Reheating dynamics of dark sectors

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Joint work with Simona Procacci and Mikko Laine
ArXiv: 2303.17973

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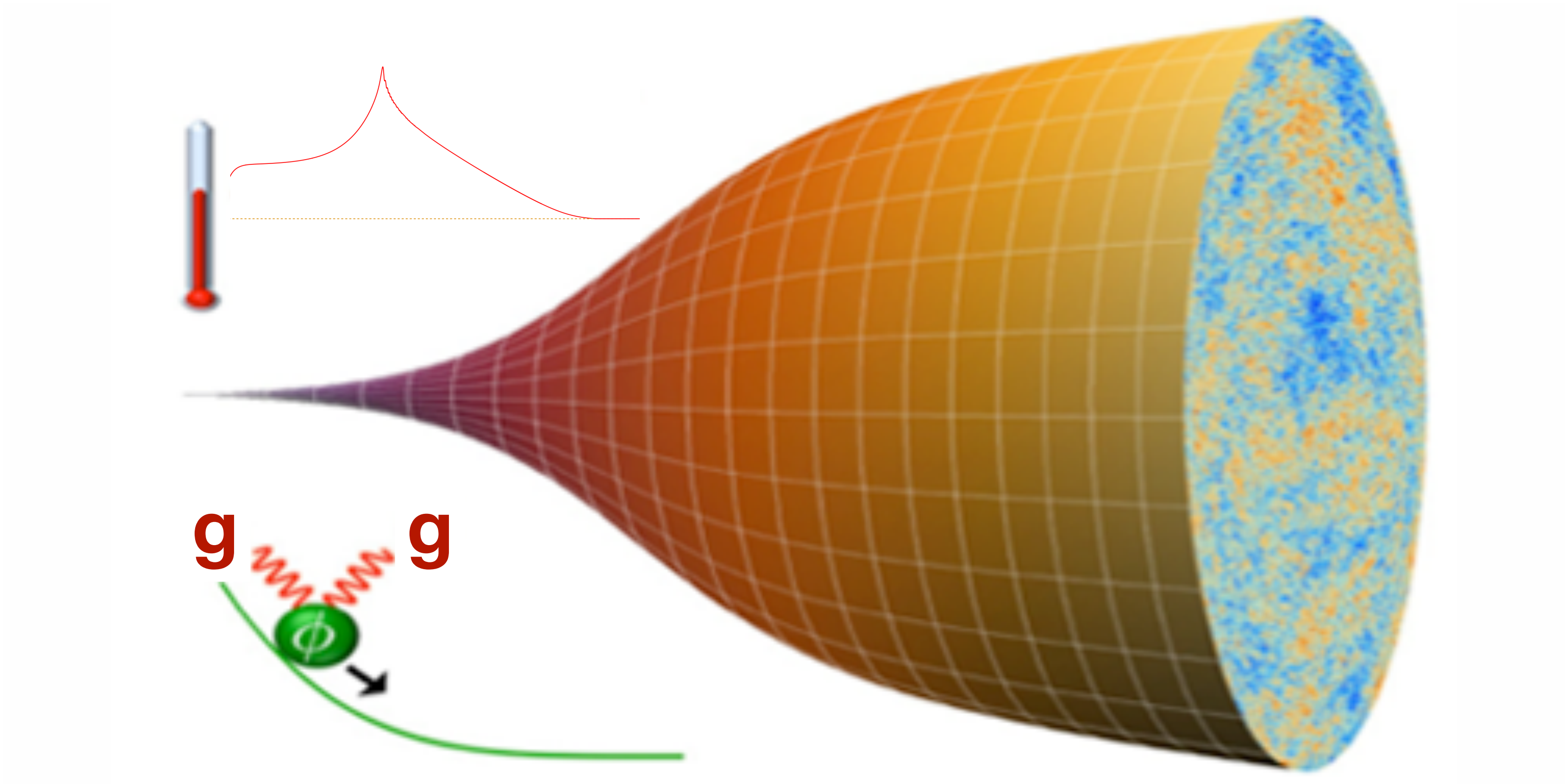
Summary

- Inflaton coupled to non-abelian dark sector (parametrised by confinement scale $\Lambda_{\rm IR}$)

- Thermal bath present throughout the inflation!

- Working example: Axion inflation coupled to SU(3) gauge sector [Laine, Procacci: 2102.09913] [Klose, Laine, Procacci: 2201.02317] [Klose, Laine, Procacci: 2210.11710]

- [HK, Laine, Procacci: 2303.17973] - evolution of dark sector temperature studied



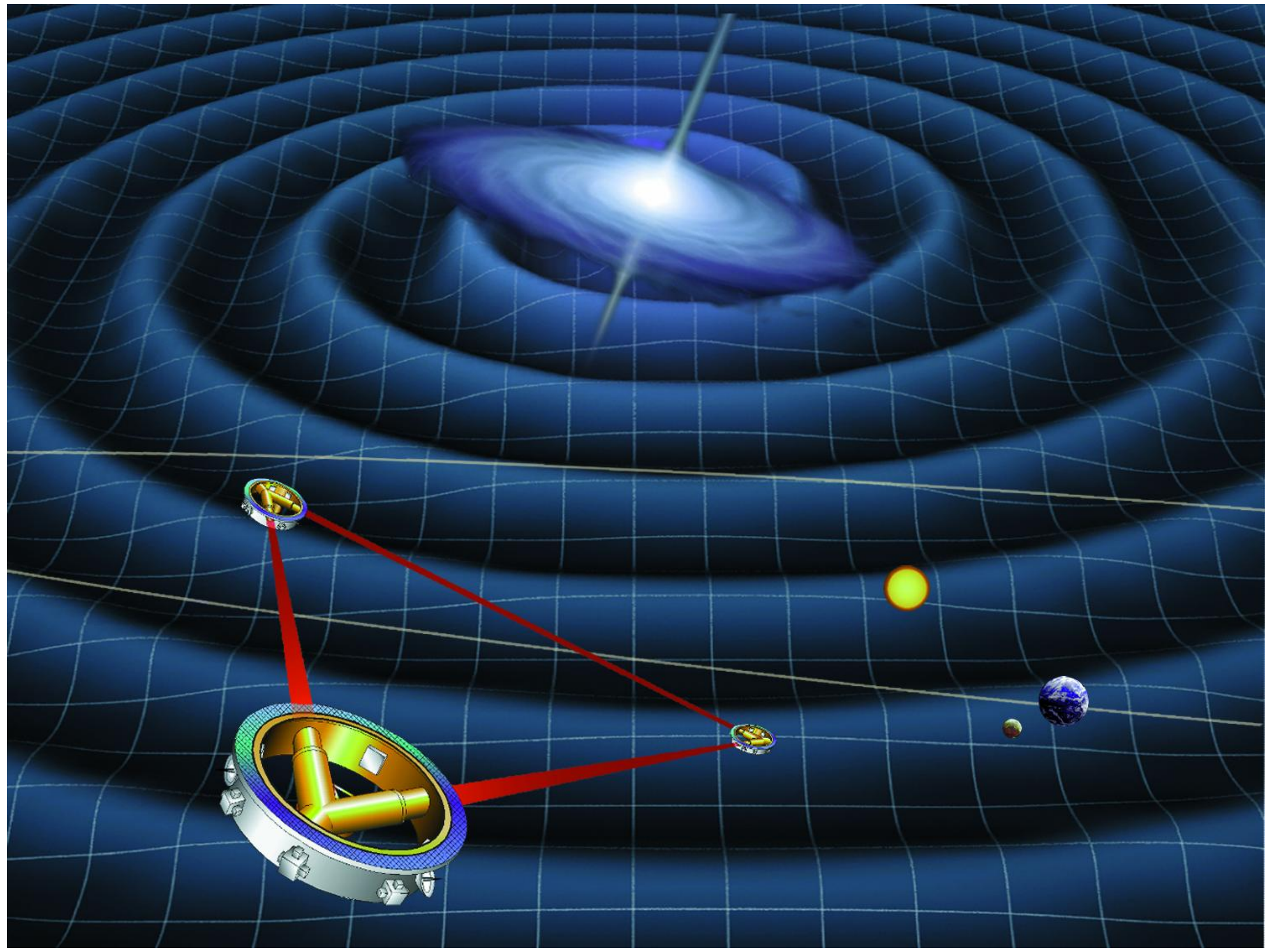
Credit: João G. Rosa/University of Aveiro; ESA and the Planck collaboration

Why is high temperature interesting?

- Possible gravitational wave signal:

  - Thermal fluctuations
    [Ghiglieri, Laine: 1504.02569]
    [Klose, Laine, Procacci: 2201.02317, 2210.11710]

  - Dark sector confinement phase transition
    [Caprini et al.: 1910.13125] [Schwaller:1504.07263]



Credit: http://lisa.jpl.nasa.gov/gallery/lisa-waves.html

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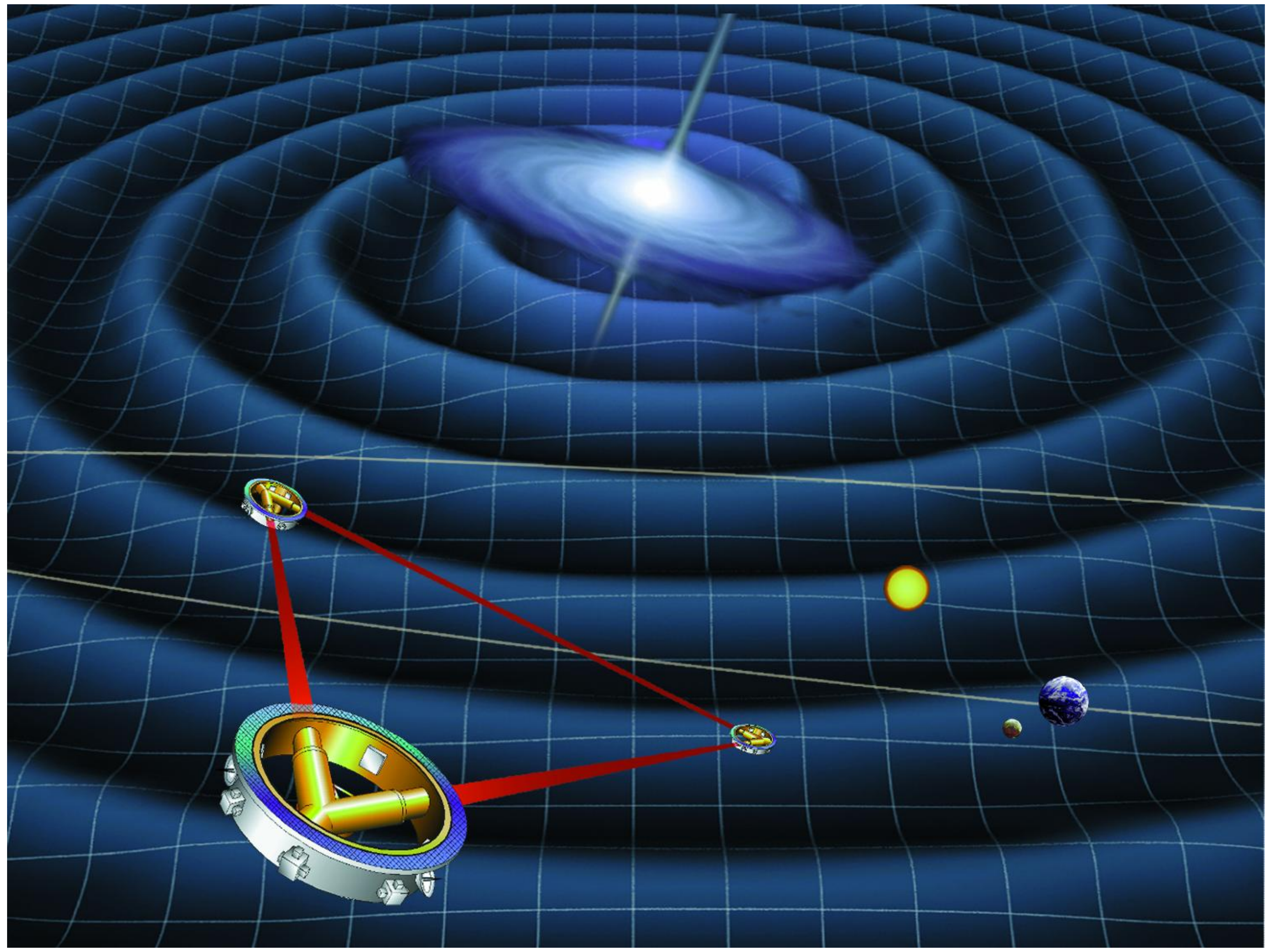
- But has the dark sector heated up above the confinement temperature?



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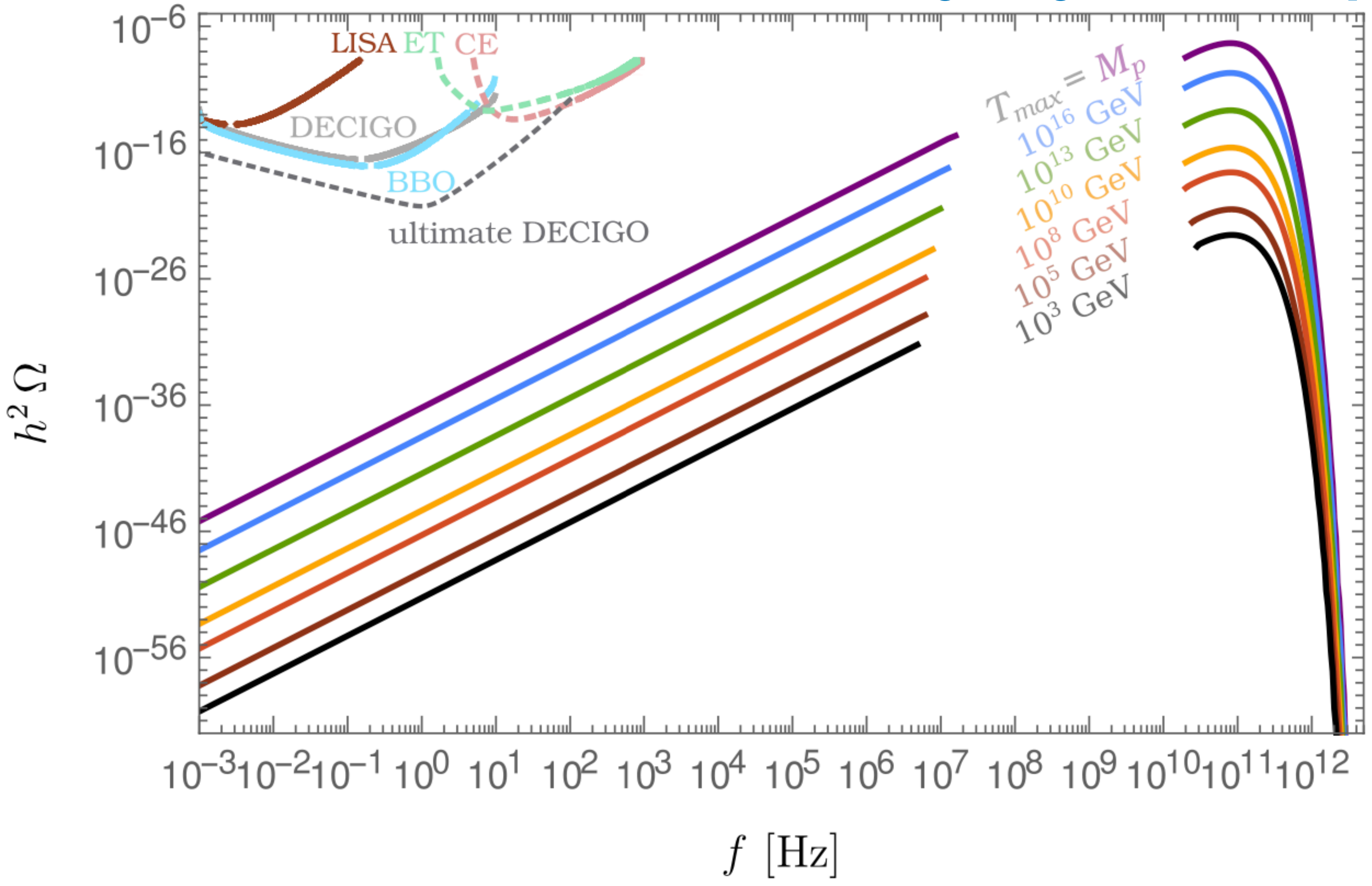
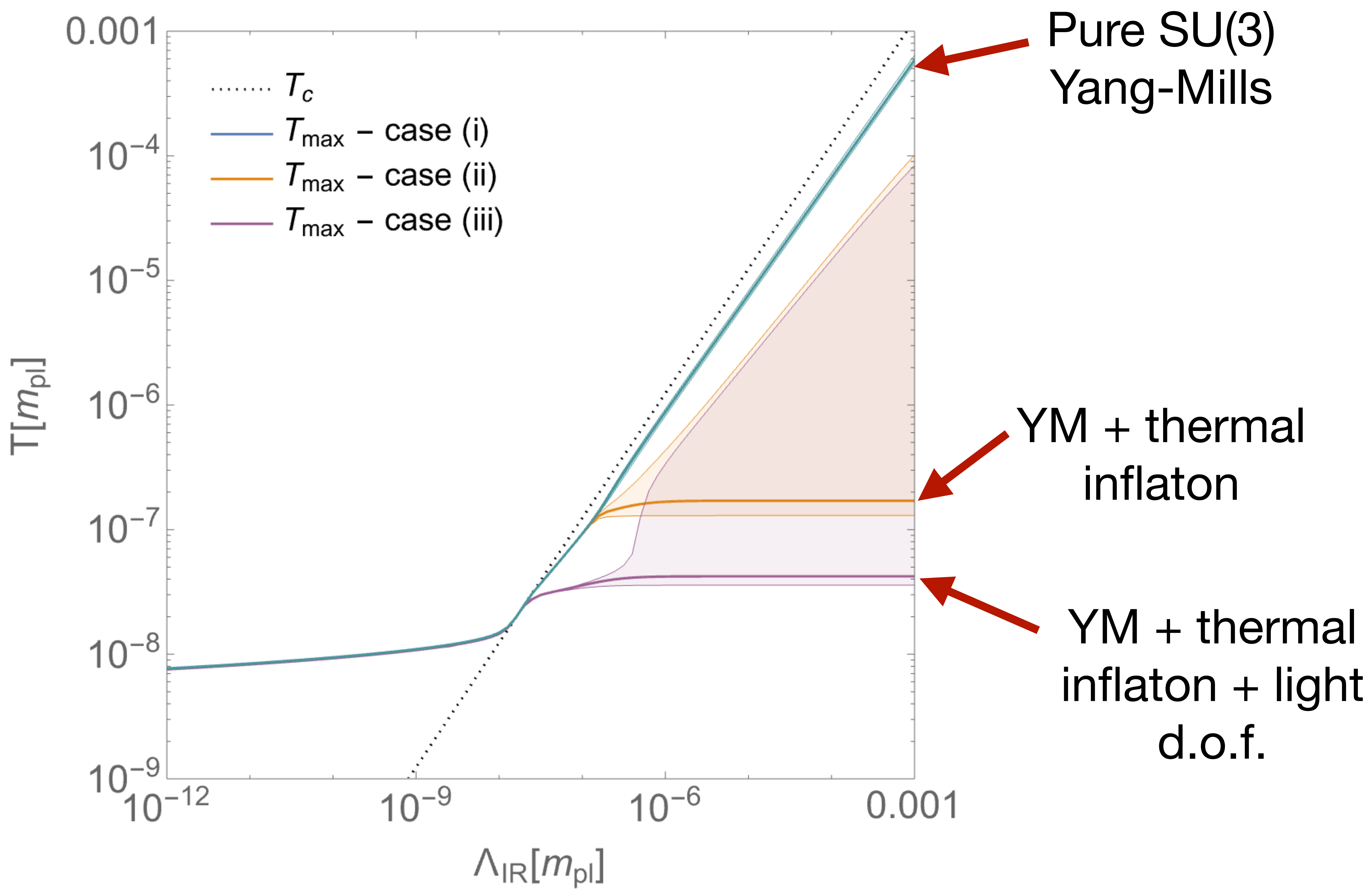
- Amplitude of gravitational waves from thermal fluctuations grows significantly with maximum reached temperature!

[Ringwald, Schütte-Engel,Tamarit: 2011.04731
Gravitational waves as a big bang thermometer]



Results: Maximal temperature of the dark sector



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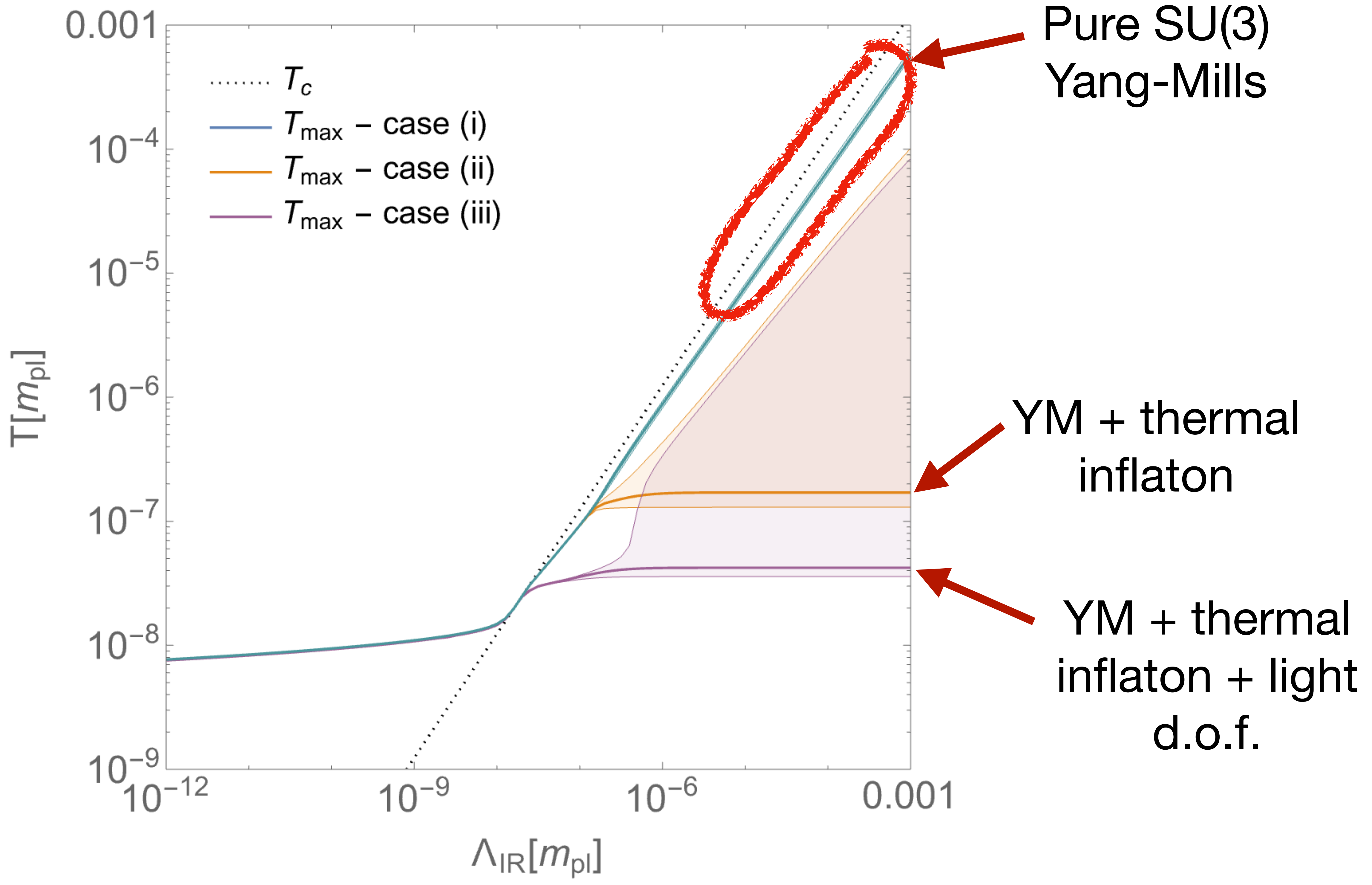

Message 1: Temperatures up to $10^{-3}\, m_{\text{pl}}$ can be reached

- For Λ_{IR} up to $10^{-3}\, m_{\text{pl}}$
- If Yang-Mills plasma not coupled to extra light d.o.f.

$\Rightarrow$ Hope for potentially detectable GW from thermal plasma!

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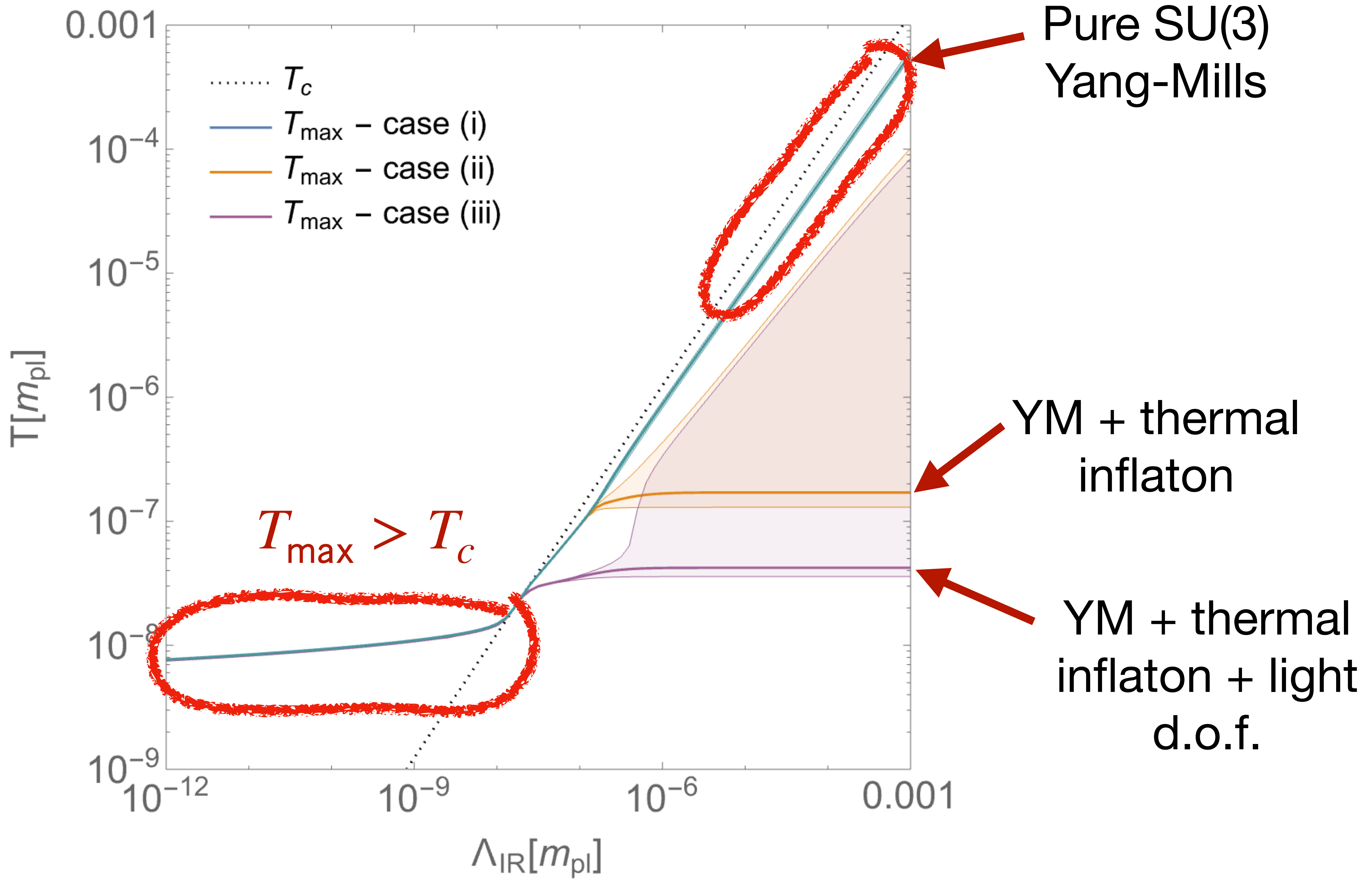

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Message 2: For lower Λ_{IR} the dark sector heats up above T_c
$\Rightarrow$ undergoes a phase transition! Possible further GW signal!

For curious listeners

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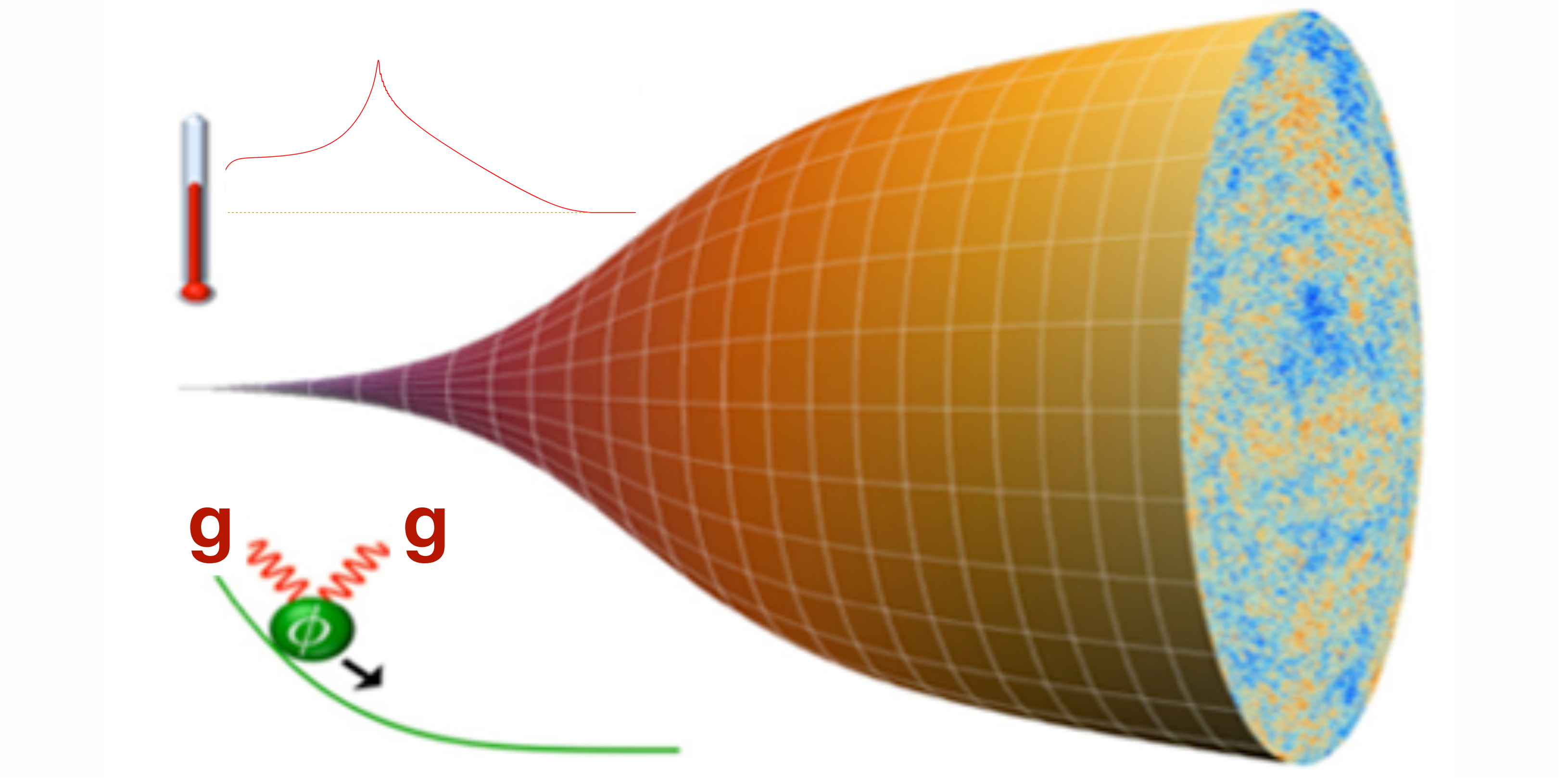
- Evolution of dark sector temperature studied



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Gauge coupling

Yang-Mills field strength

$$\mathscr{L} \supset \frac{1}{2}\partial^{\mu}\varphi\, \partial_{\mu}\varphi - V_0(\varphi) - \frac{\alpha\, \varphi\, \epsilon^{\mu\nu\rho\sigma} F^c_{\mu\nu} F^c_{\rho\sigma}}{16\pi f_a}$$

Inflaton field

Inflaton potential:

$$V_0 \simeq m^2 f_a^2 \left[1 - \cos\left(\frac{\bar{\varphi}}{f_a}\right)\right]$$

Axion decay constant

"Natural/axion inflation"
[Freese, Frieman, Olinto: Phys.Rev.Lett. 65 (1990)]

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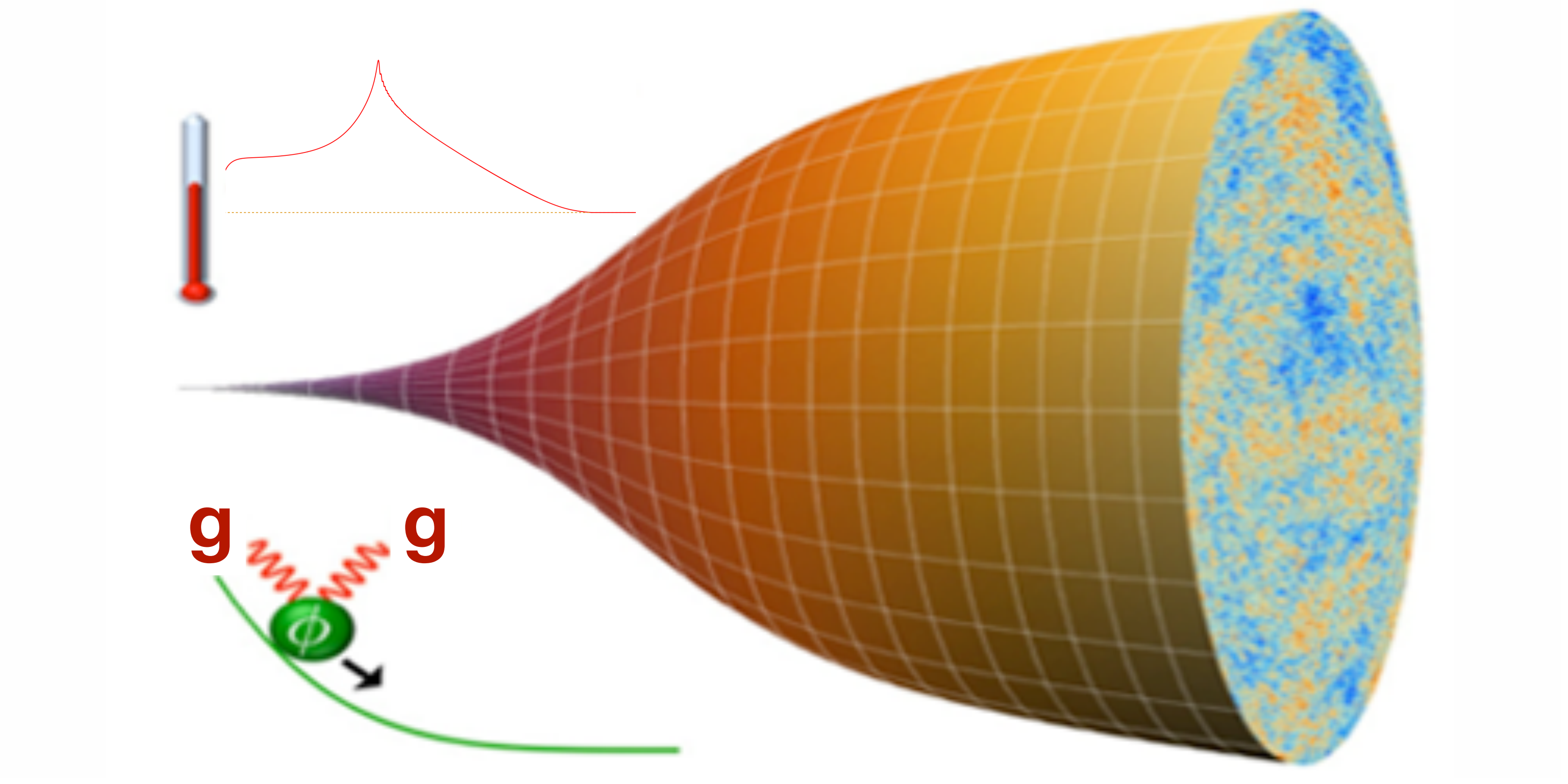

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Axion decay constant

$\Rightarrow$

$$\ddot{\bar{\varphi}} + (3H + \Upsilon)\dot{\bar{\varphi}} + V_\varphi \simeq 0$$

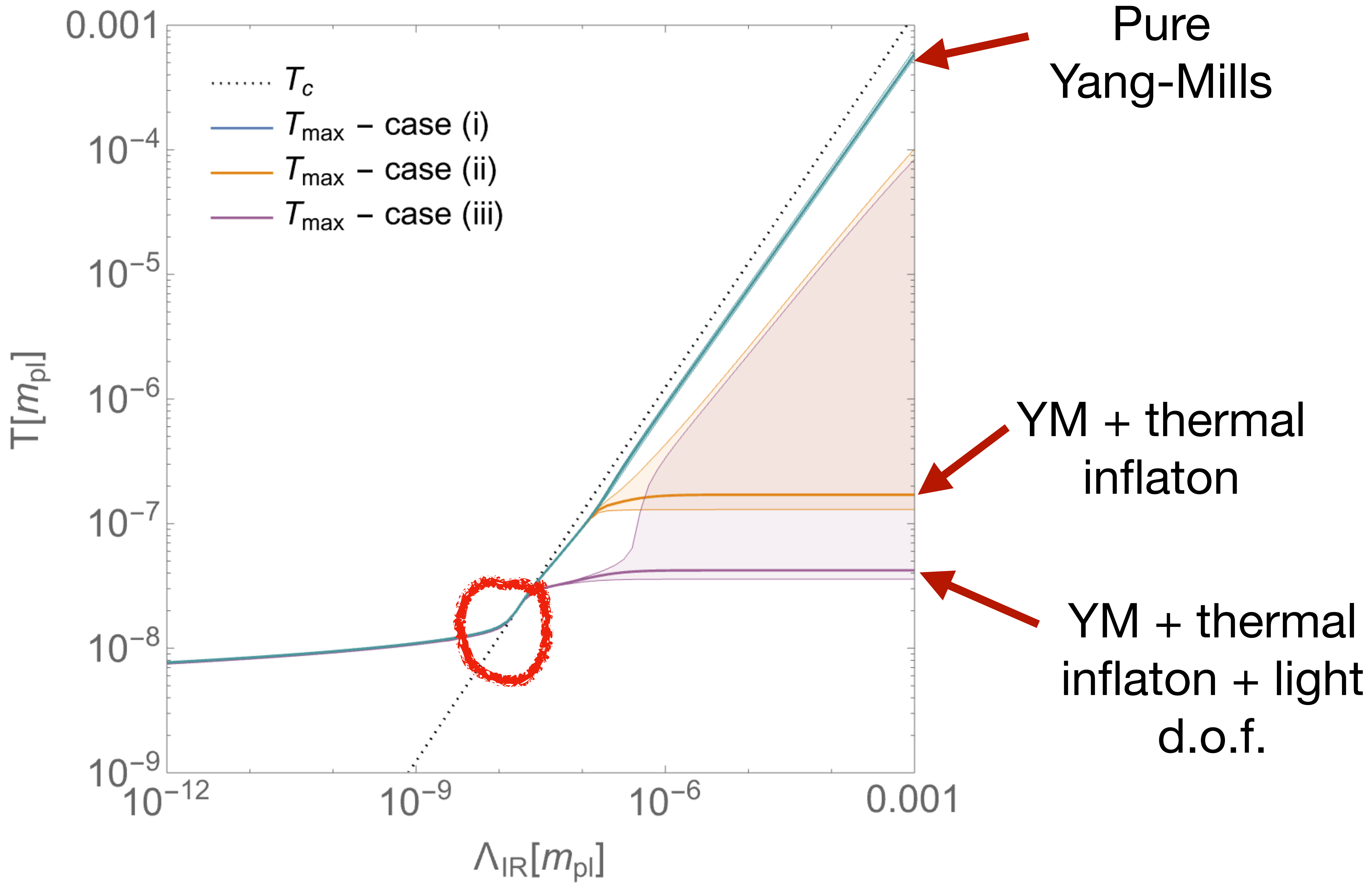
$$\dot{e}_r + 3H\left(e_r + p_r\right) \simeq \Upsilon \dot{\bar{\varphi}}^2$$

Hubble rate

Friction due to inflaton coupling to dark sector!

Dark radiation energy and pressure densities

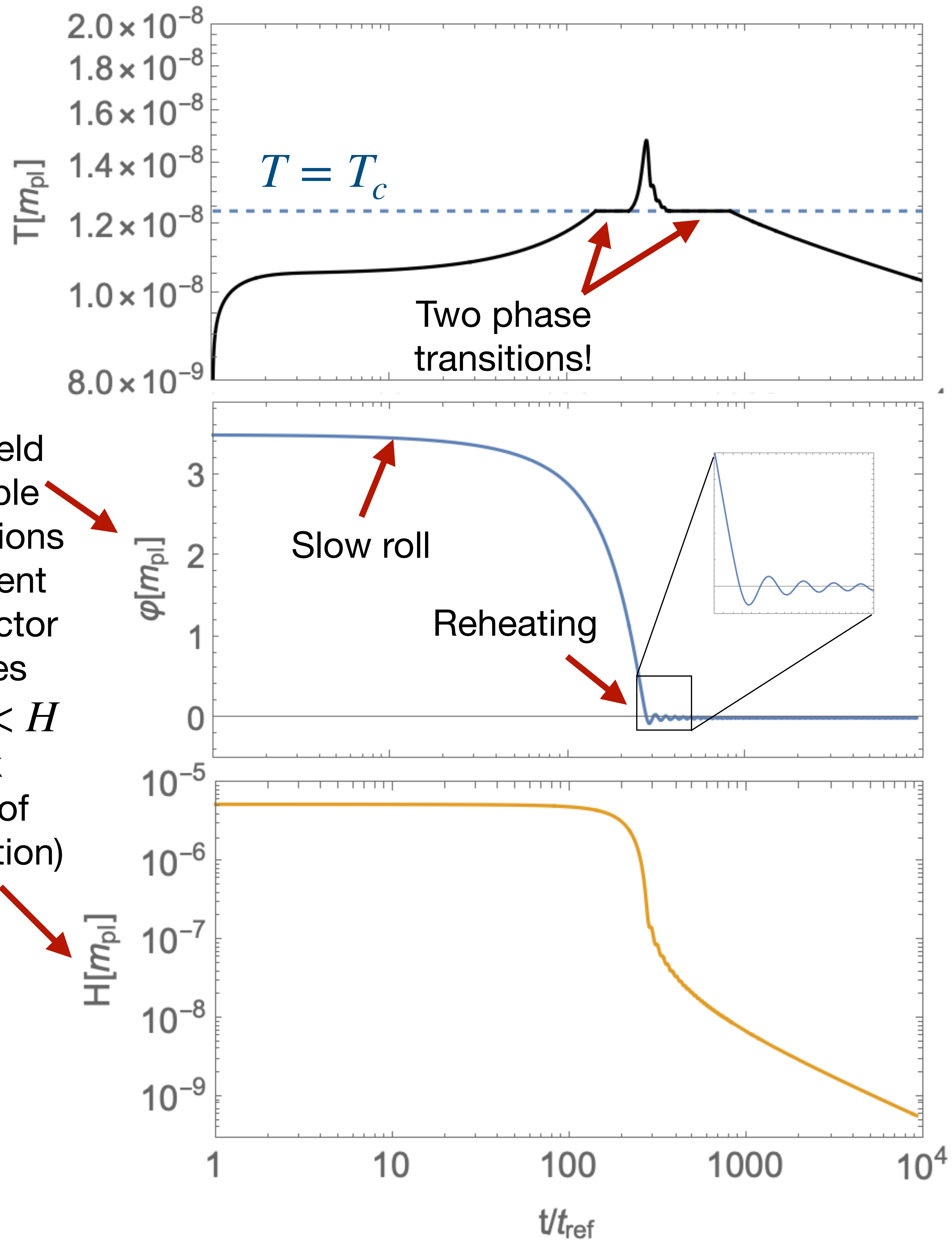
Results: Maximal temperature of the dark sector



Message 3: There can even be two phase transitions!

Example: $\Lambda_{\rm IR} = 10^{-8} m_{\rm pl}$

Inflaton field and Hubble rate evolutions independent of dark sector properties since $\Upsilon \ll H$ ("Weak regime" of warm inflation)



Benchmark parameter choice
(axion inflation consistent with CMB data)
[Klose, Laine, Procacci: 2201.02317]:

axion mass: $m = 1.09 \times 10^{-6}\, m_{\rm pl}$,

axion decay constant: $f_a = 1.25\, m_{\rm pl}$,

initial time: $t_{\rm ref} \sim H^{-1}_{\rm initial}$

$\Rightarrow \Upsilon \sim 10^{-23} m_{\rm pl}$

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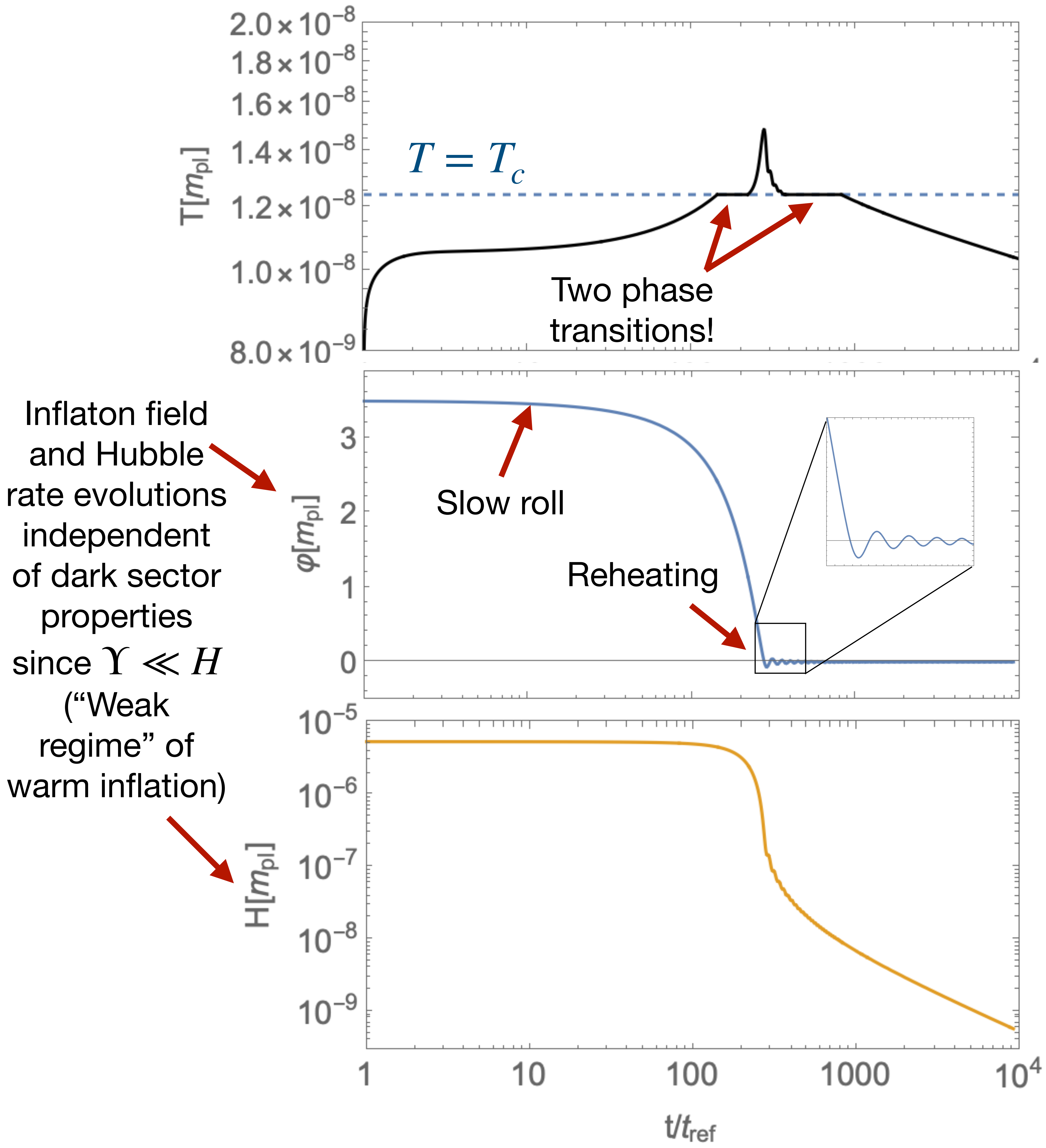

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  [Buen-Abad, Chang, Hook: 2305.09712]

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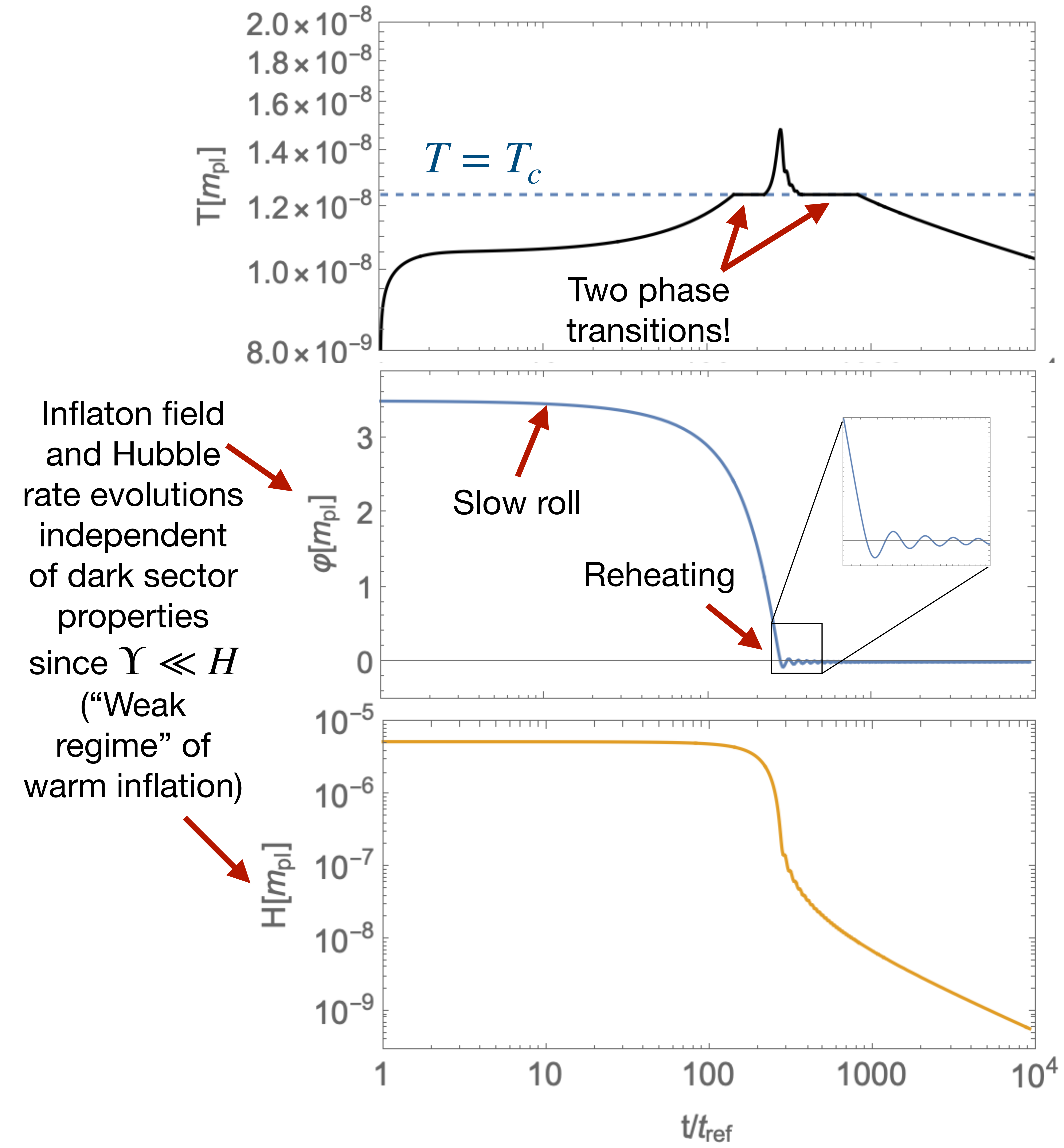

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- How and when SM is reheated?

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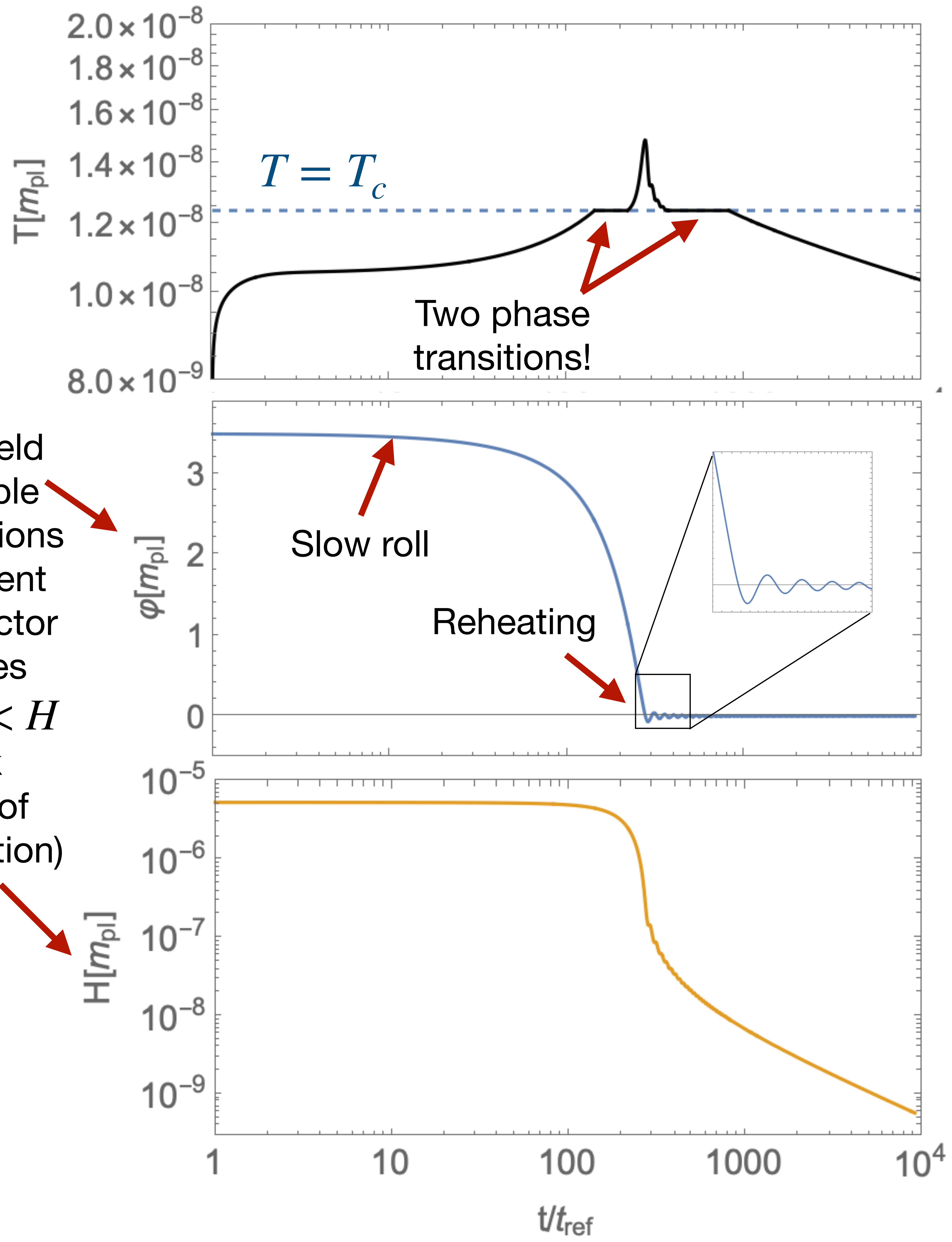

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To be worked out!

Why large temperatures?

$$\ddot{\varphi} + (3H + \Upsilon)\dot{\varphi} + V_{\varphi} \simeq 0$$

$$\dot{e}_r + 3H\left(e_r + p_r\right) \simeq \Upsilon \dot{\varphi}^2$$

Parametrize
e_r, p_r by T

$$c_r(T)\,\dot{T} + 3H\left[e_r(T) + p_r(T)\right] \simeq \Upsilon \dot{\varphi}^2$$

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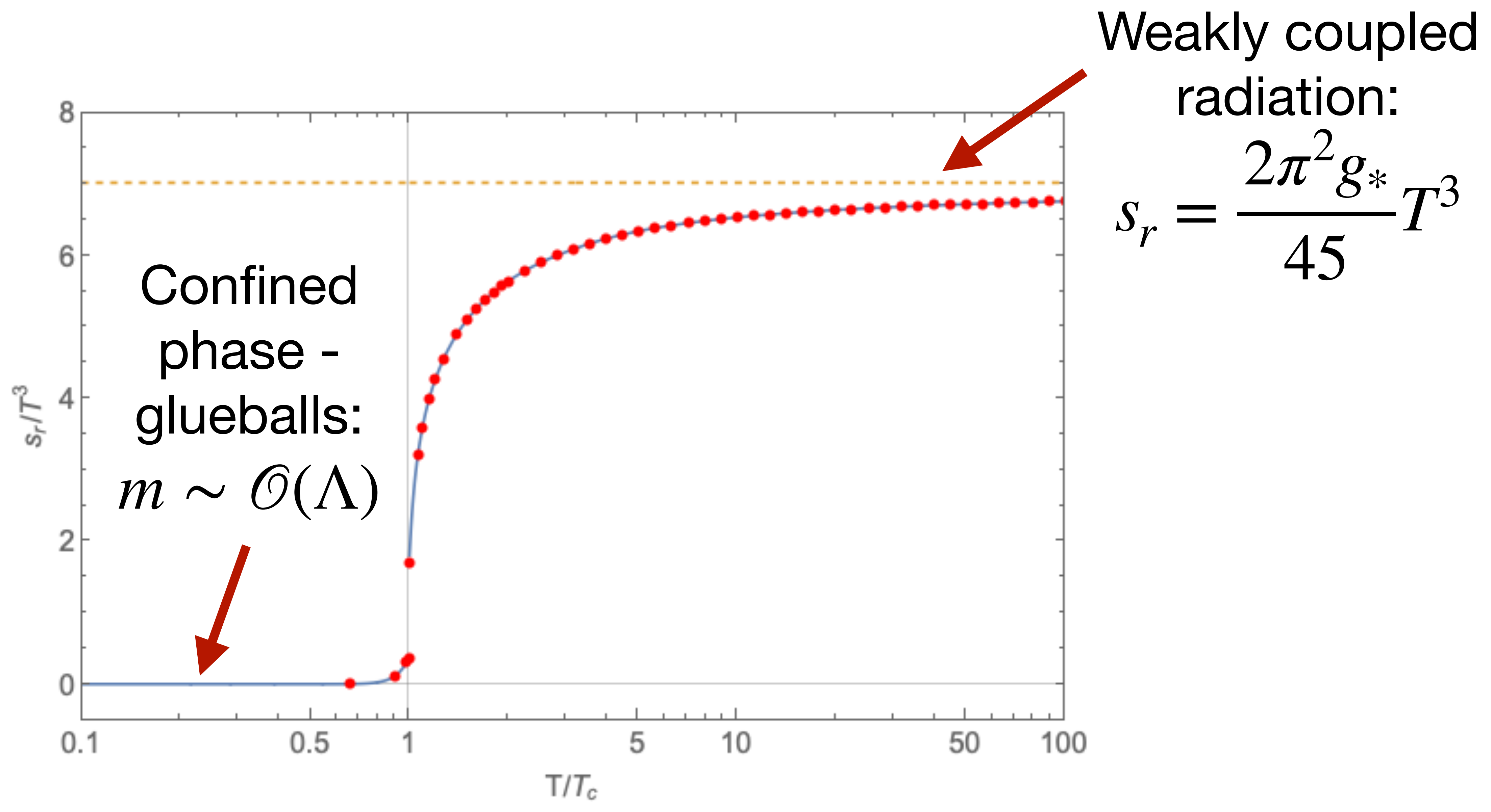

Entropy density of pure $SU(3)$ measured on lattice
[Giusti, Pepe: 1612.00265]

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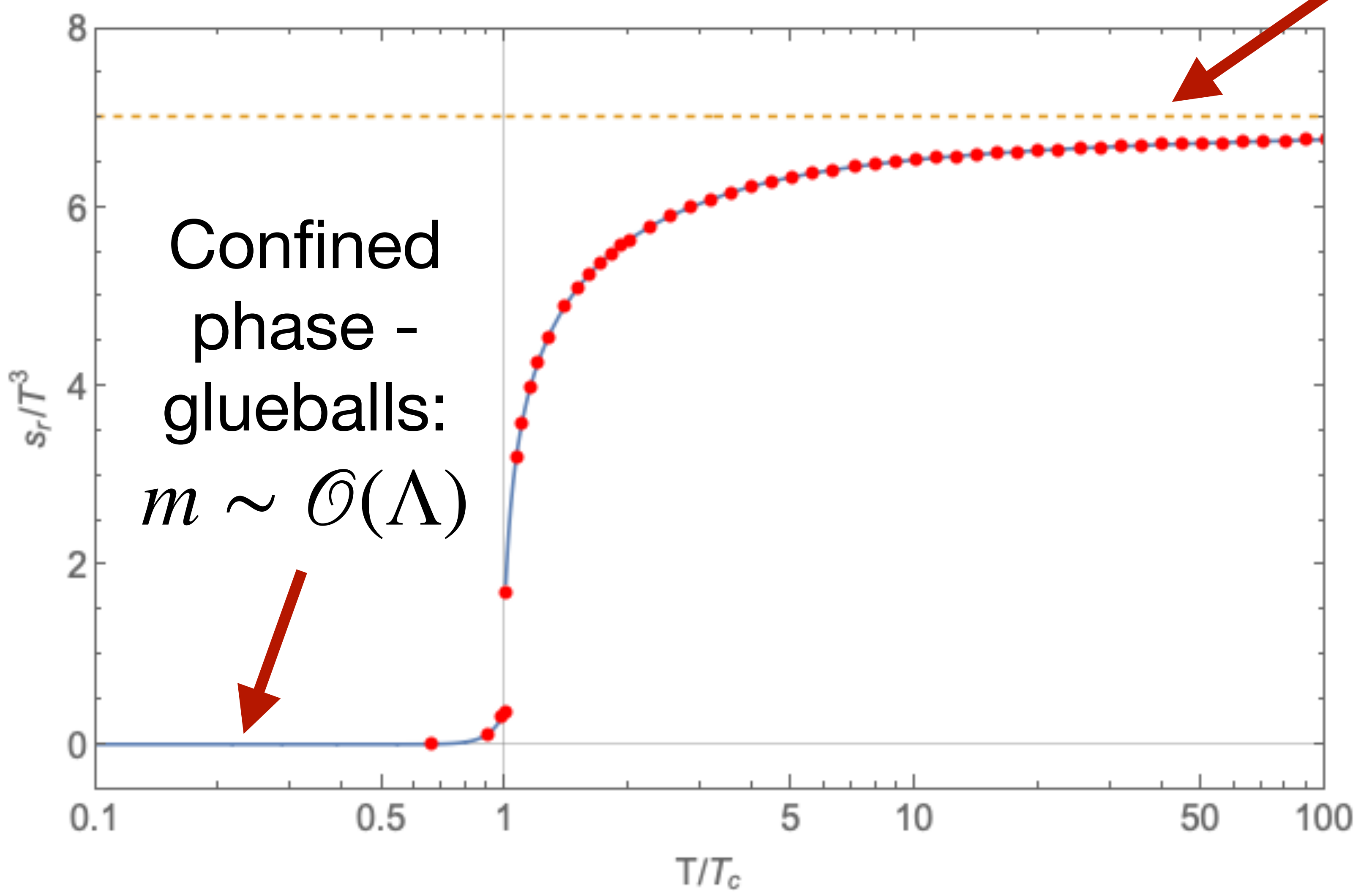
Heat capacity:
$c_r = \partial_T e_r$

Weakly coupled radiation:
$$s_r = \frac{2\pi^2 g_*}{45} T^3$$



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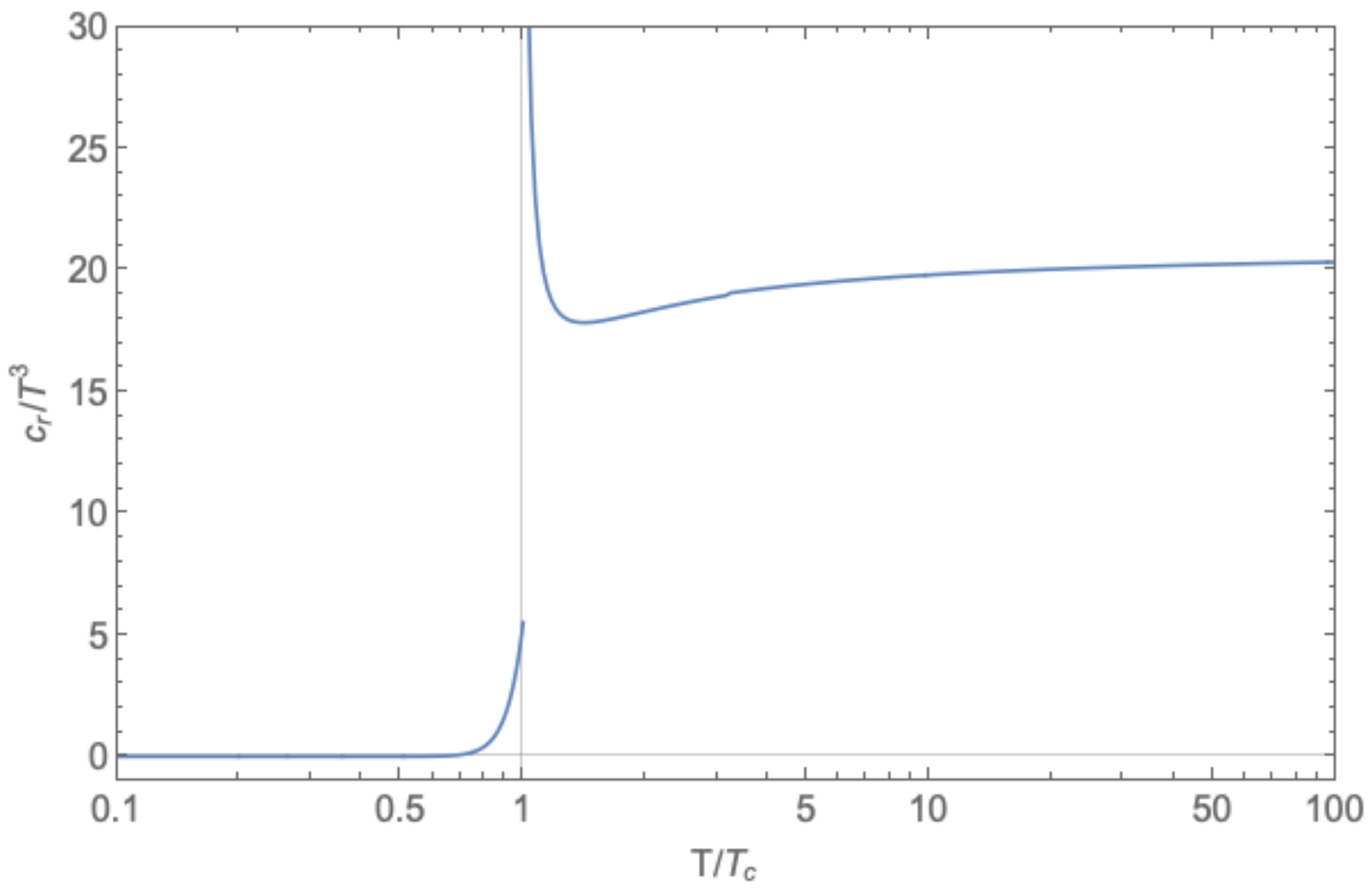

Fit of lattice data for s_r,
$s_r = \partial_T p_r$,
$e_r = T s_r - p_r$

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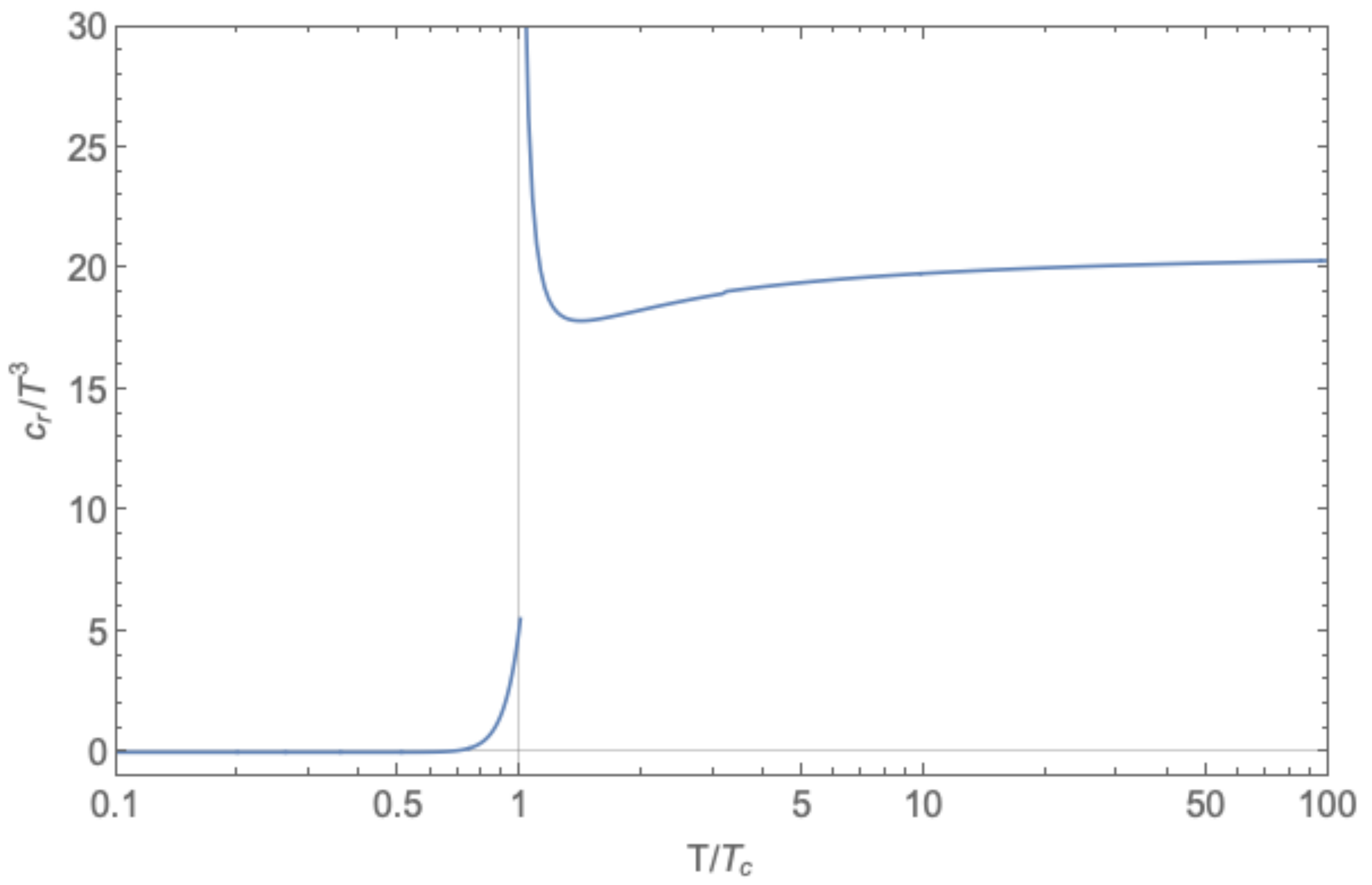
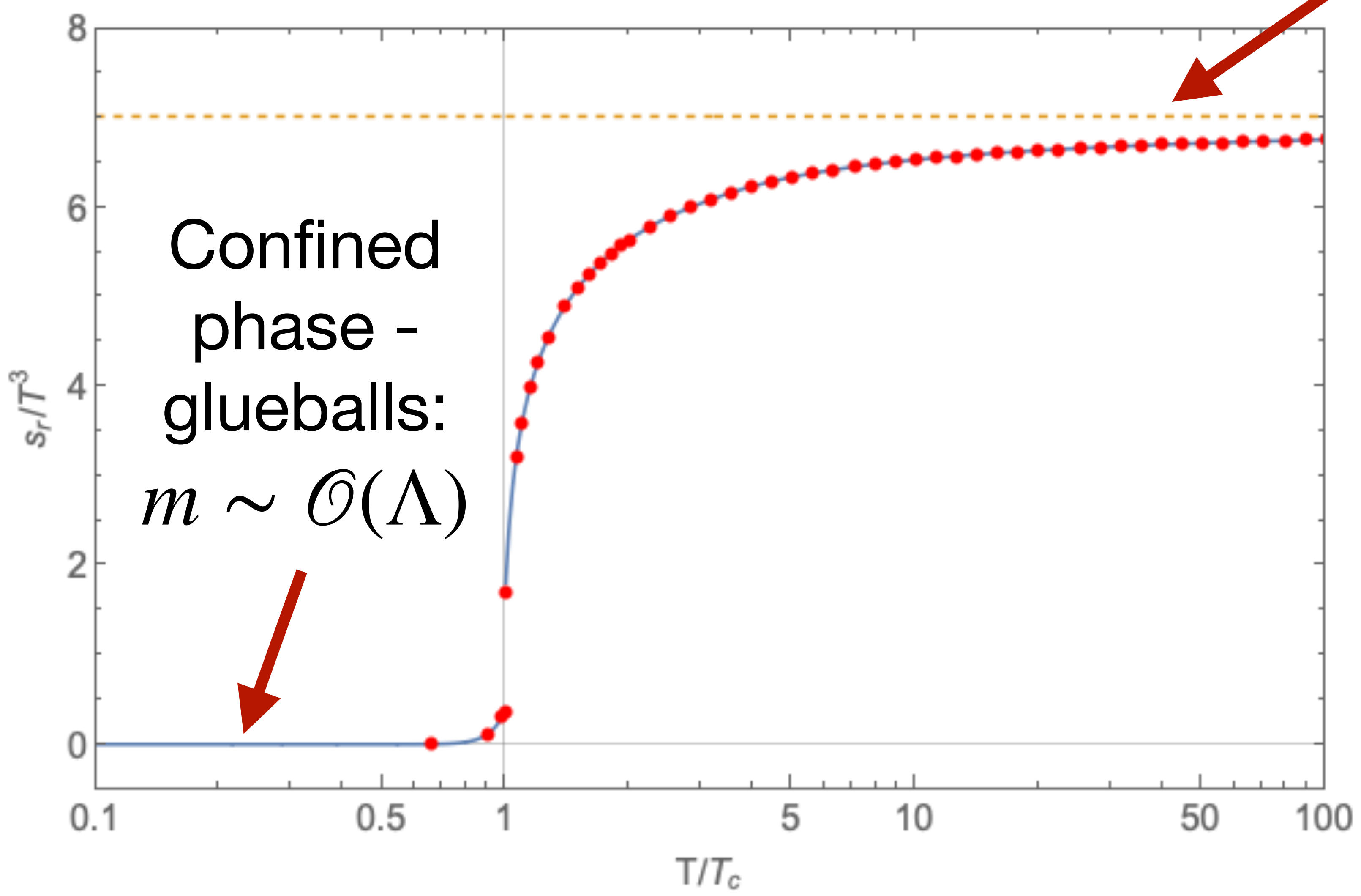
c_r exponentially small well below $T_c \Rightarrow$ rapid temperature growth!





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