

# **PBH formation from an aborted phase transition**

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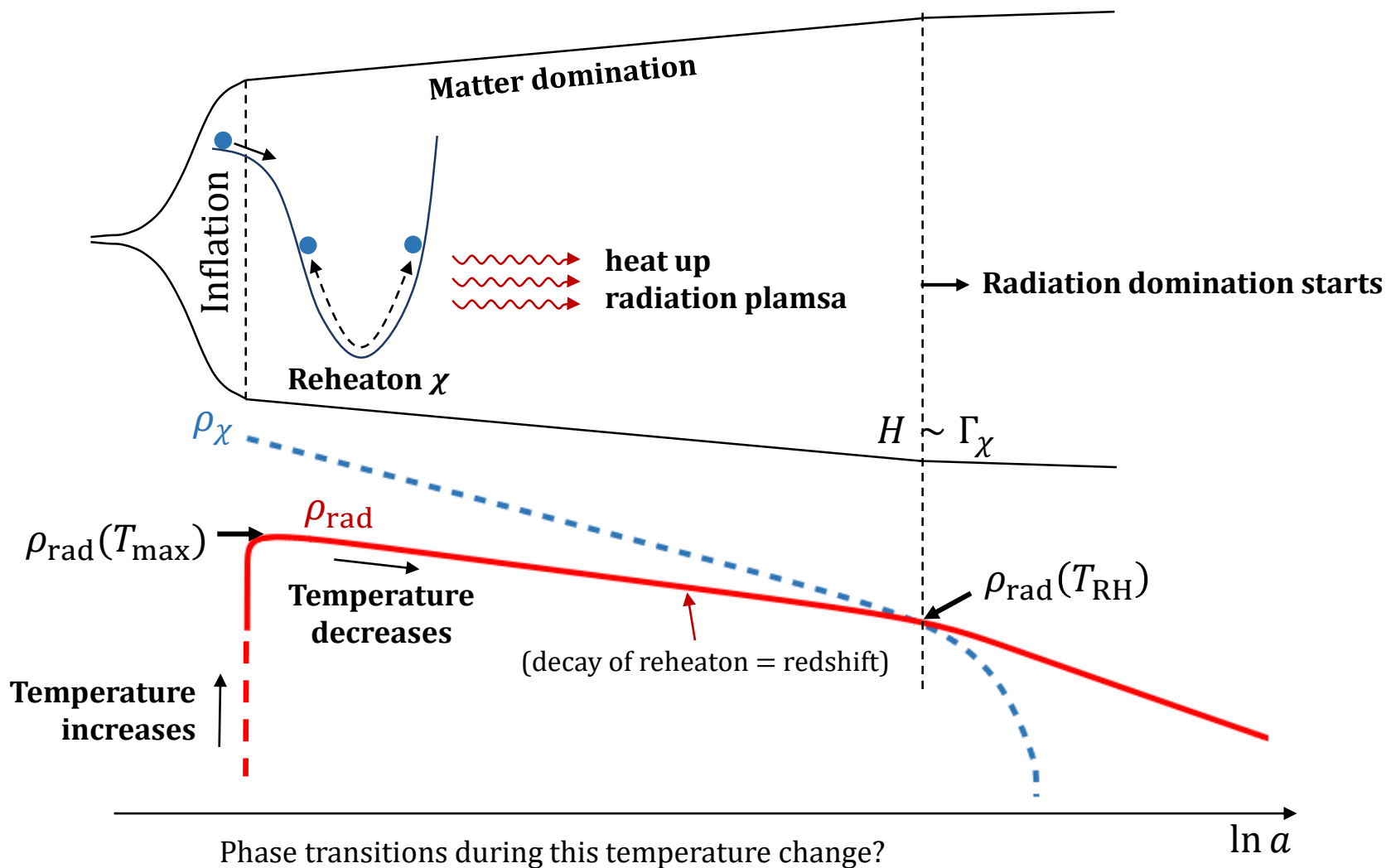
## 2. Primordial black hole formation

- Fate of bubbles in aborted PT
- Post-accretion collapse
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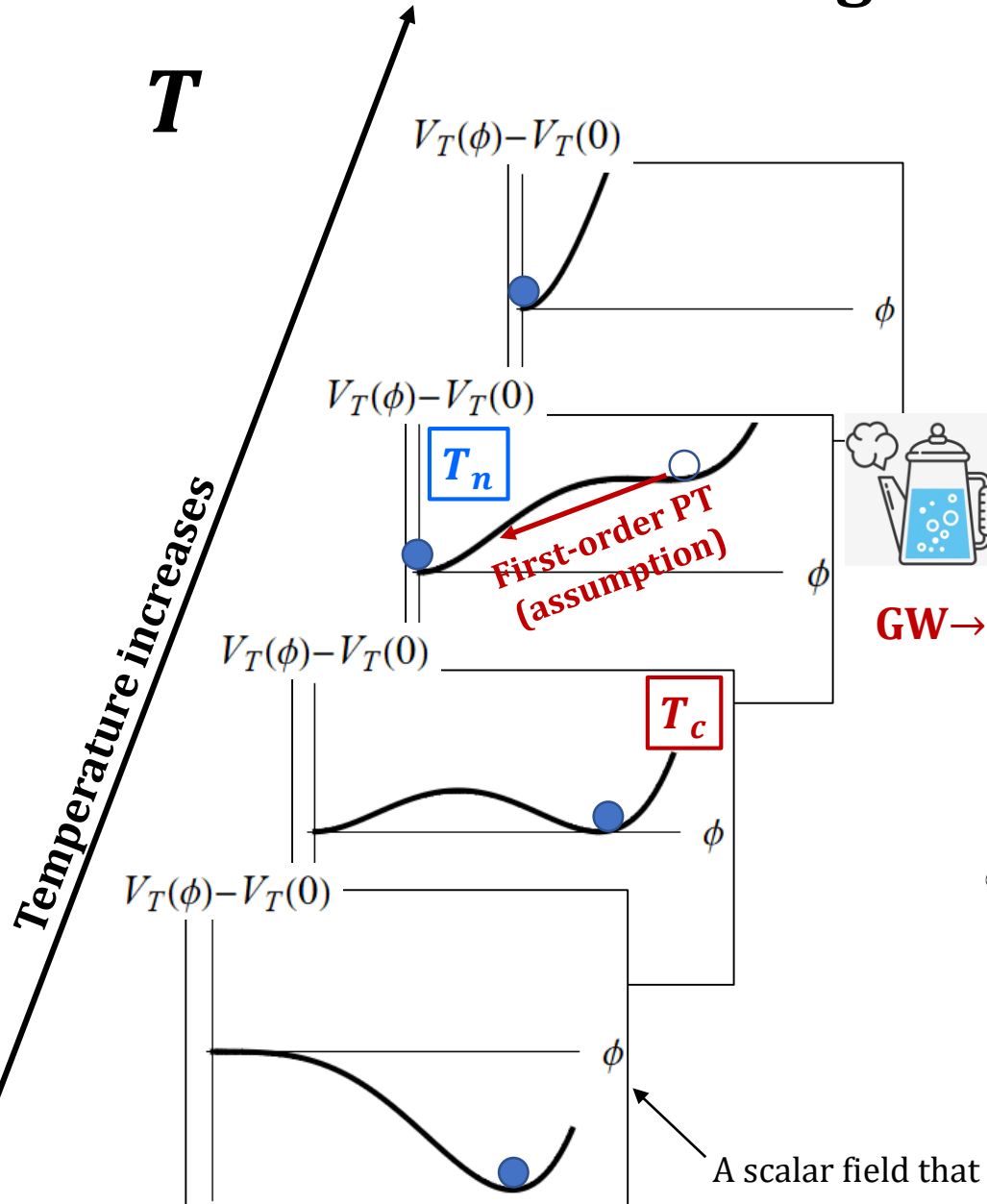
## 3. Summary

# Reheating after inflation

- After inflation (when the inflaton exits the slow-roll phase), it starts coherent oscillation. The decay of the oscillation heats up the radiation plasma.



# Phase transitions during temperature increase

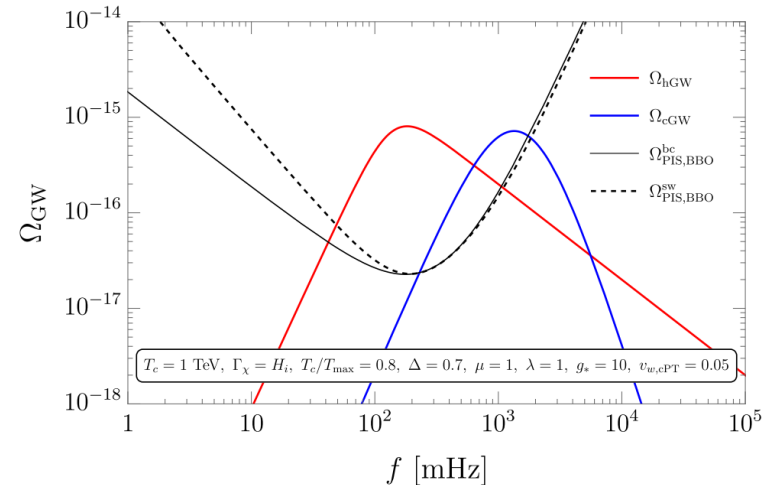


(bubble nucleation rate per unit volume)

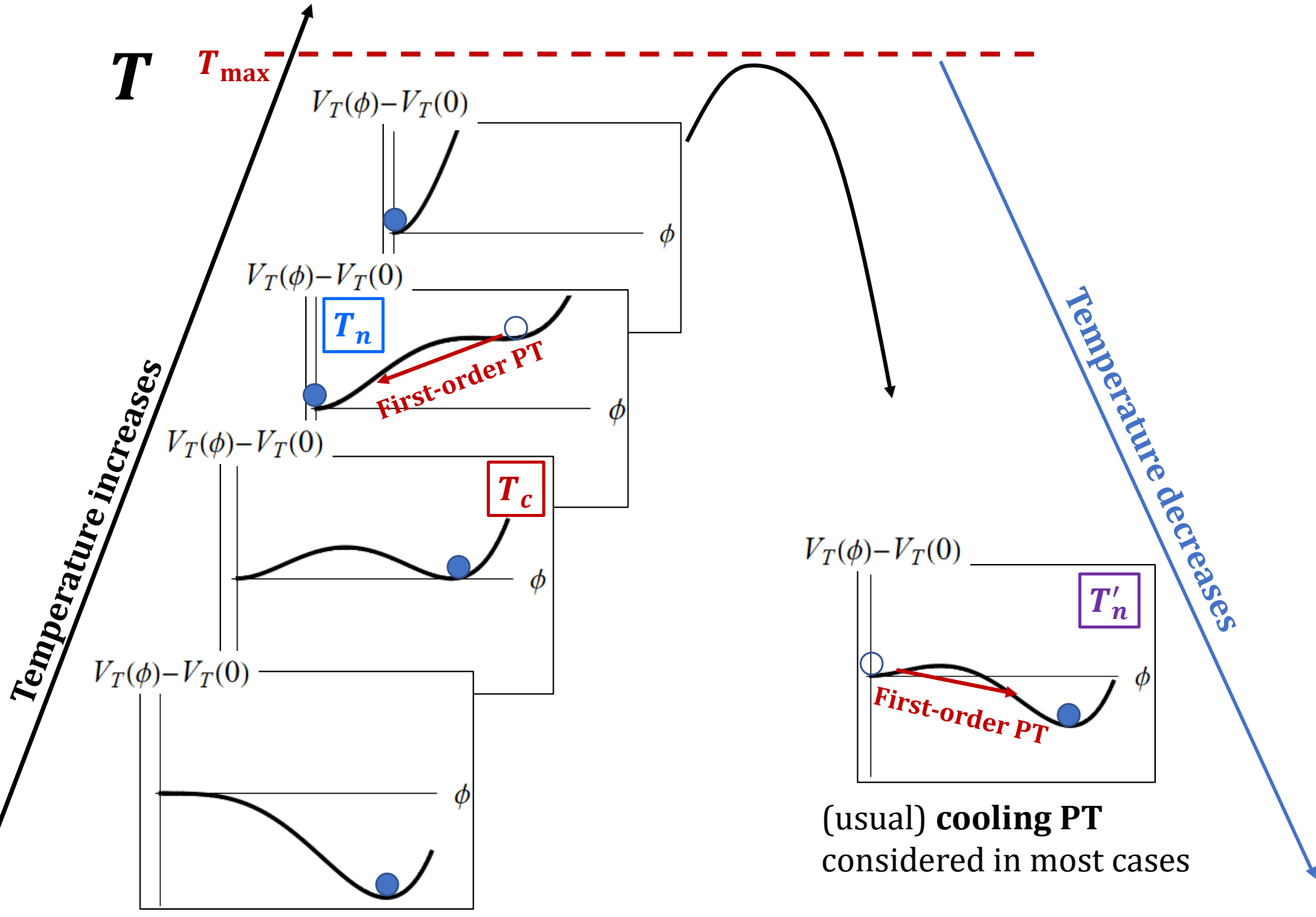
$$\Gamma(T_n) = H^4(T_n)$$

“Heating” phase transition

GW → Buen-Abad, Chang, Hook, 2305.09712



# When $T_{\max} > T_n$ : heating PT and cooling PT



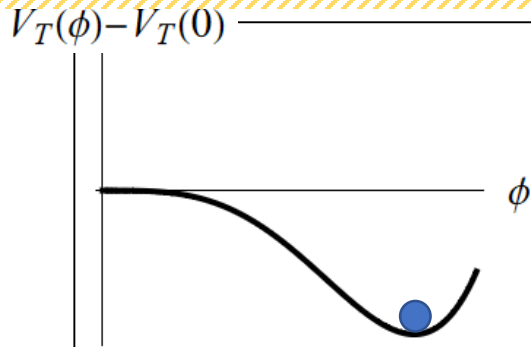
When  $T_{\max} < T_c$ : No PT

$T$

Temperature increases

Temperature decreases

$T_{\max}$



# When $T_c < T_{\max} < T_n$ : (heating) PT is **aborted**

$T$

At  $T > T_c$ , bubbles can be nucleated,  
but  $\Gamma < H^4$  (since  $T_{\max} < T_n$ ).

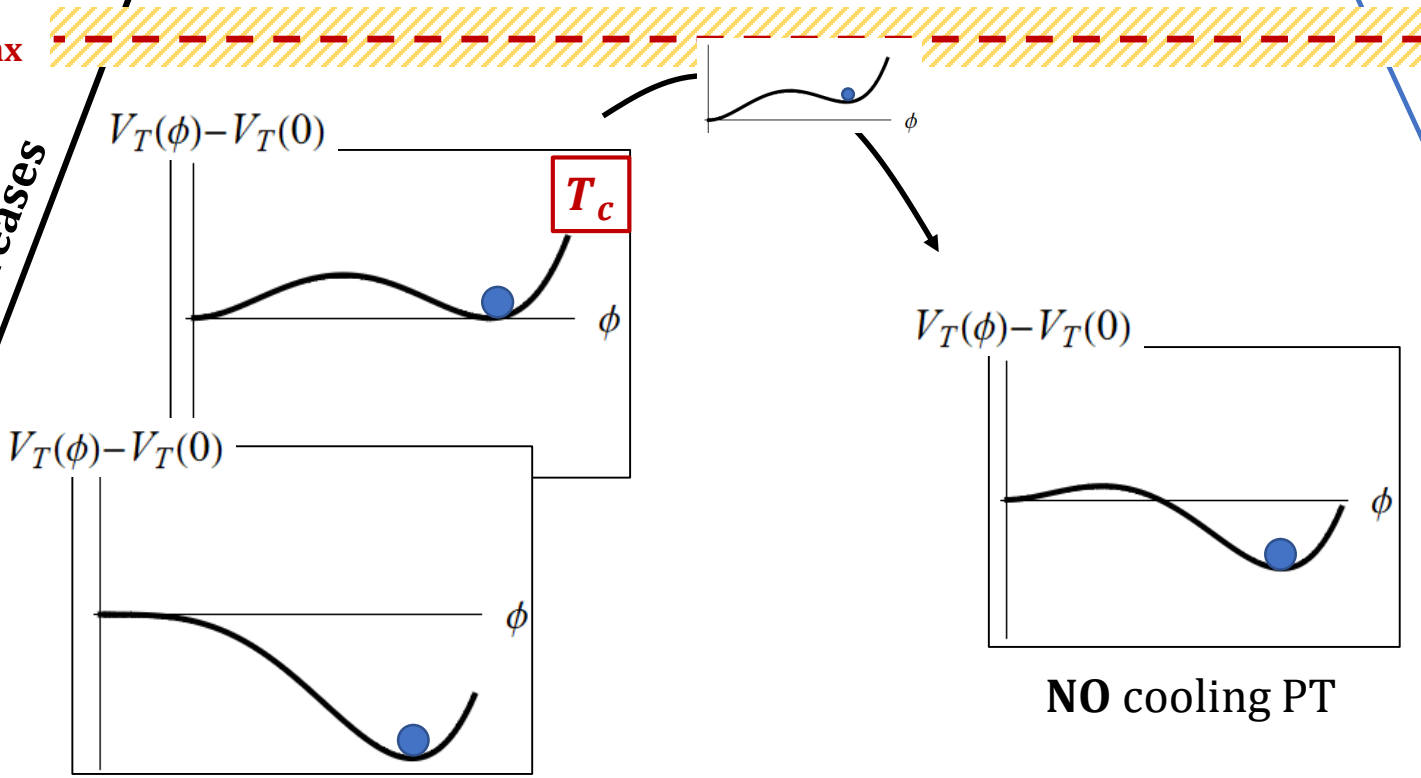
They are too far away from each other  
and PT is **not** finished because of cosmic expansion.  
(spacetime expansion between bubbles are faster)

PT is "**aborted**" before completion by the temperature's turning  
around at  $T_{\max}$ .

$T_{\max}$

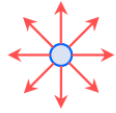
Temperature increases

Temperature decreases

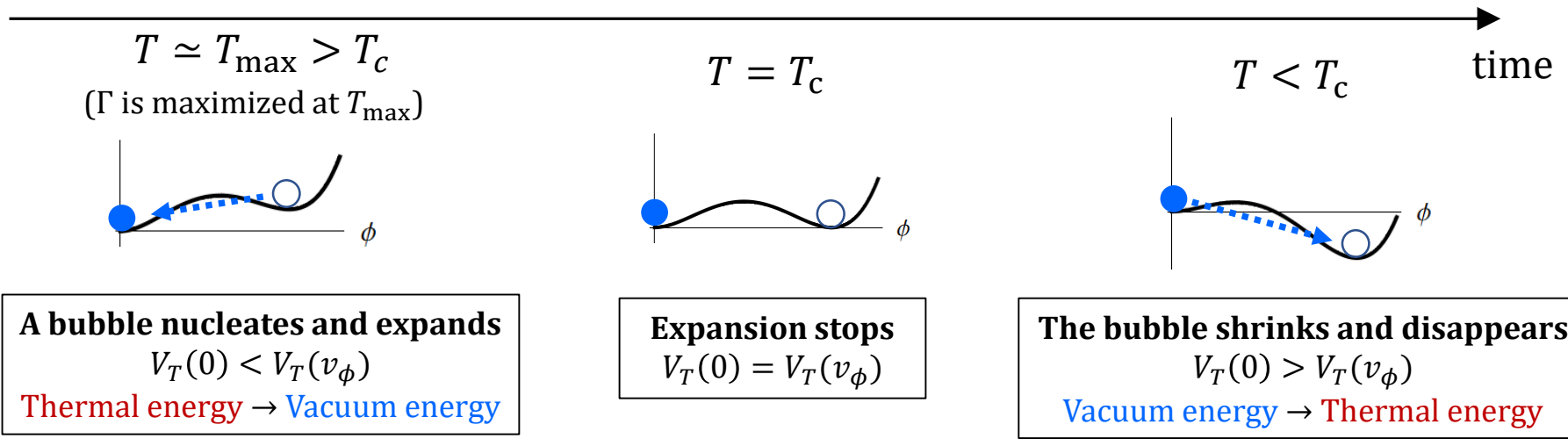
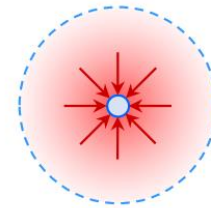
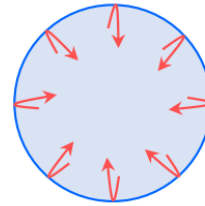


NO cooling PT

# Fate of bubbles nucleated in aborted PT



Symmetry-restoring  
bubble



- Vacuum energy is not redshifted while the surrounding thermal plasma gets redshifted.

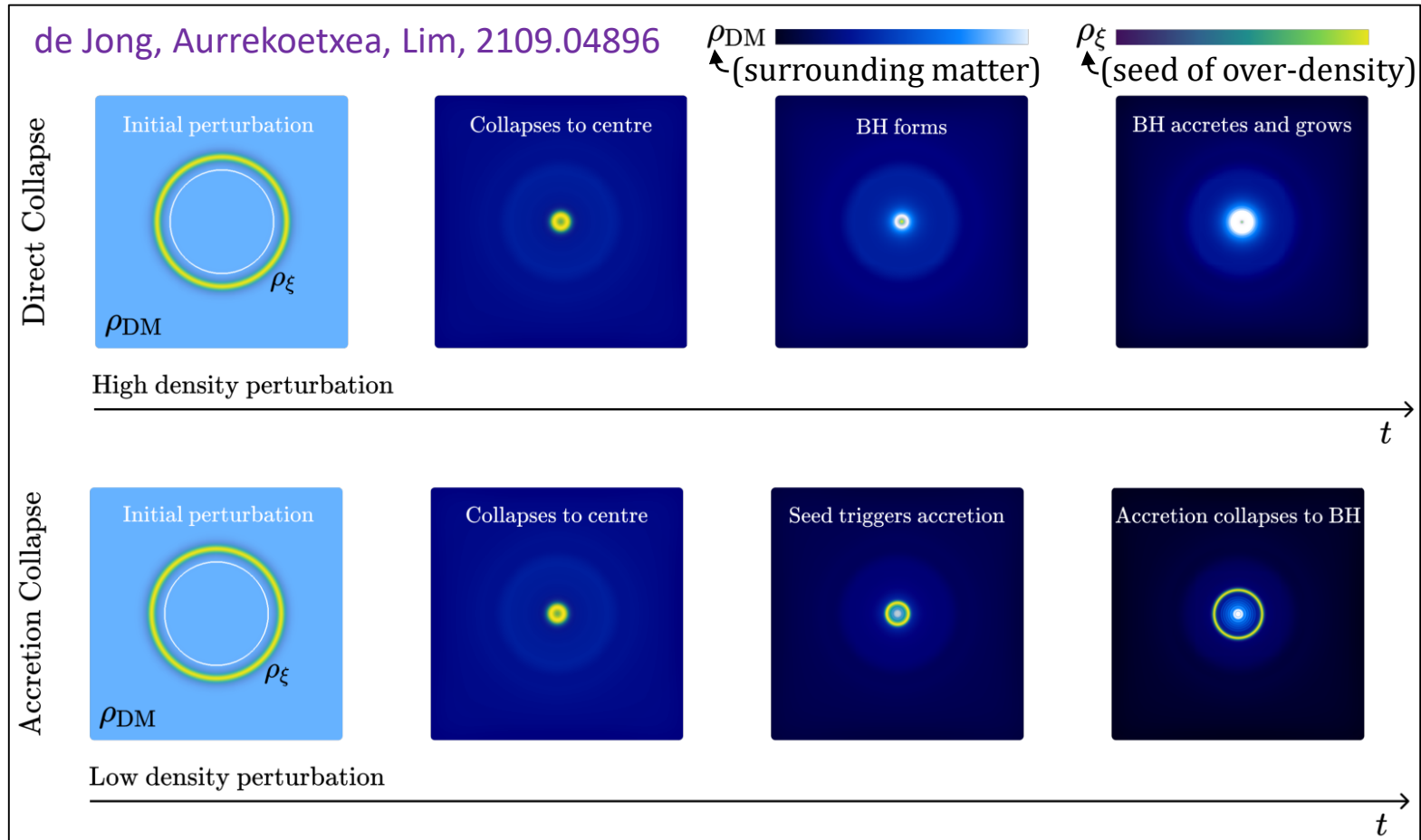
**$\Rightarrow$  A positive density perturbation is generated in the macroscopic region affected by the bubble dynamics.**



# PBH formation via post-accretion collapse

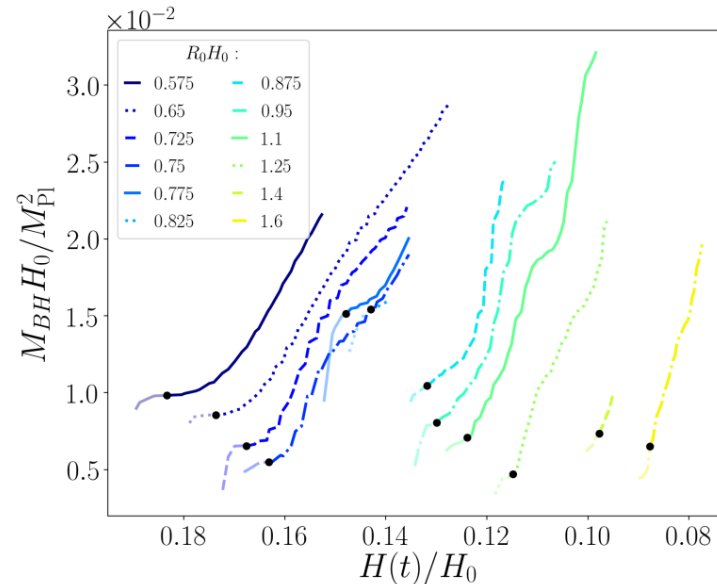
Since we are in the matter (reheaton) domination, the positive density perturbation accretes surrounding matter and collapses into a black hole: “**post-accretion collapse**”

**NR simulation confirmed it.**



# PBH mass

- The PBH keeps accreting surrounding matter and its mass grows quickly up to around the maximally allowed mass, which is the mass inside one Hubble patch.



- $M_{PBH}$  adiabatically follows one Hubble mass until the radiation domination starts.  
 $\Rightarrow$  **The final PBH mass is determined by around one Hubble mass at  $T_{RH}$**

$$\Rightarrow M_{PBH} \sim 3.5 \times 10^{-12} M_{\odot} \alpha \left( \frac{10^5 \text{ GeV}}{T_{RH}} \right)^2 \left( \frac{100}{g_*(T_{RH})} \right)^{1/2}$$

$\alpha$   
 $O(0.1 - 1)$  efficiency param  
 (we don't know the exact evolution)

# PBH abundance

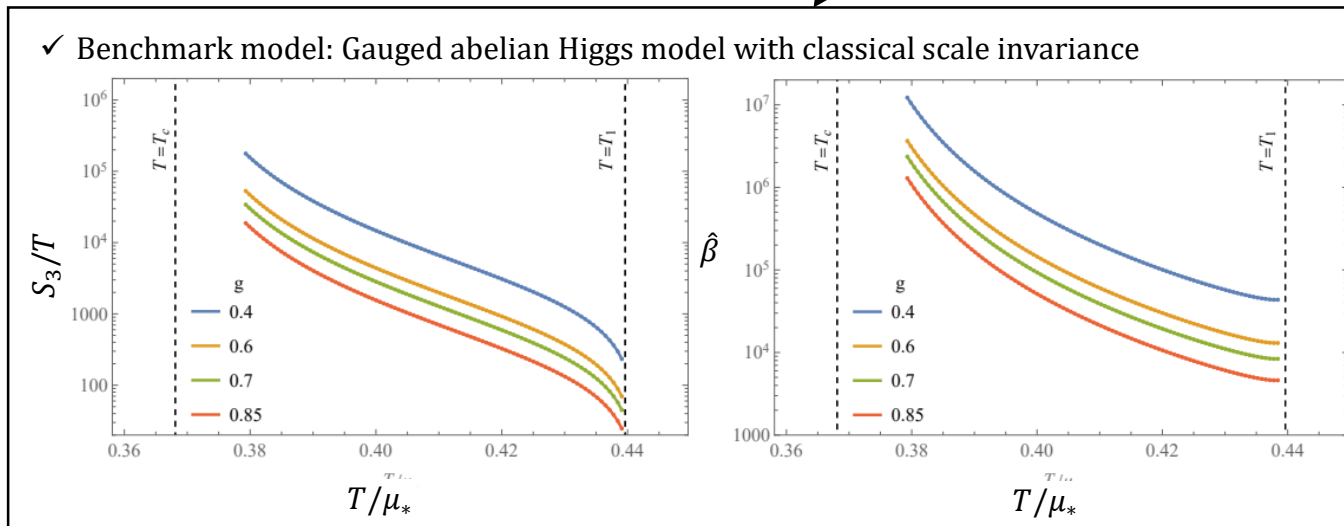
$$dN_{\text{PBH}} = dN_{\text{bubble}} = dt V \Gamma$$

(All bubbles become PBHs during the aborted PT)

- Bubble nucleation rate  $\Gamma(T)$  is maximal at  $T_{\text{max}} \Rightarrow$  Largest contribution comes from  $T_{\text{max}}$

$$\Gamma(T) \simeq T^4 e^{-S_3/T} \Rightarrow \Gamma(T) \simeq \Gamma(T_{\text{max}}) \left(\frac{T}{T_m}\right)^{\hat{\beta}_{\text{max}}+4}$$

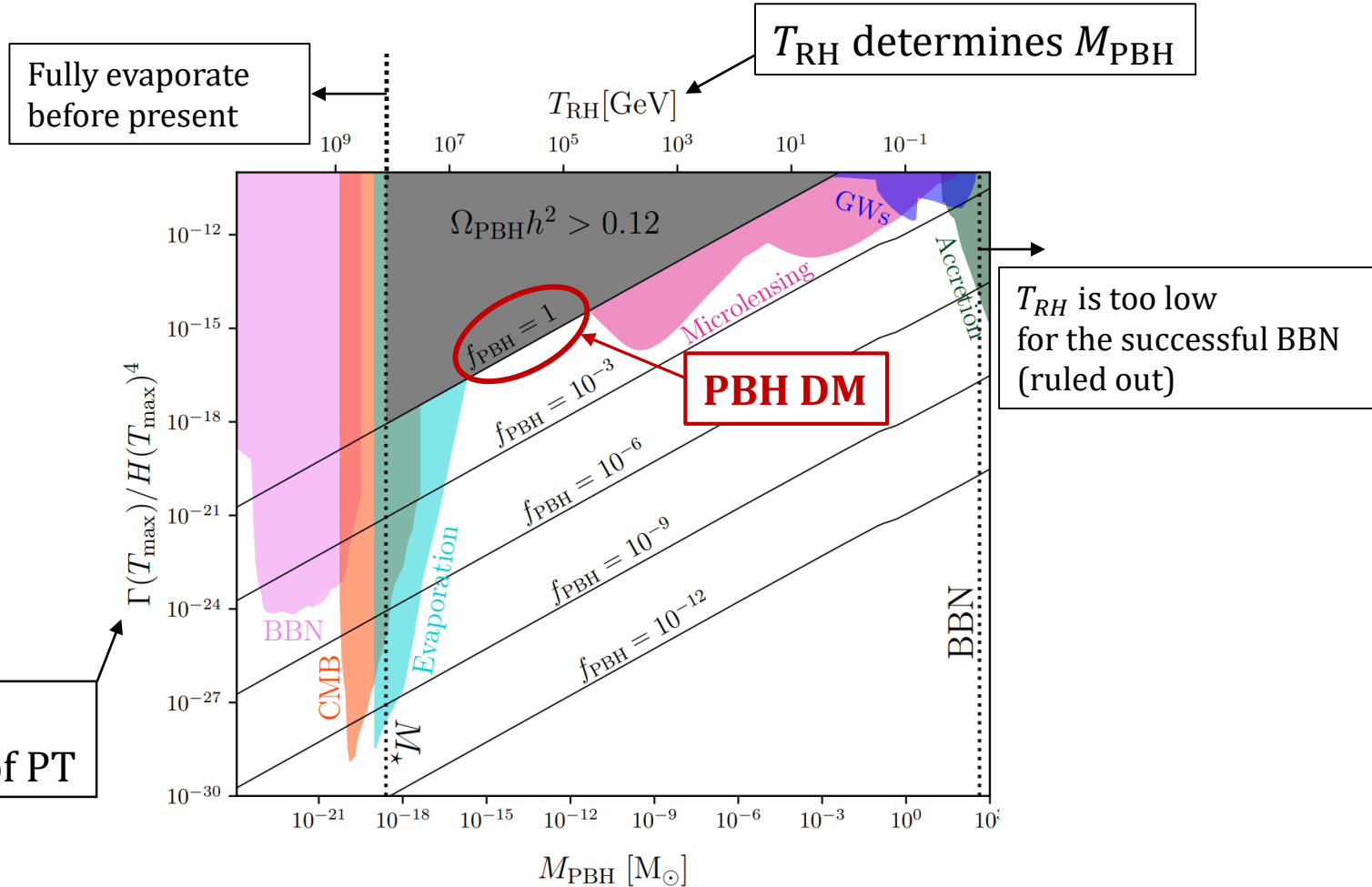
$\hat{\beta} \equiv -\frac{d(S_3/T)}{d \ln T}$  : PT rapidity parameter



$$f_{\text{PBH}} = \frac{M_{\text{PBH}} n_{\text{PBH}}/s}{\rho_{\text{DM}}/s} \sim 1 \alpha \left(\frac{T_{\text{RH}}}{10^5 \text{ GeV}}\right) \left(\frac{\Gamma(T_{\text{max}})}{H_{\text{max}}^4}\right) \left(\frac{10^5}{\hat{\beta}_{\text{max}}}\right)^{\frac{1}{2}} \left(\frac{a_{\text{RH}}/a_{\text{max}}}{10^2}\right)^{\frac{3}{2}}$$

(PBH relic density normalized by the observed DM relic)

# Result



Parameter choices

$$\alpha = 0.1, \quad \frac{a_{\text{RH}}}{a_{\text{max}}} = 10^2, \quad \hat{\beta}_{\text{max}} = 10^5$$

efficiency param in PBH mass estimation  
 $(M_{\text{PBH}} = \alpha M_H)$

# Summary

- During reheating after inflation, a heating PT can be aborted if  $T_c < T_{\max} < T_n$ .
- In the aborted PT, symmetry-restoring bubbles can still be nucleated although they never collide.
- These bubbles shrink and disappear while positive density perturbations are generated on a macroscopic scale.
- They lead to PBH formation via post-accretion collapse mechanism, so the PBH mass is determined by the reheating temperature.
- PBH abundance is estimated by counting the number of bubbles.

Thank you!

