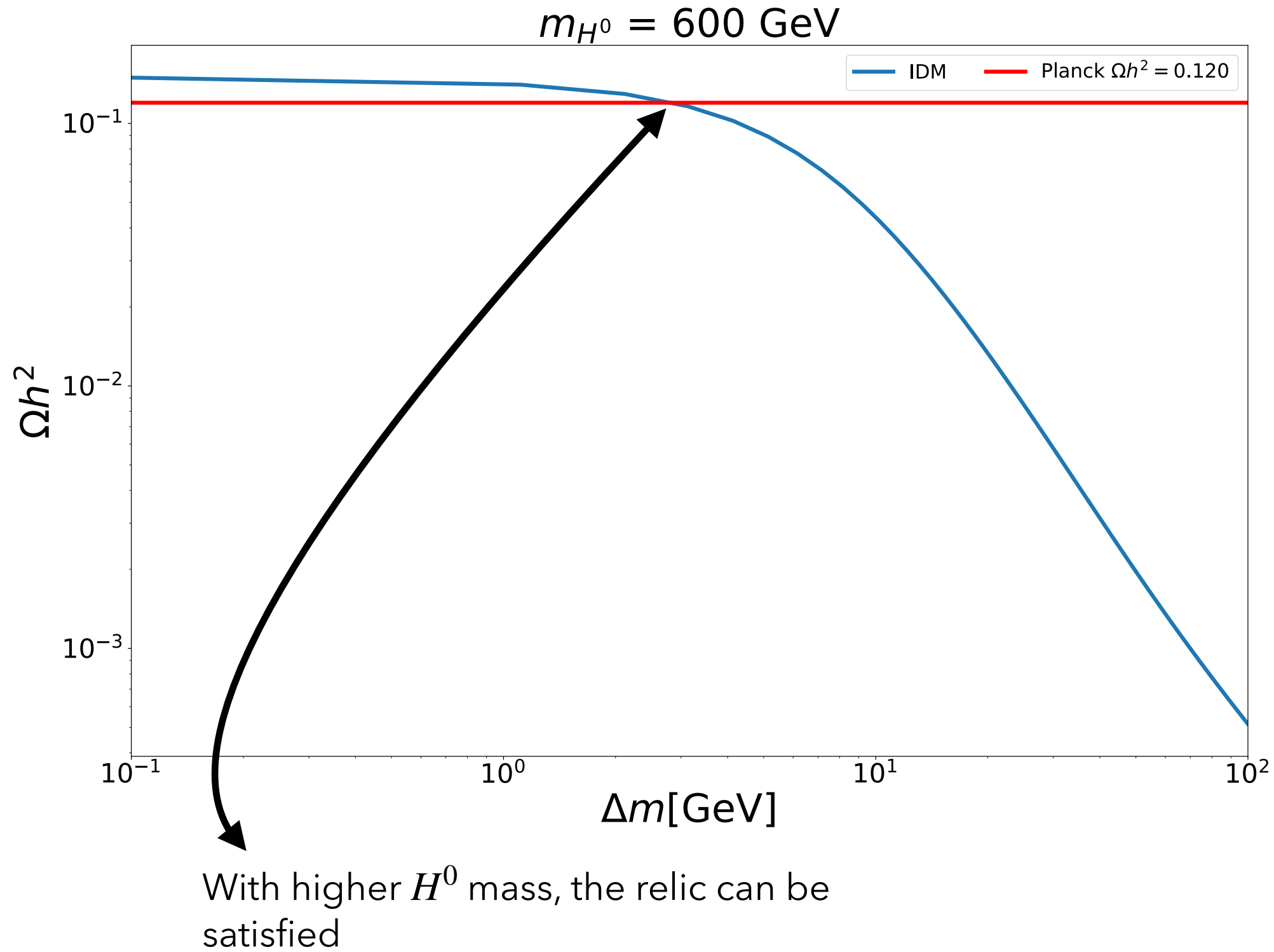
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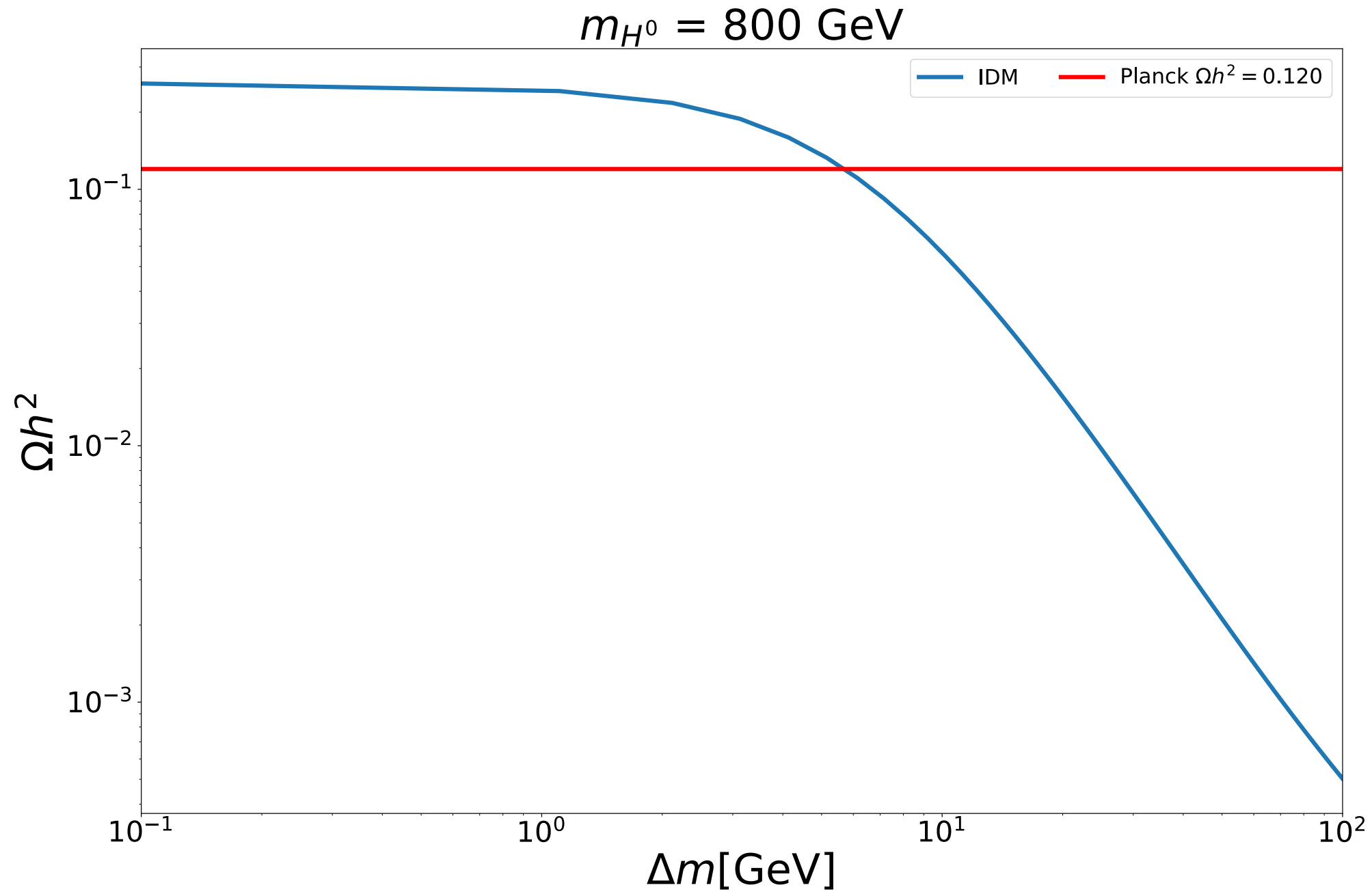
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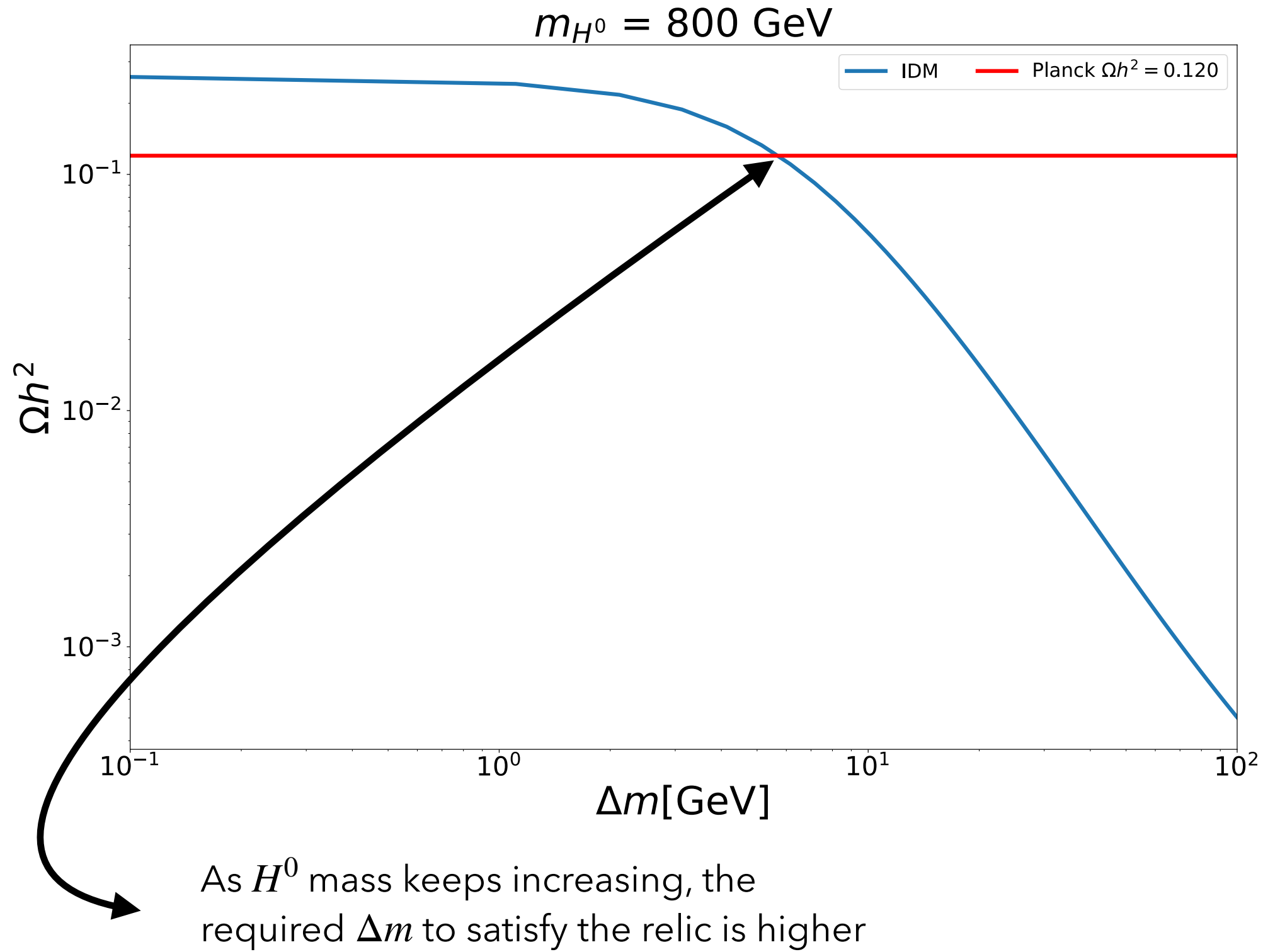
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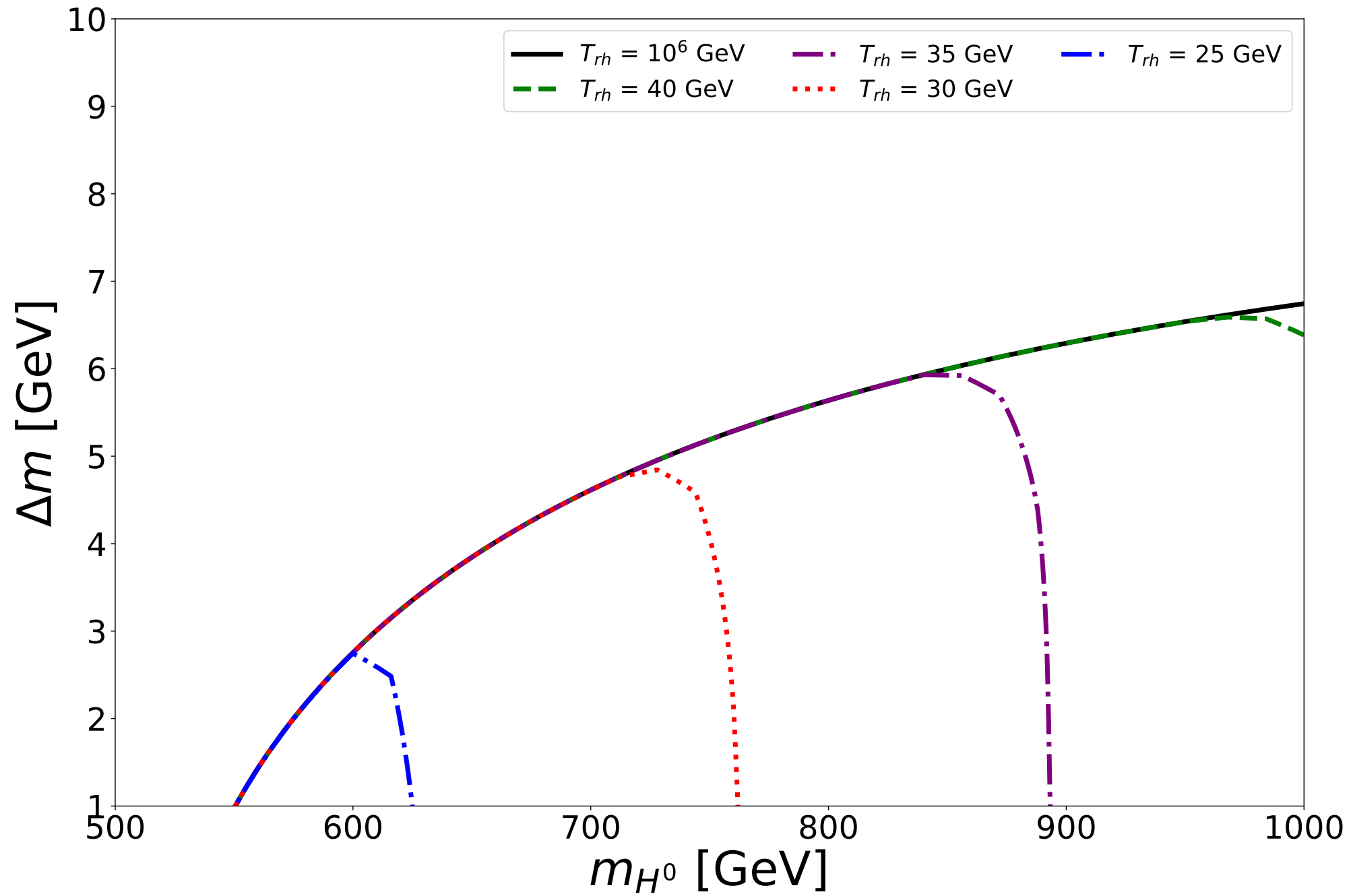
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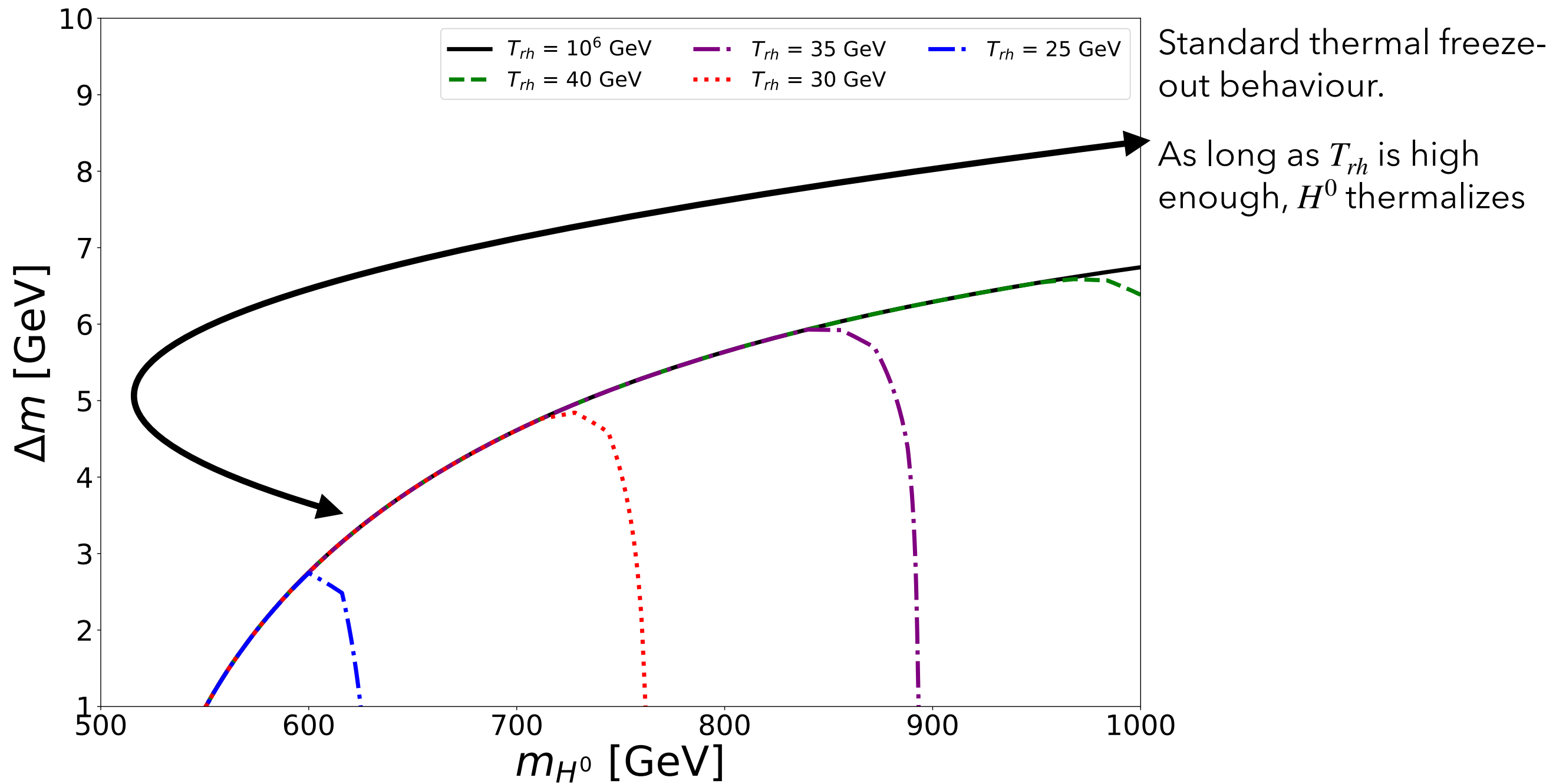
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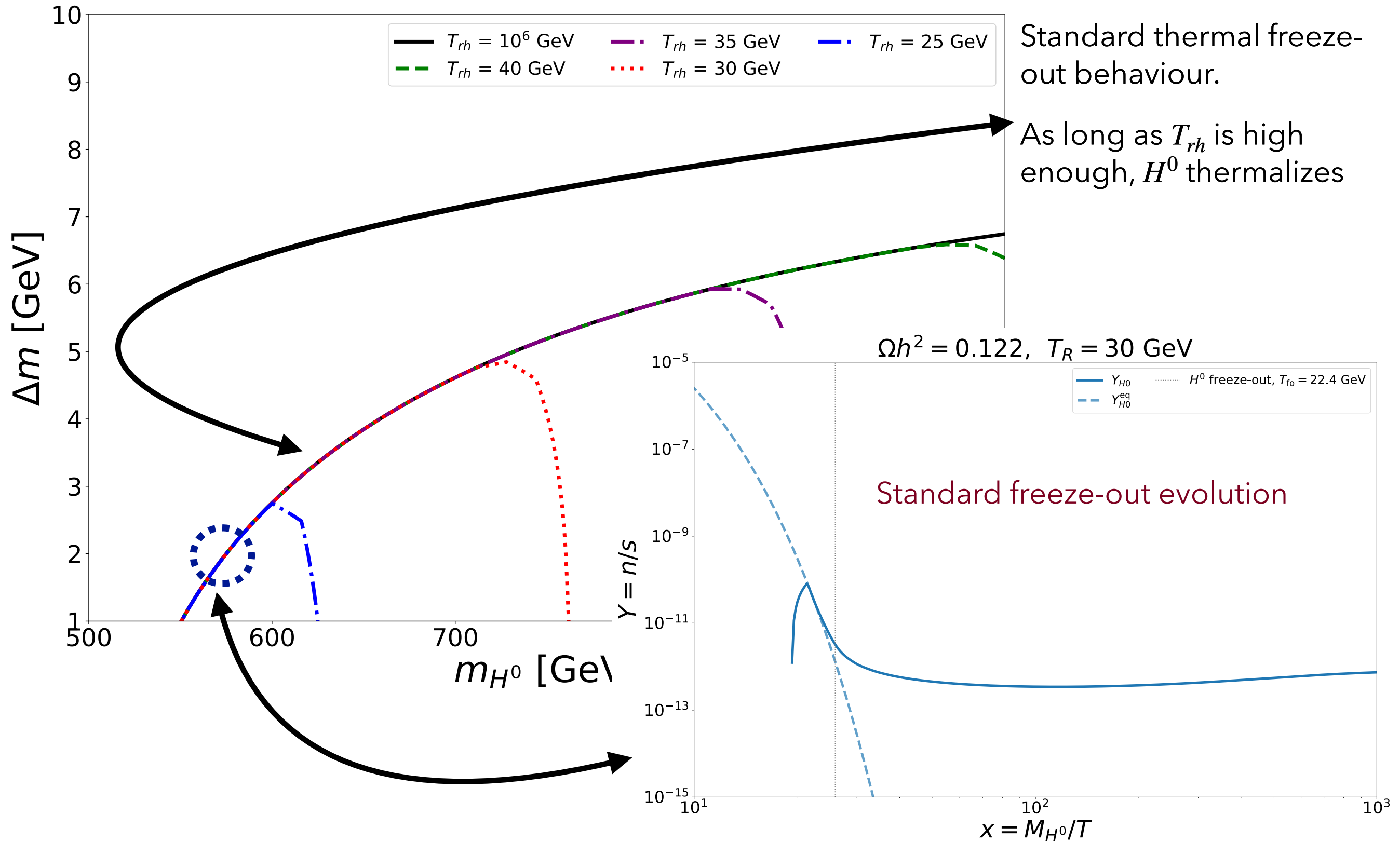
Relic density with low instantaneous reheating



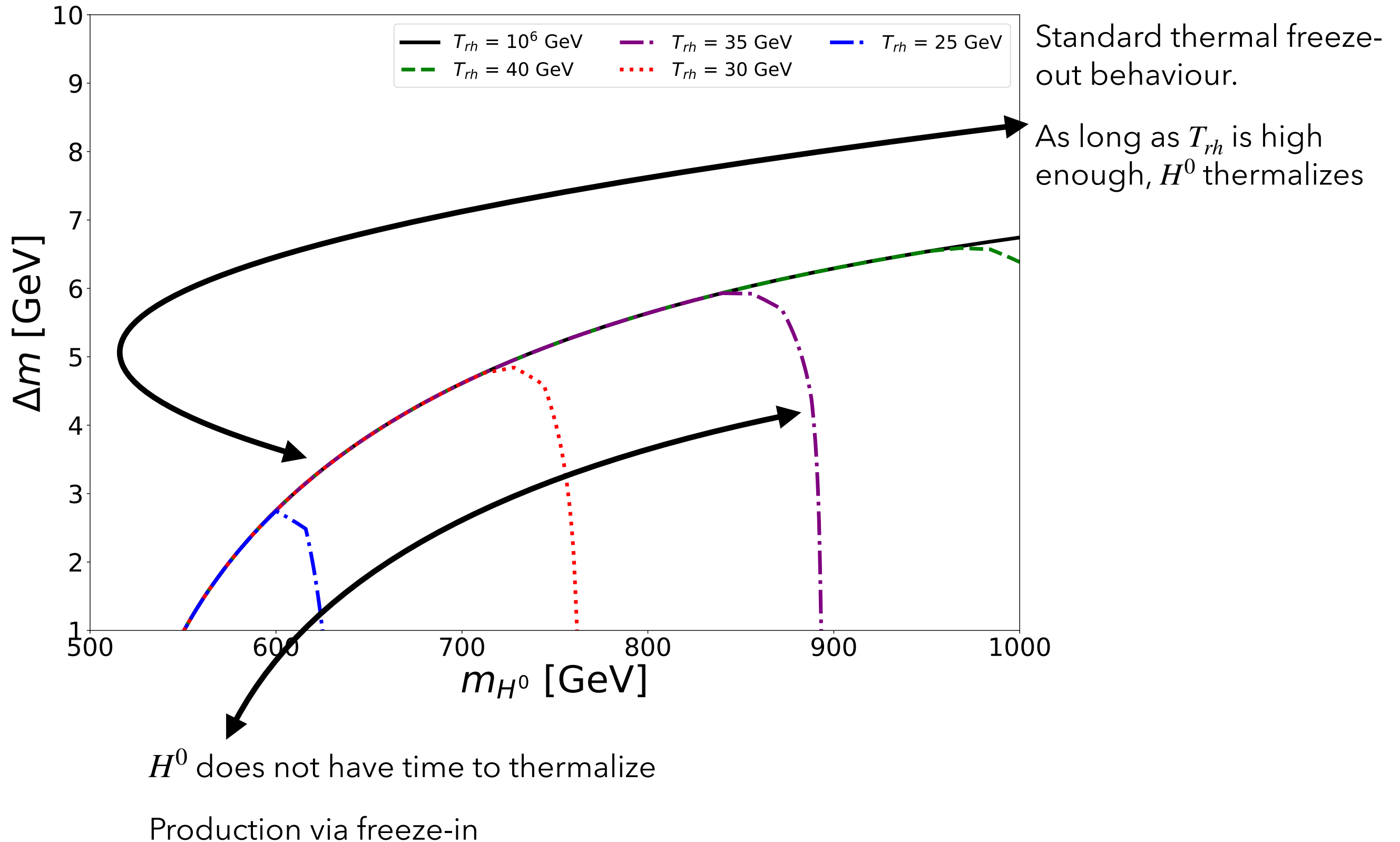
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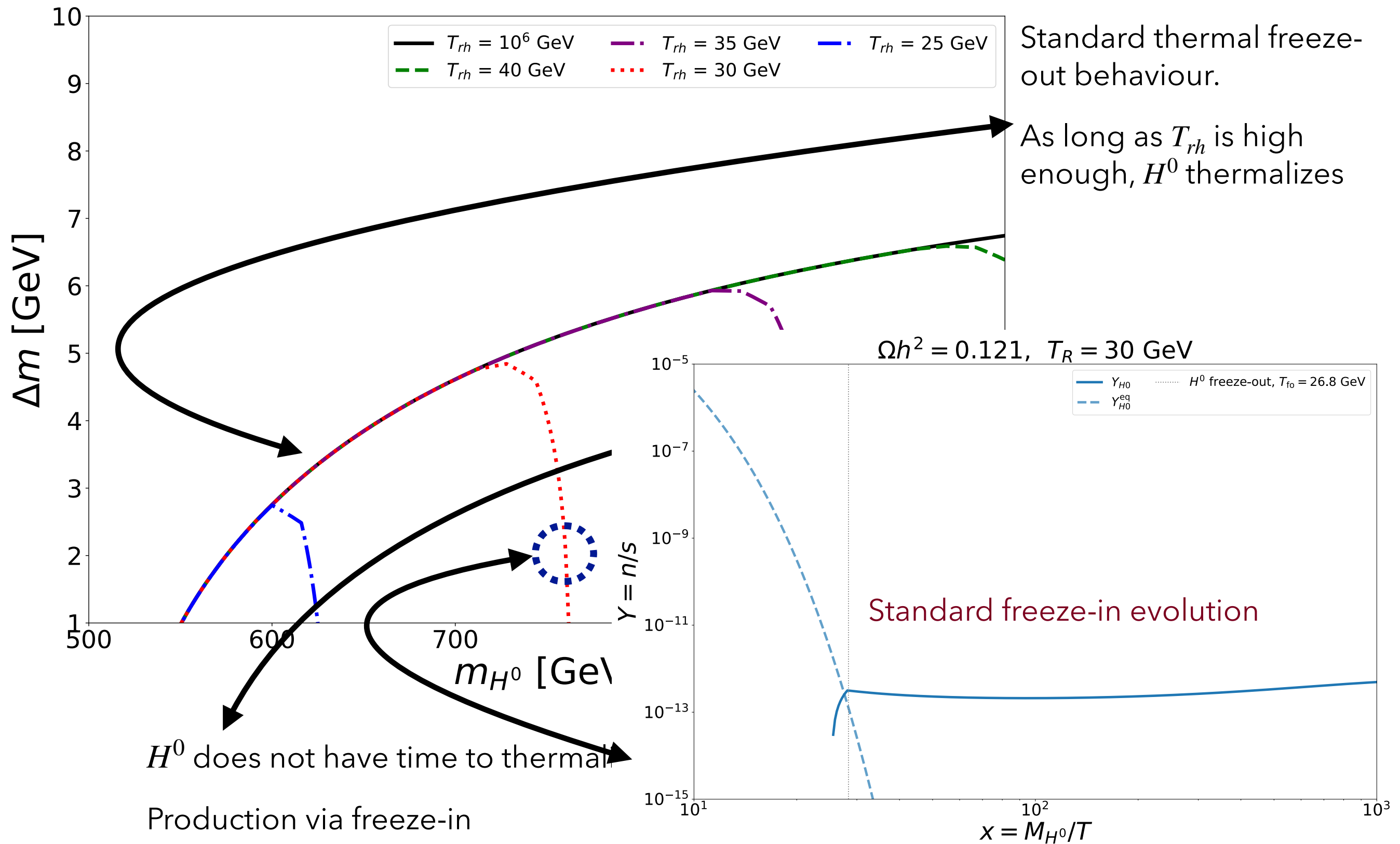
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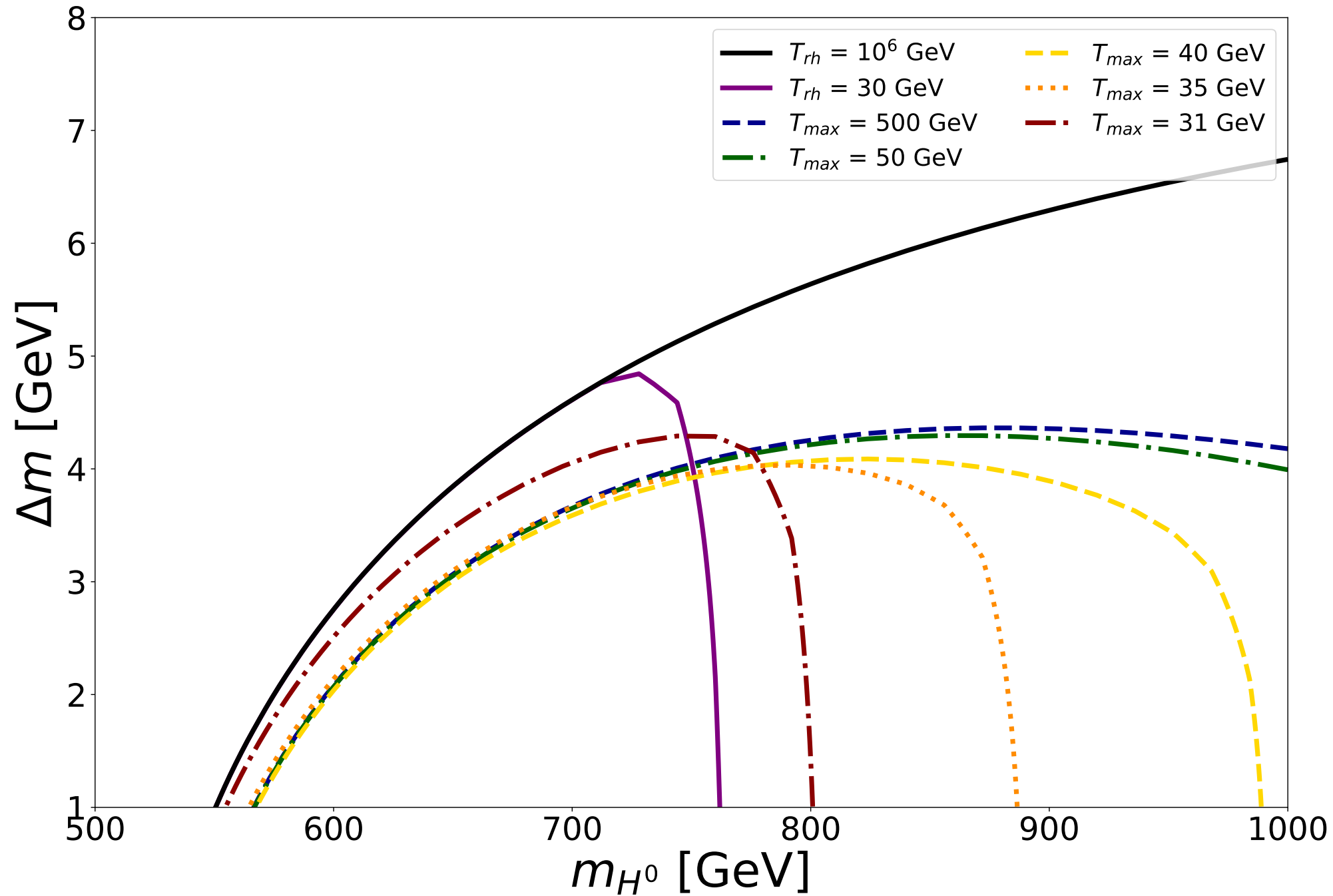
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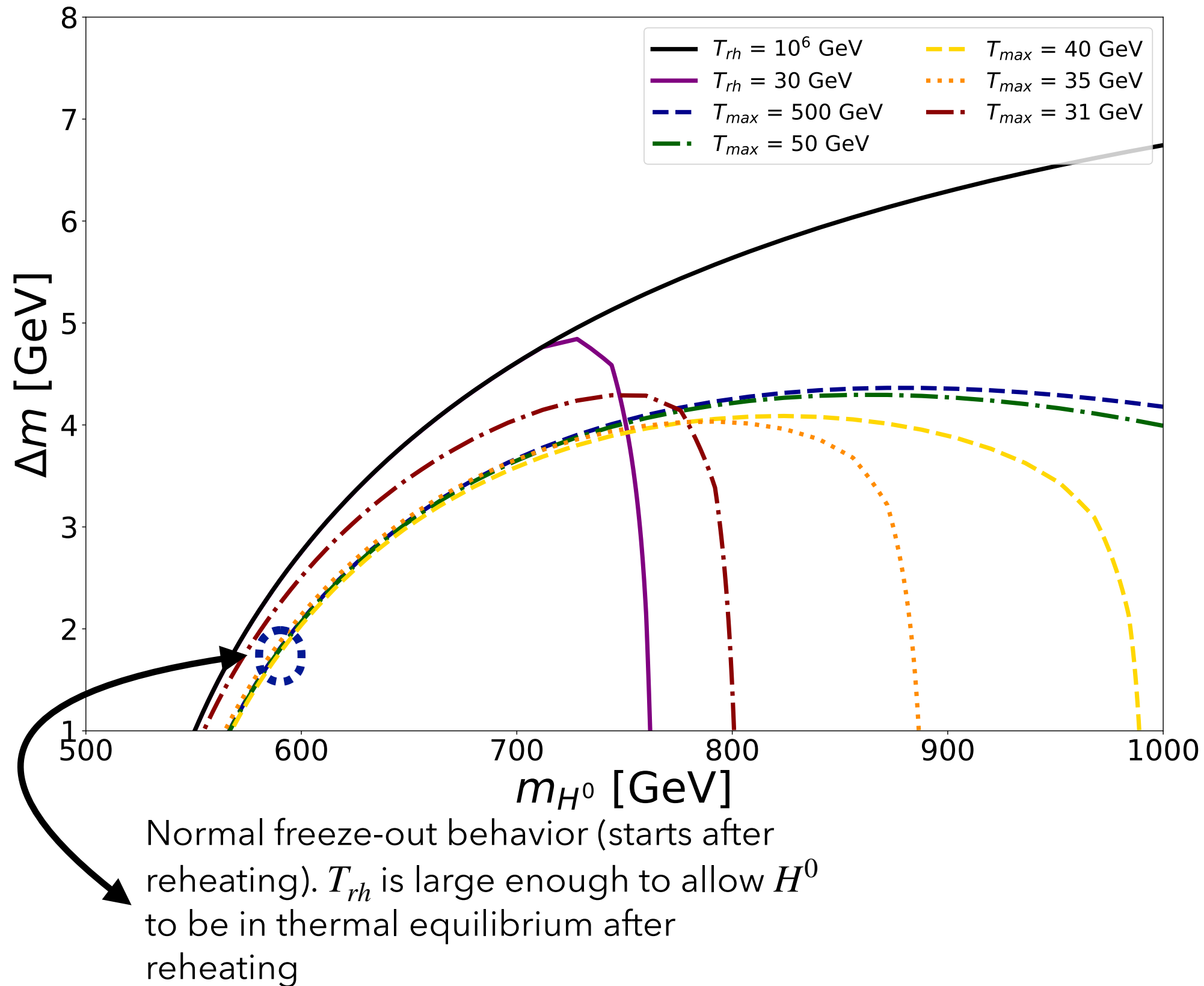
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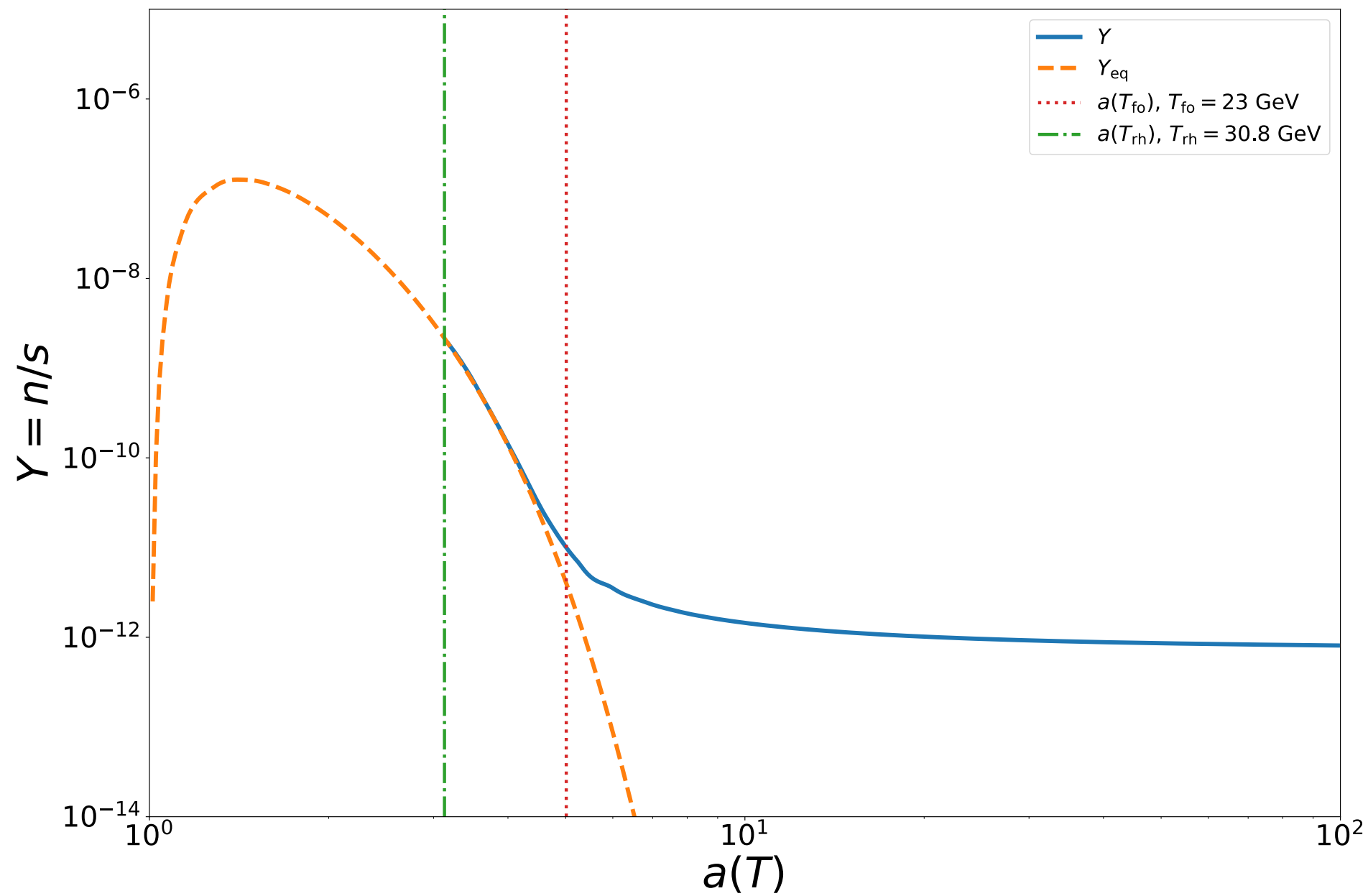
Relic density with non-instantaneous reheating(1)



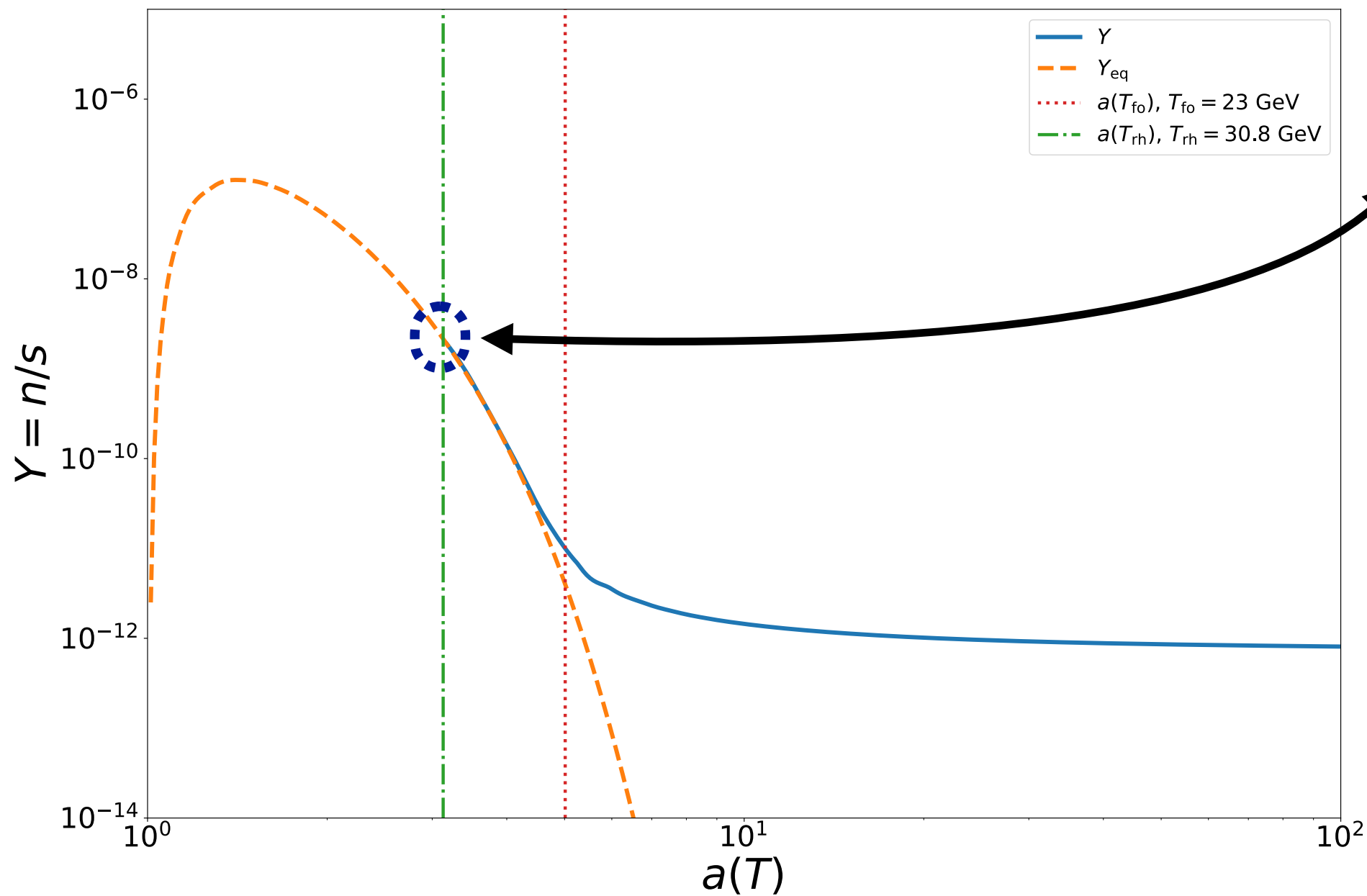
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Abundance evolution : FO after reheating

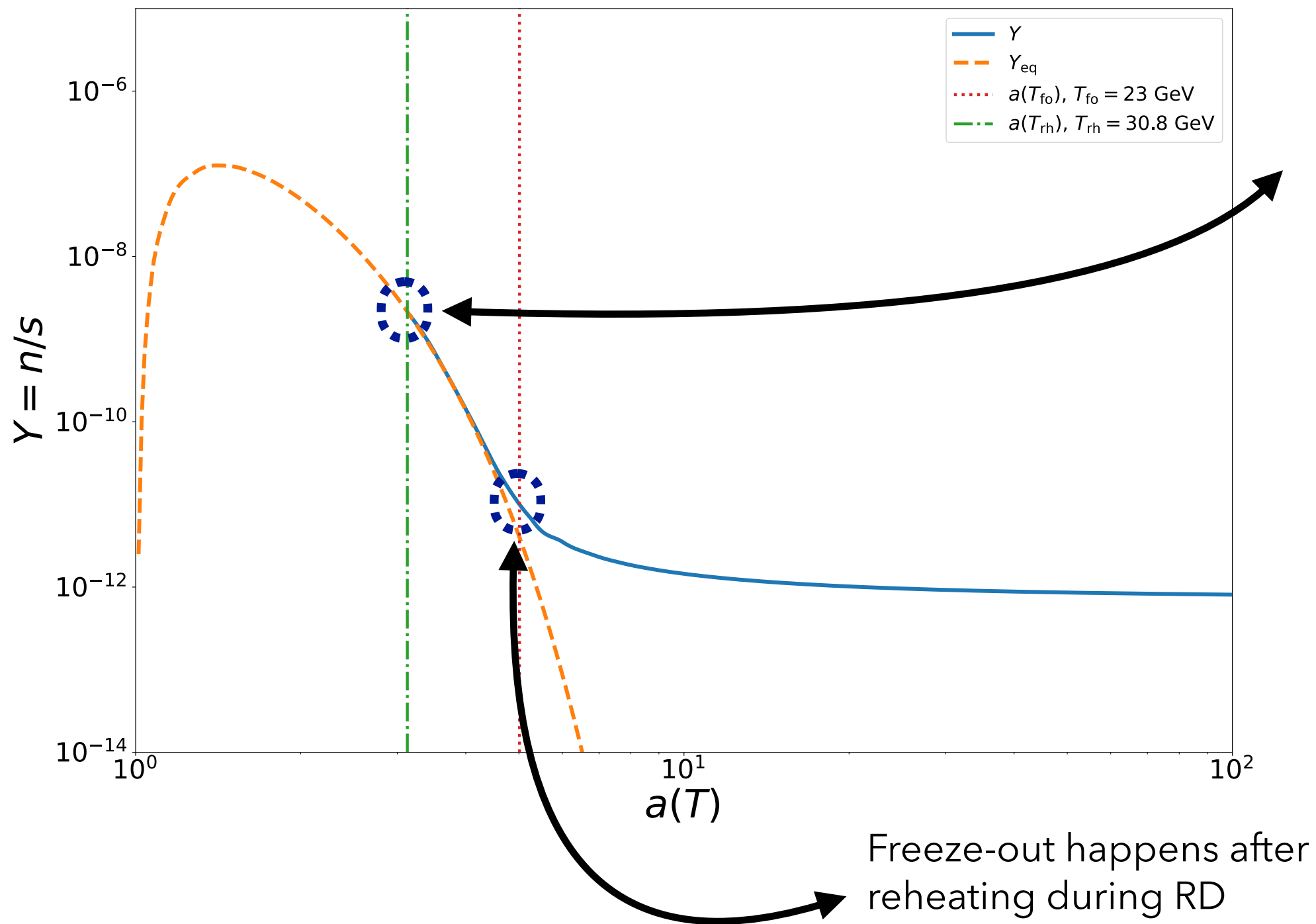


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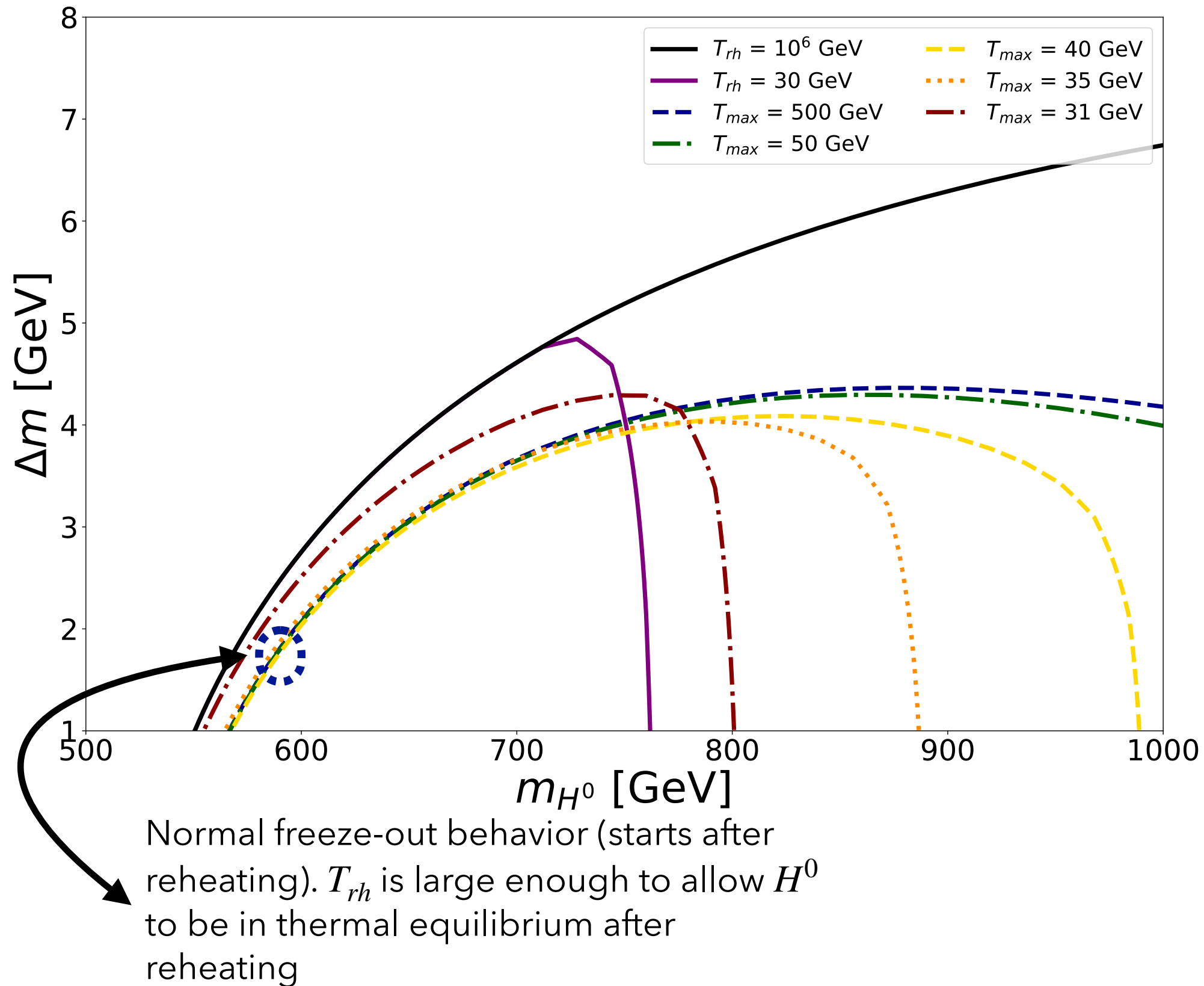


At T_{rh} , the dark matter density is in equilibrium

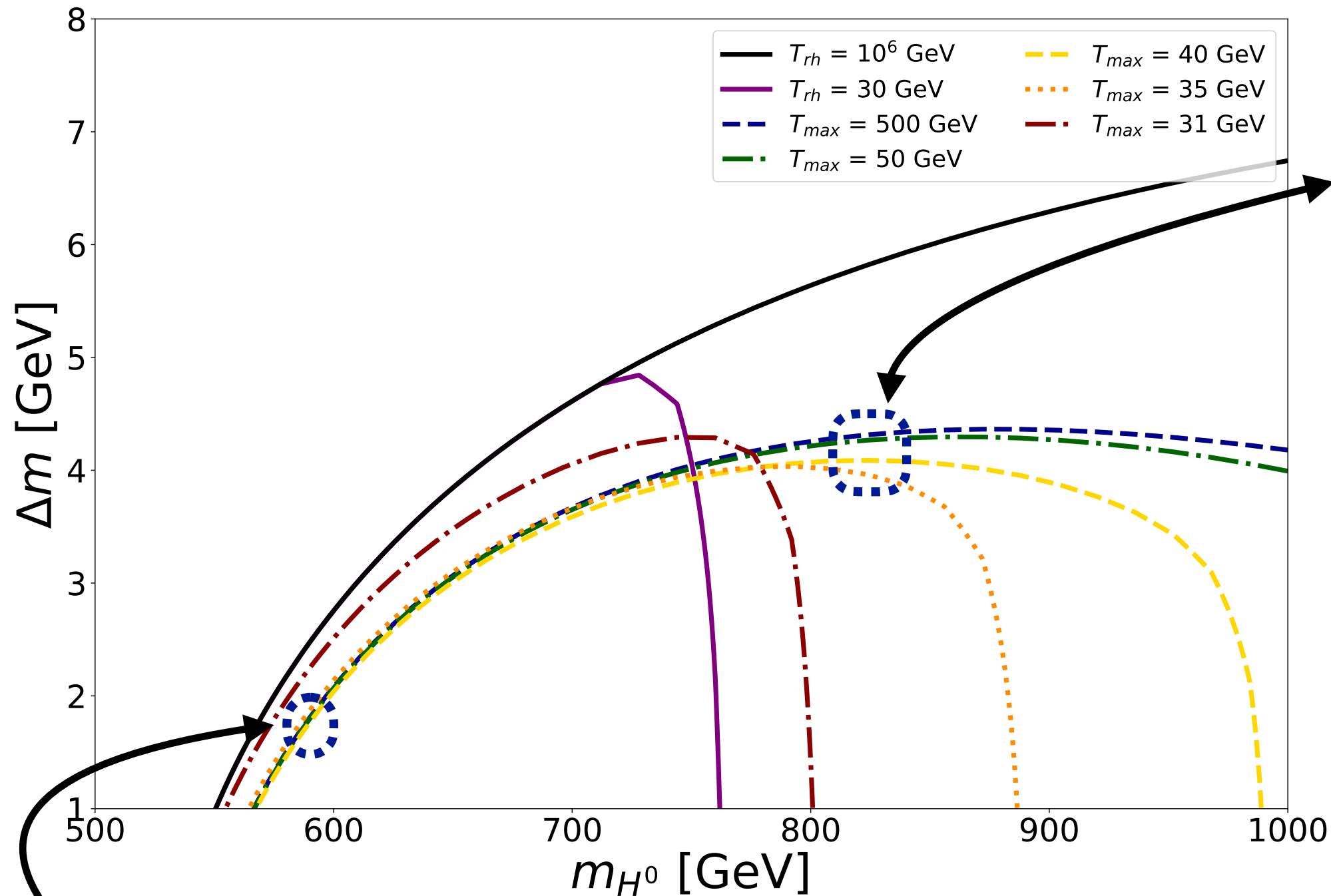
Abundance evolution : FO after reheating



Relic density with non-instantaneous reheating(2)



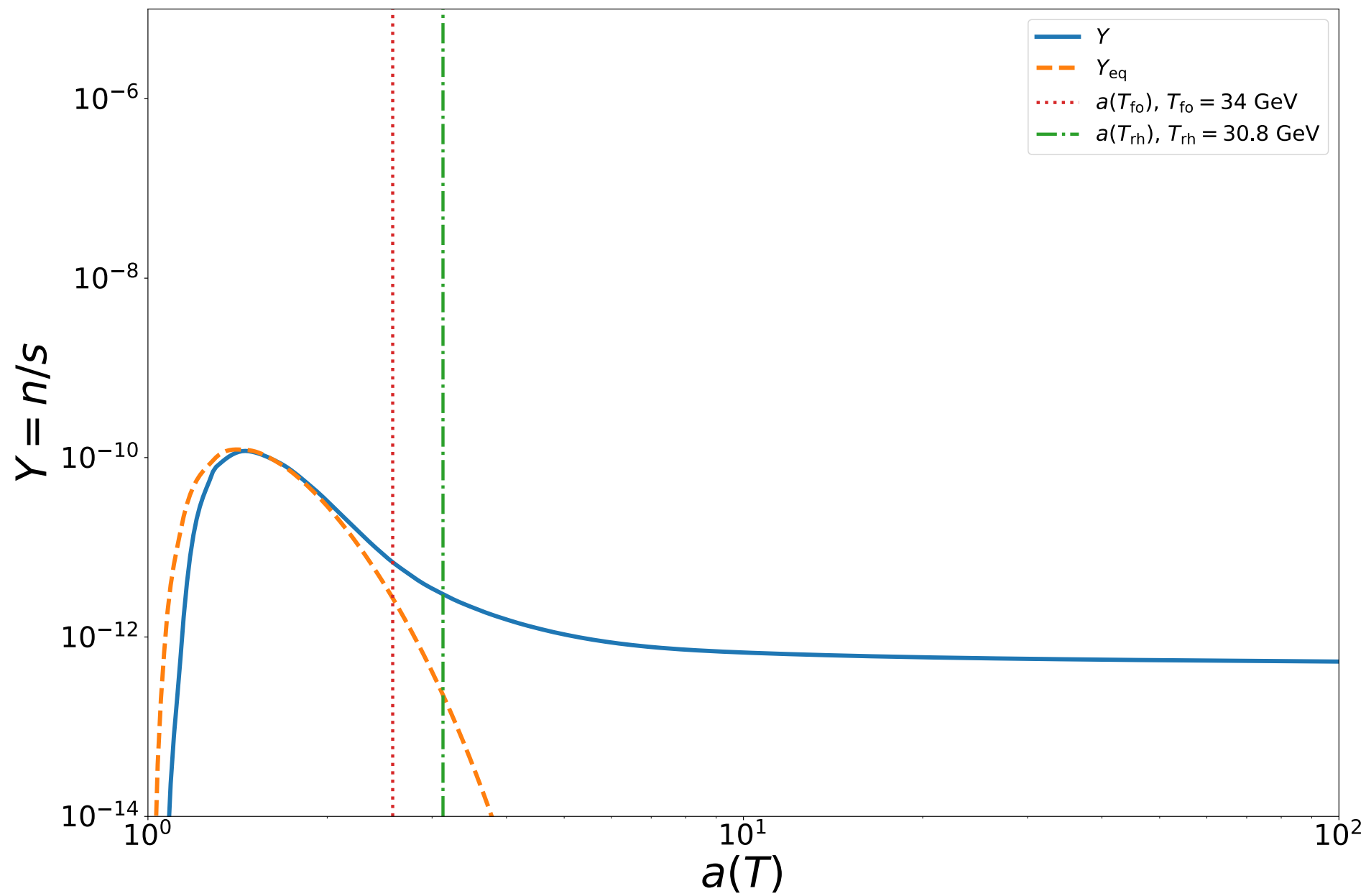
Relic density with non-instantaneous reheating(2)



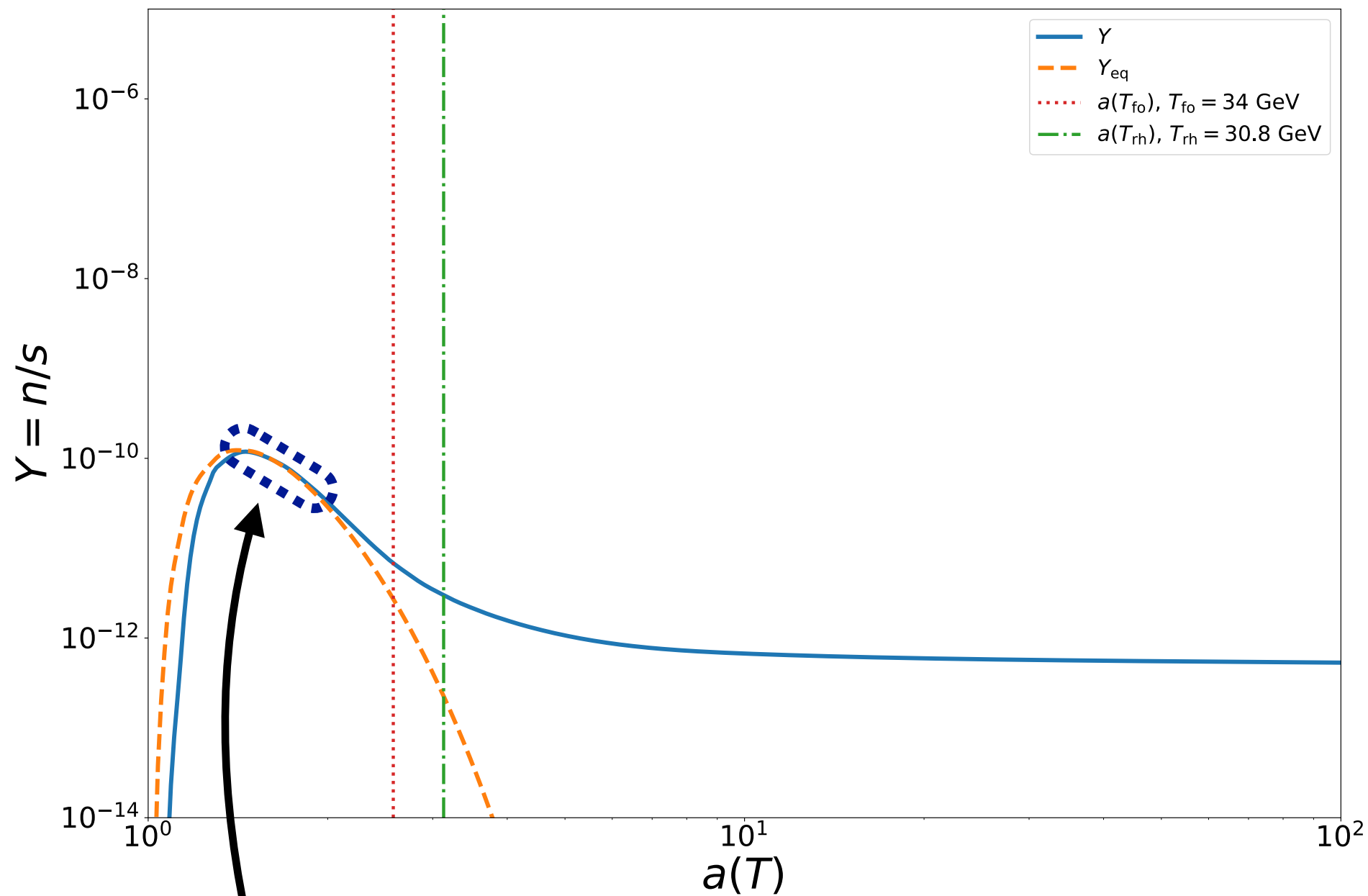
T_{fo} is higher than T_{rh} . Freeze-out happens during reheating. T_{max} is large enough for H^0 to thermalize during reheating

Normal freeze-out behavior (starts after reheating). T_{rh} is large enough to allow H^0 to be in thermal equilibrium after reheating

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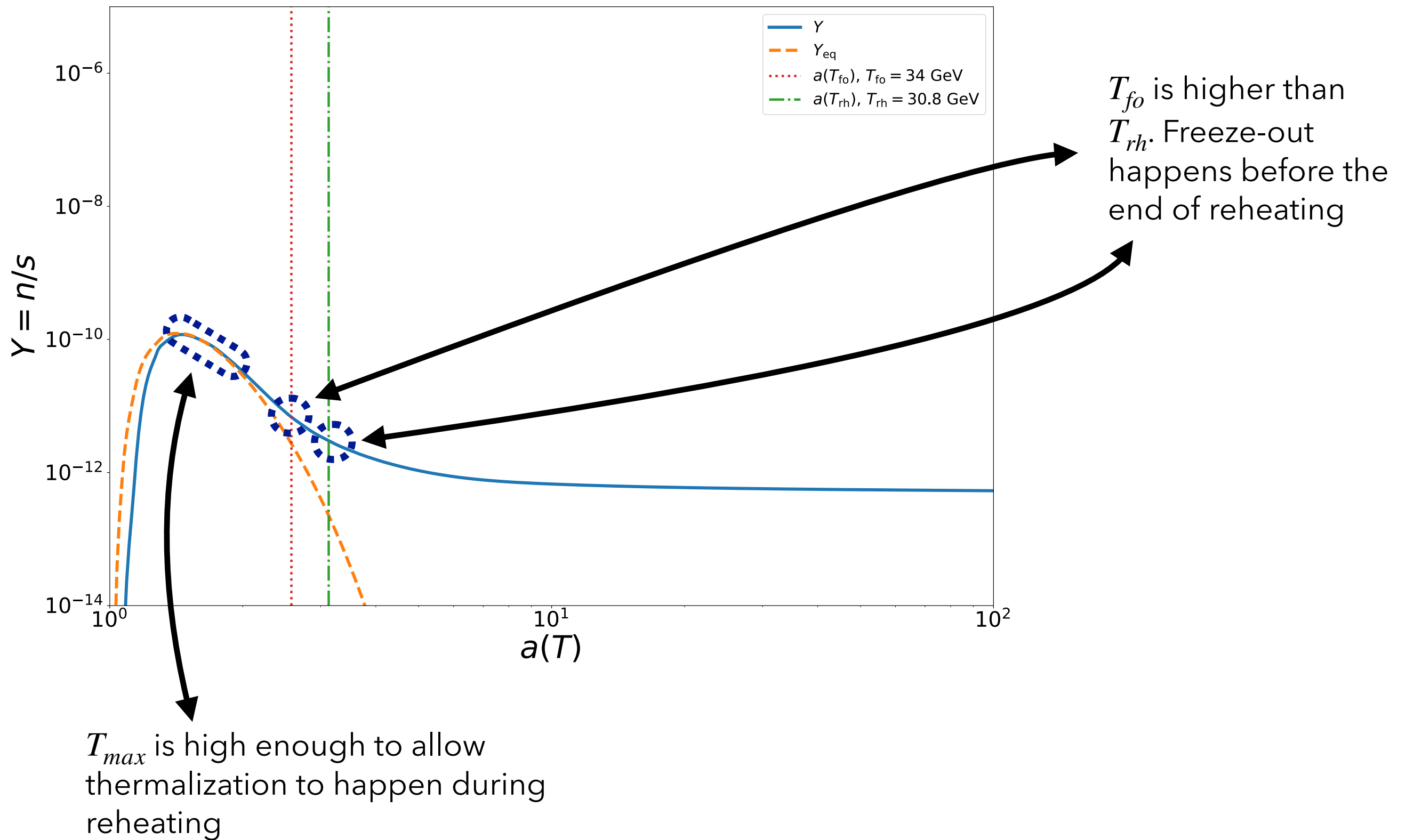


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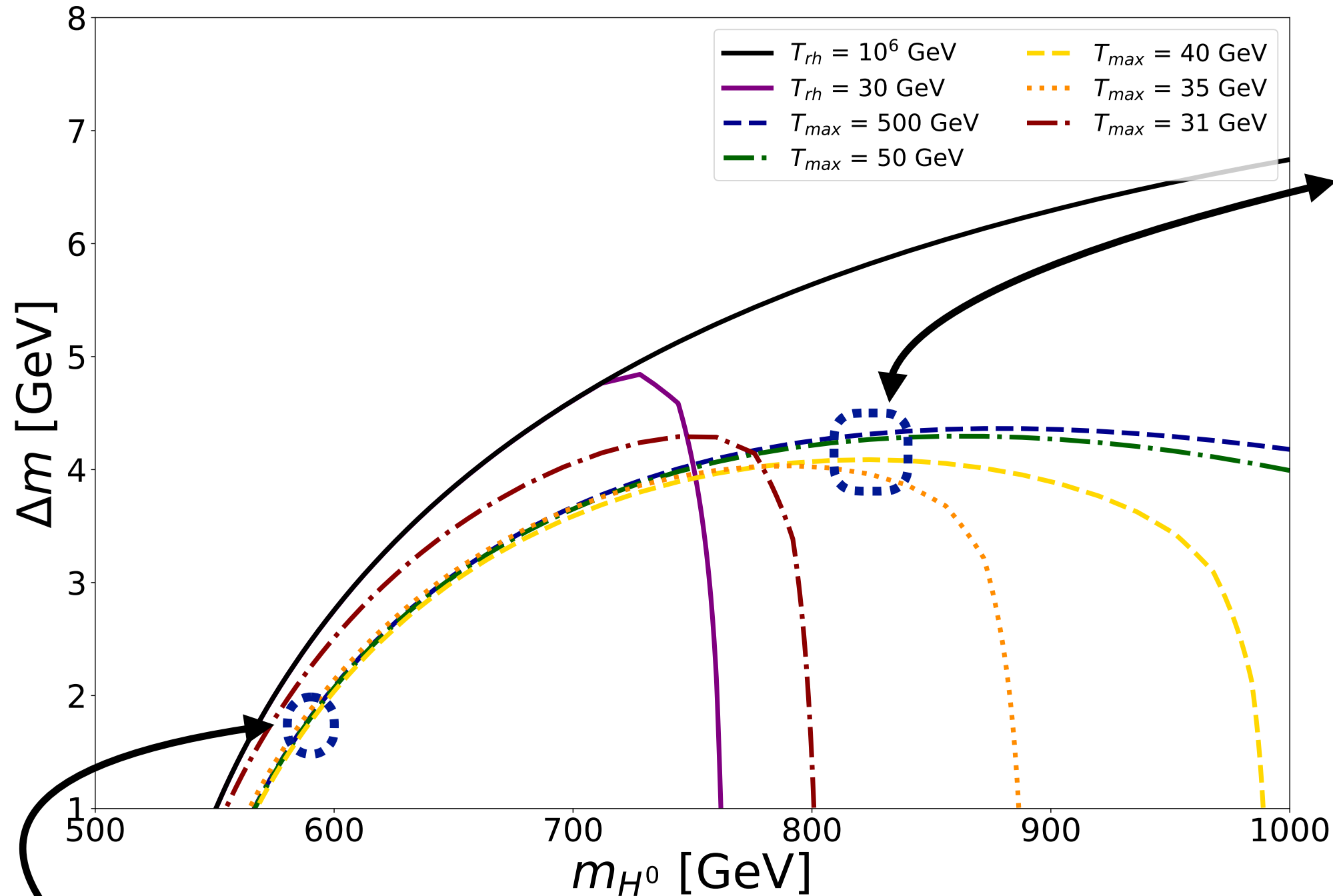


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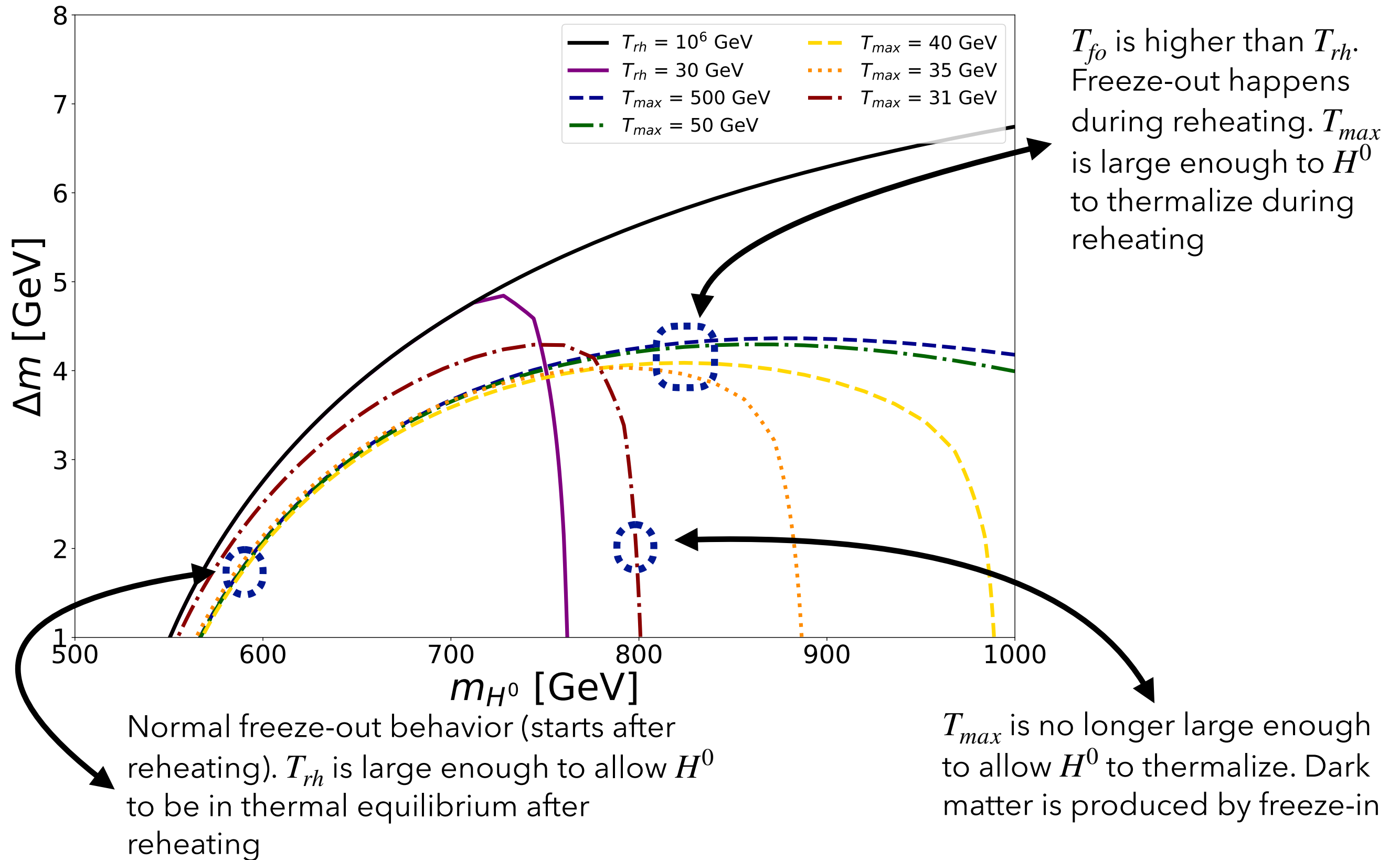
Relic density with non-instantaneous reheating(3)



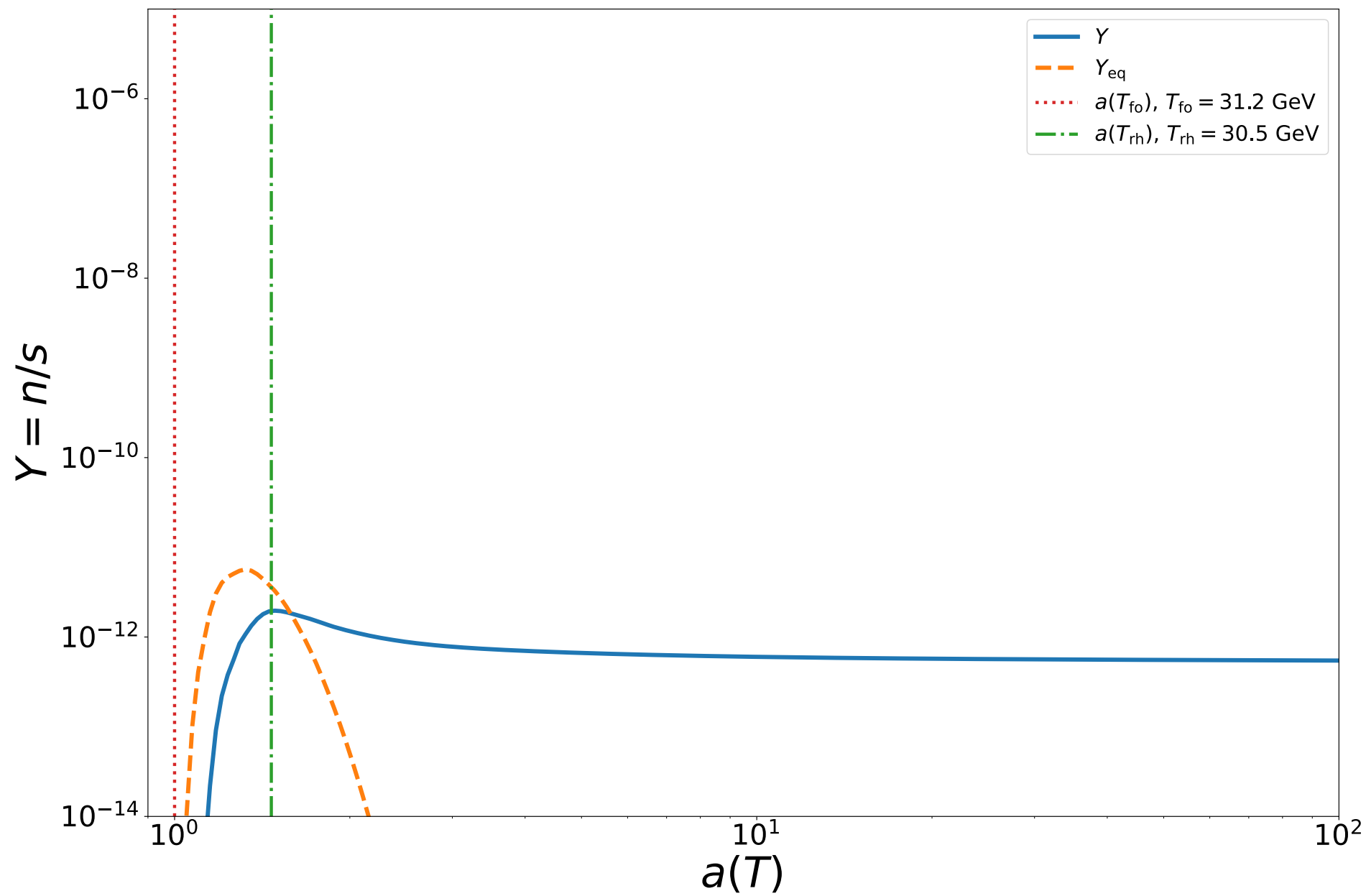
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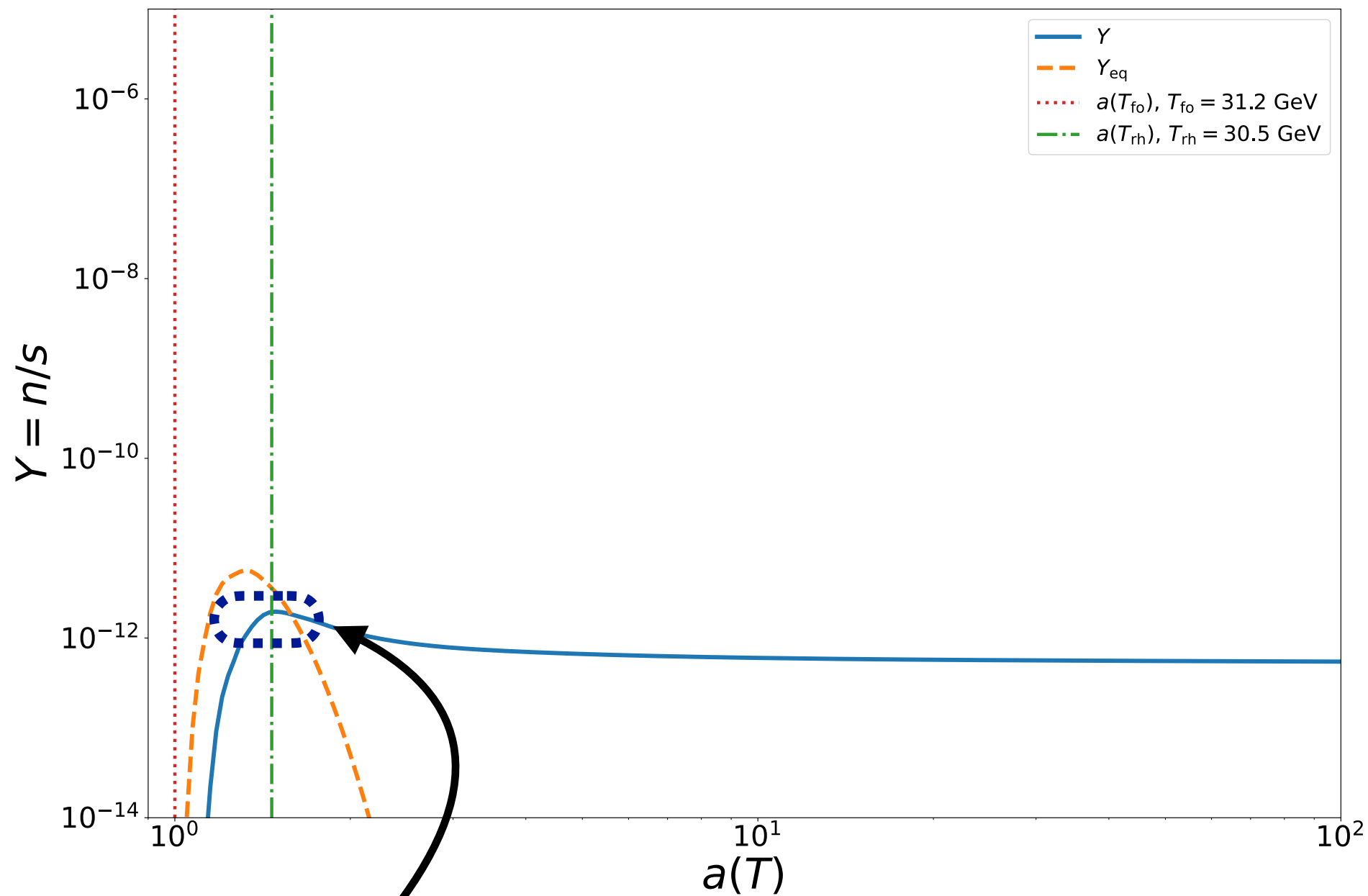
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Abundance evolution : FI during reheating

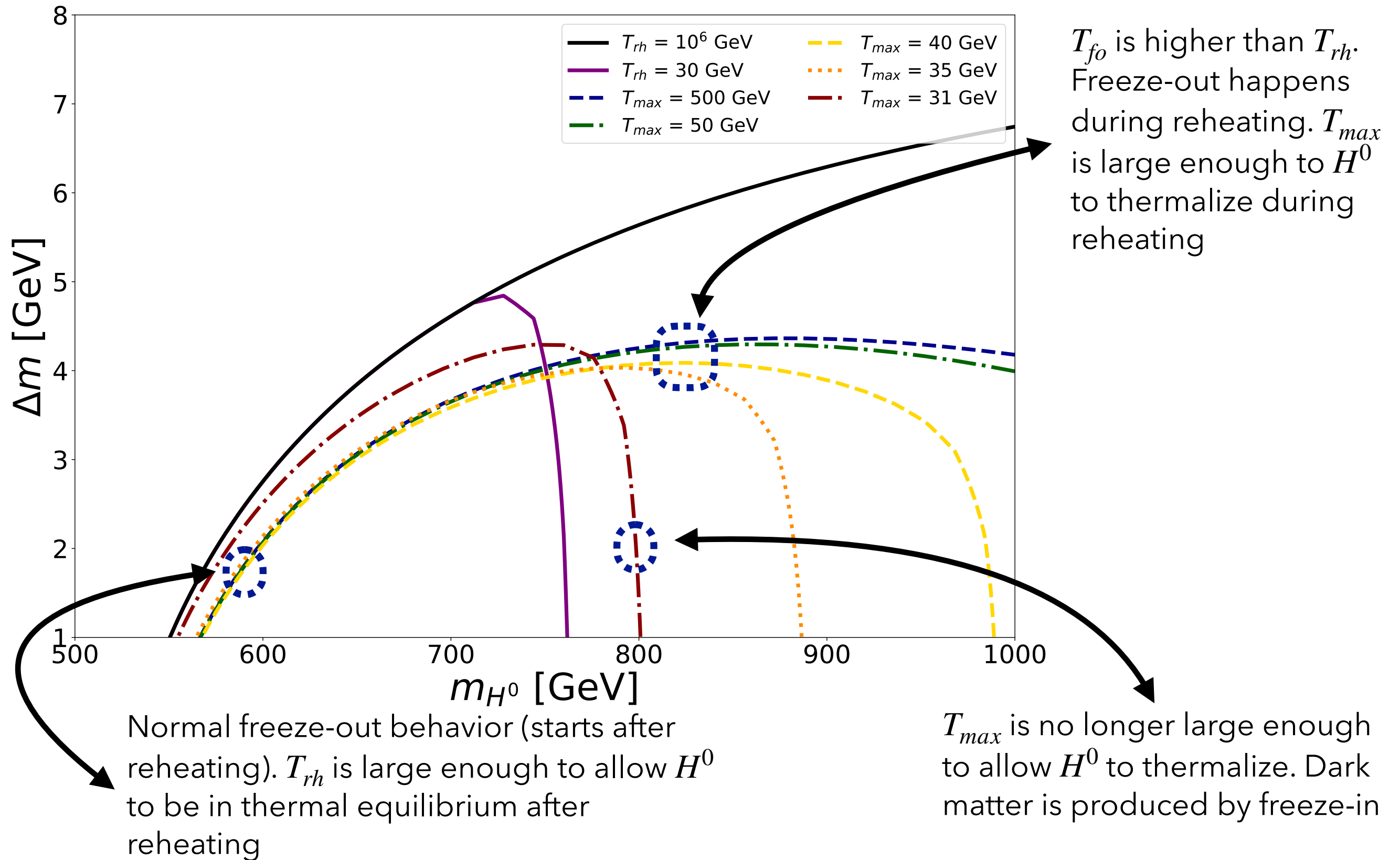


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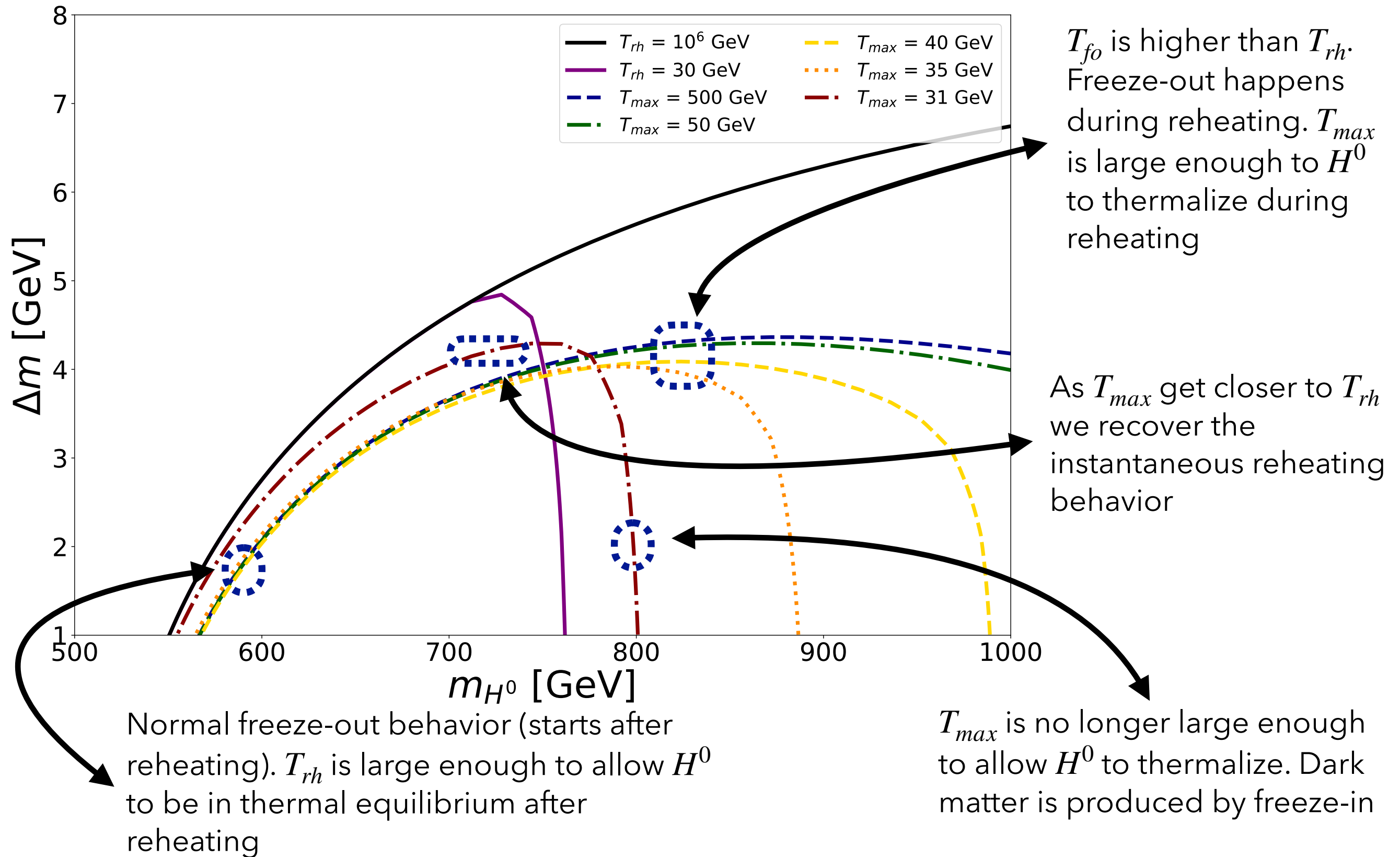


T_{max} is too small and H^0 never reaches equilibrium, leading to production via freeze-in

Relic density with non-instantaneous reheating(4)



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- In progress :
 - Precise constraints on Δm_{min}
 - $\lambda_L \neq 0$ case
 - Other alternative cosmology scenarios
 - LZ ?

Thank you for your attention !!

Backup slides