Form PBHs from supercooled 1stOPT

Yann Gouttenoire

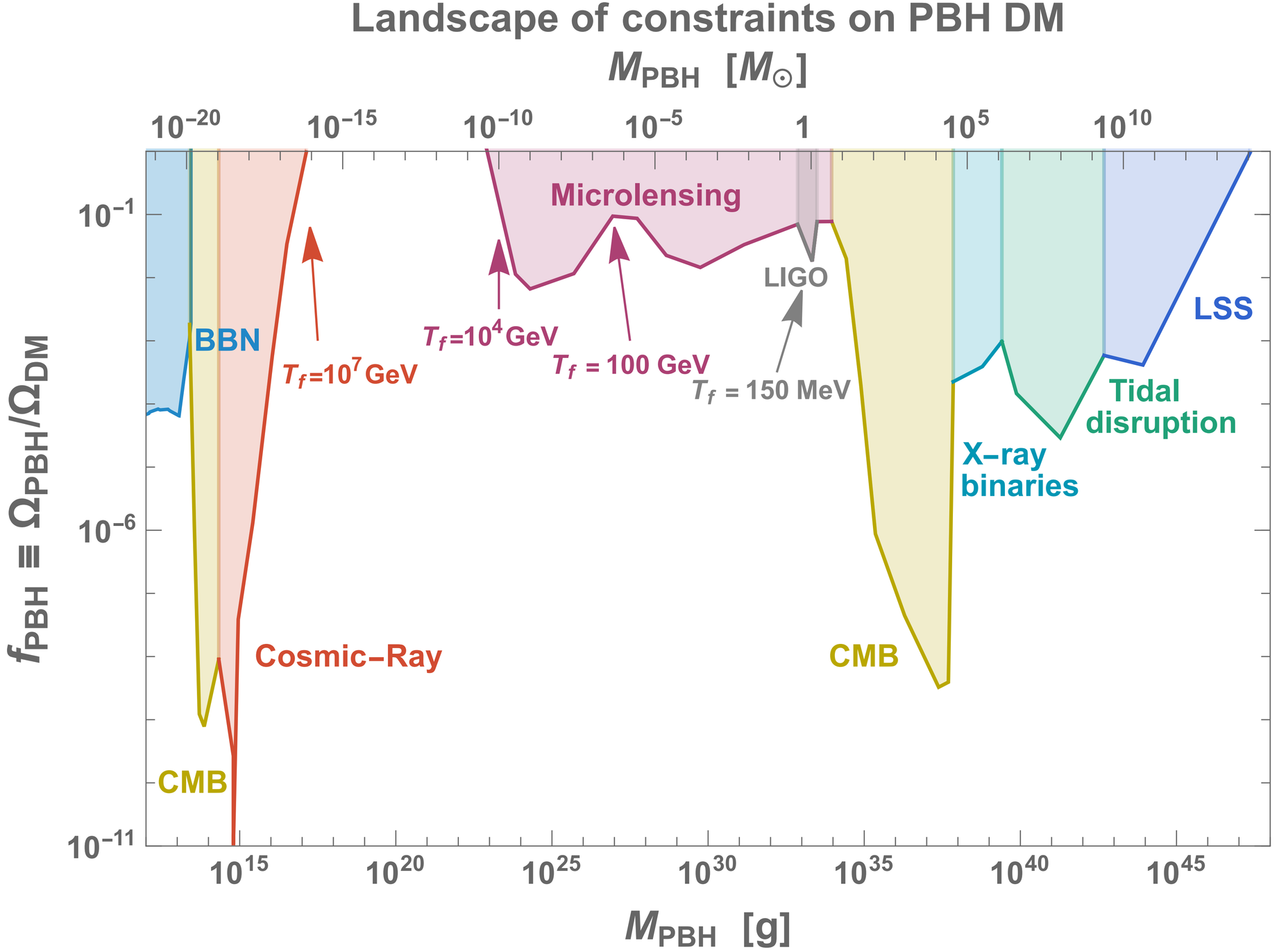
In collaboration with Tomer Volansky

25/05/2022

Founded by

Azrieli International Postdoctoral Fellows

33e Rencontre de Blois


Landscape of constraints on PBH DM
M_{PBH} [$M_\odot$]
10^{-20}
10^{-15}
10^{-10}
10^{-5}
1
10^{5}
10^{10}
10^{-1}
10^{-6}
10^{-11}
$f_{PBH} \equiv \Omega_{PBH}/\Omega_{DM}$
Microlensing
LIGO
BBN
T_f=10^7 GeV
T_f=10^4 GeV
T_f = 100 GeV
T_f = 150 MeV
LSS
Tidal disruption
X–ray binaries
Cosmic–Ray
CMB
CMB
10^{15}
10^{20}
10^{25}
10^{30}
10^{35}
10^{40}
10^{45}
M_{PBH} [g]

PBH cookbook

PBH cookbook

1) PBHs from primordial scalar fluctuation

Carr, Lidsey 1993 P. Ivanov+ 1994

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2) PBHs from cosmic string loop

Hawking 1989

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3) PBHs from 1stOPT:

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c) PBHs from snowplow effects

Baker, Breitbach, Kopp, Mittnacht 2021
Kawana, Xie 2021
Gross, Landini, Strumia, Teresi 2021

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d) PBHs from fluctuation of the percolation time

Liu, Bian, Strumia, Cai, Guo, Wang 2021 Hashino, Kanemura, Takahashi 2021

PBHs from fluctuation of the percolation time

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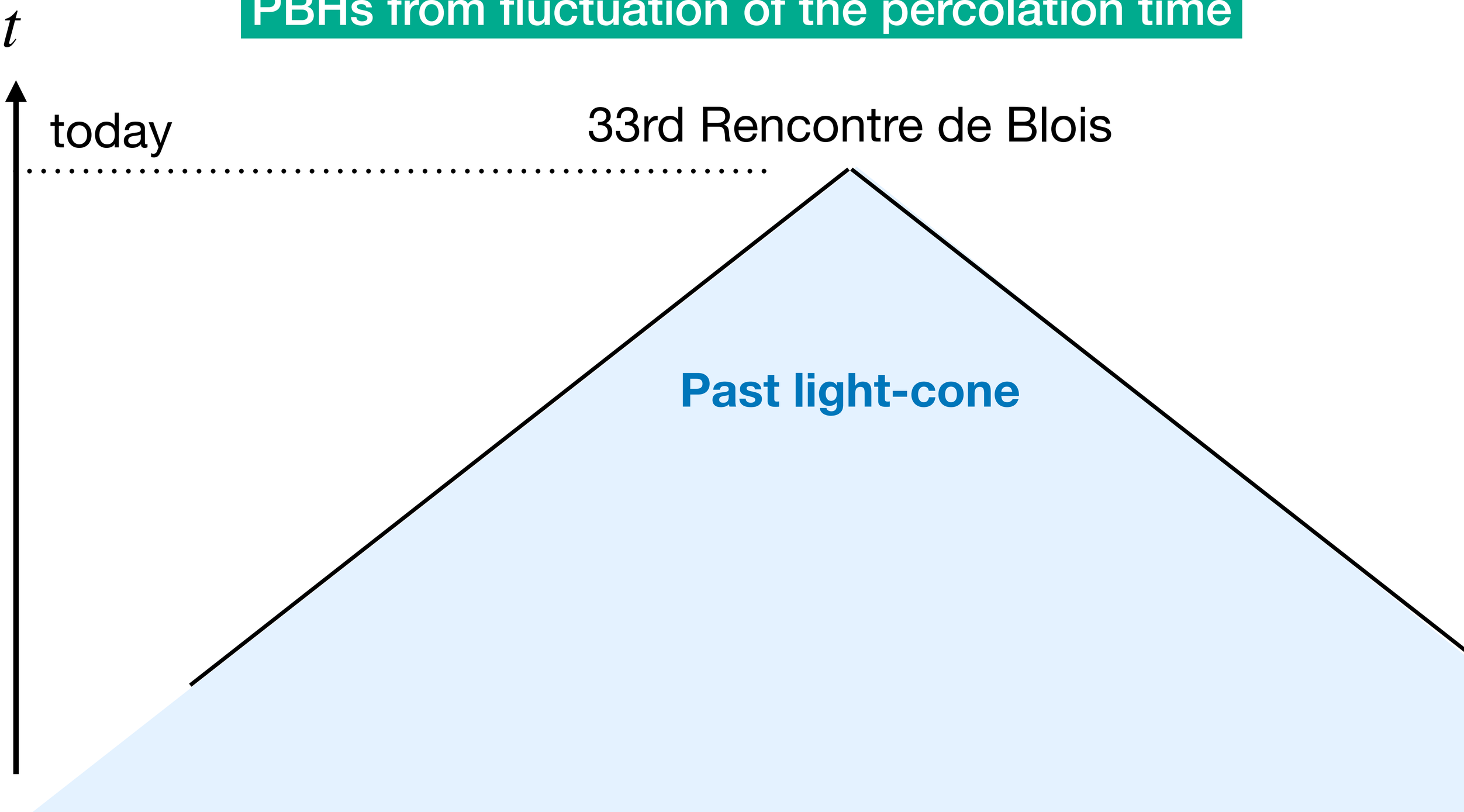
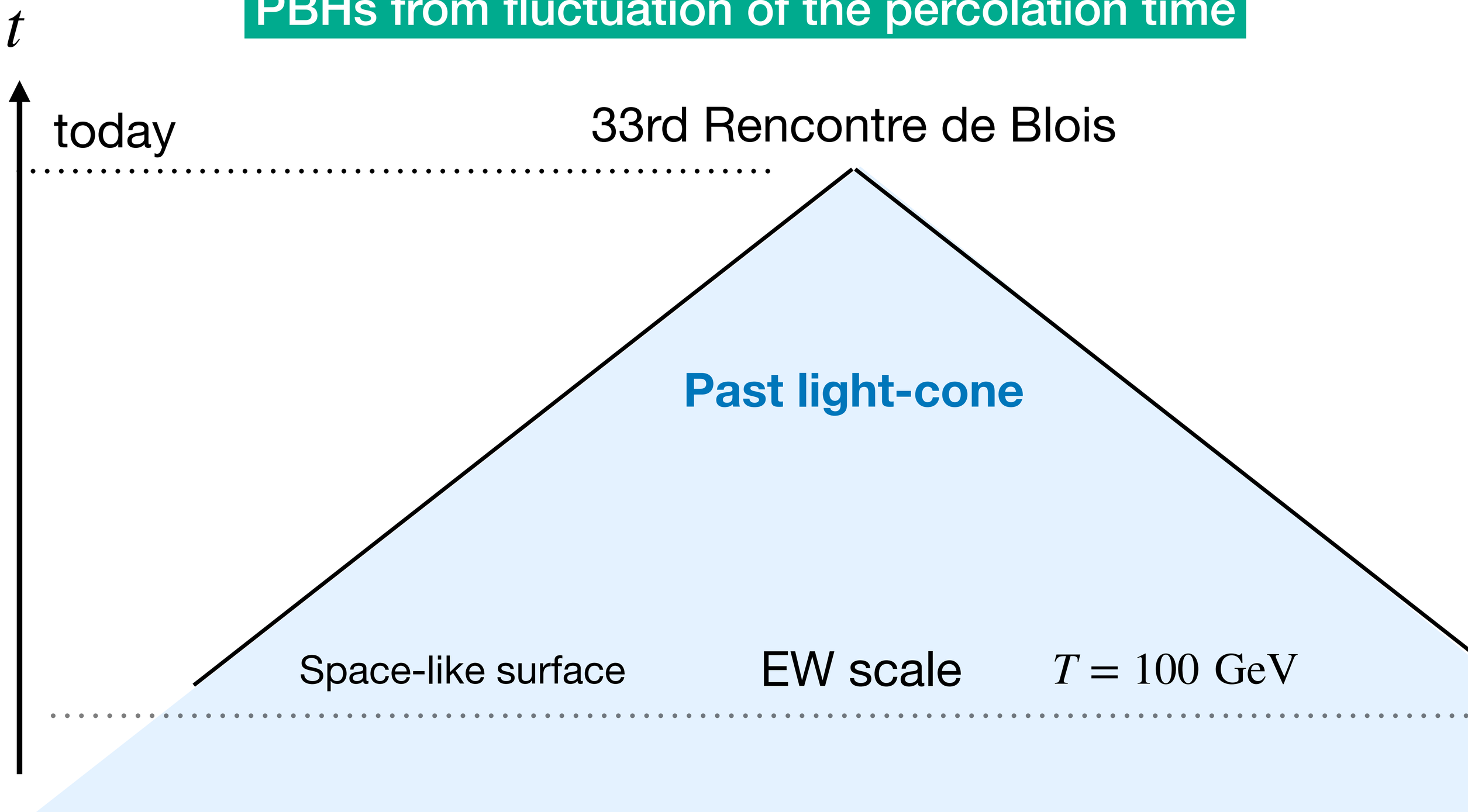


PBHs from fluctuation of the percolation time



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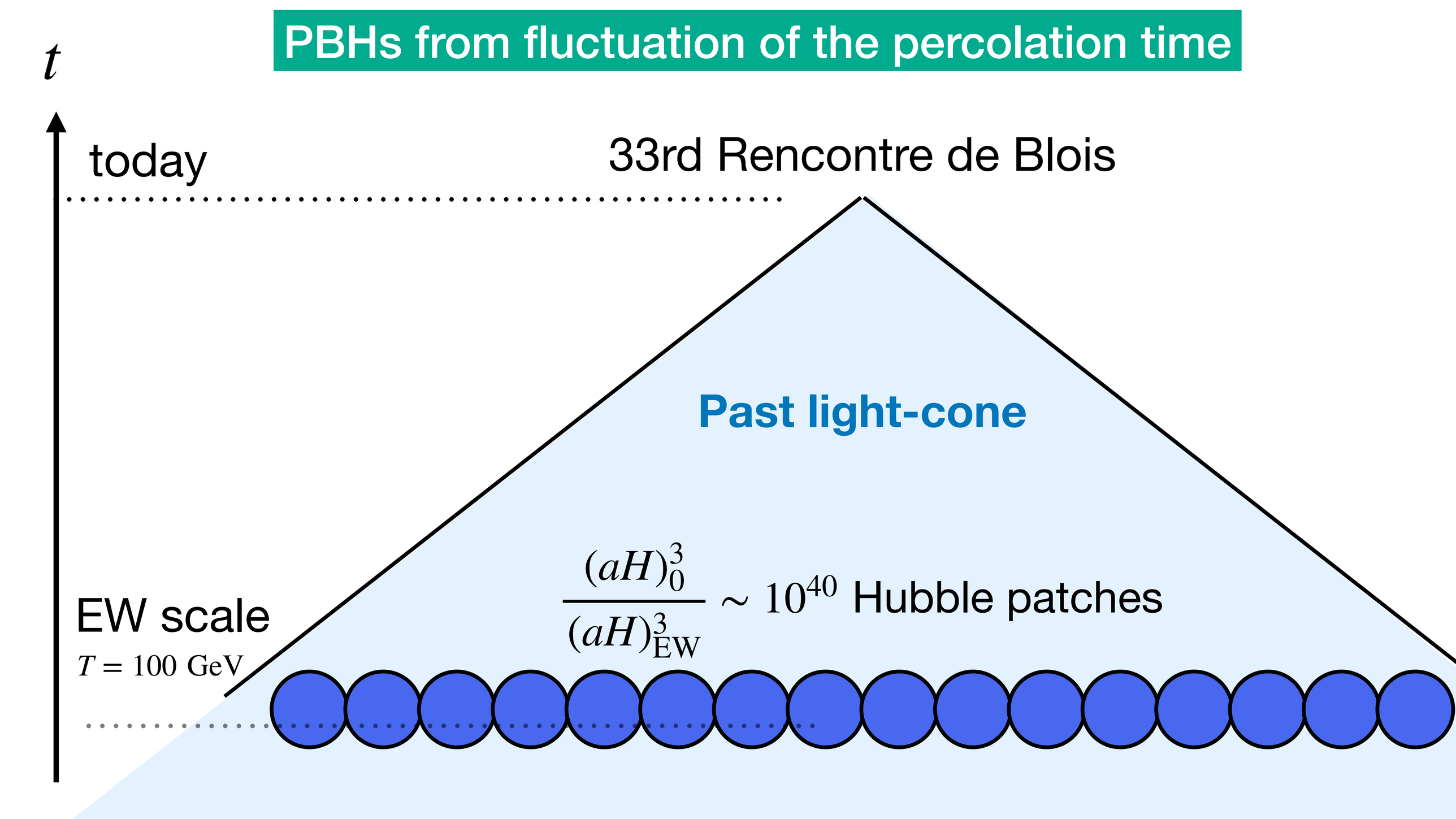

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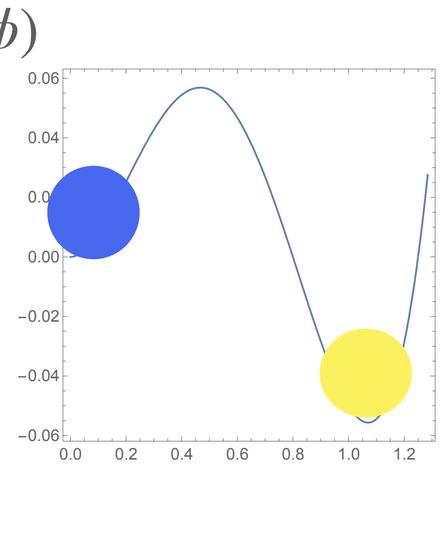

t

today

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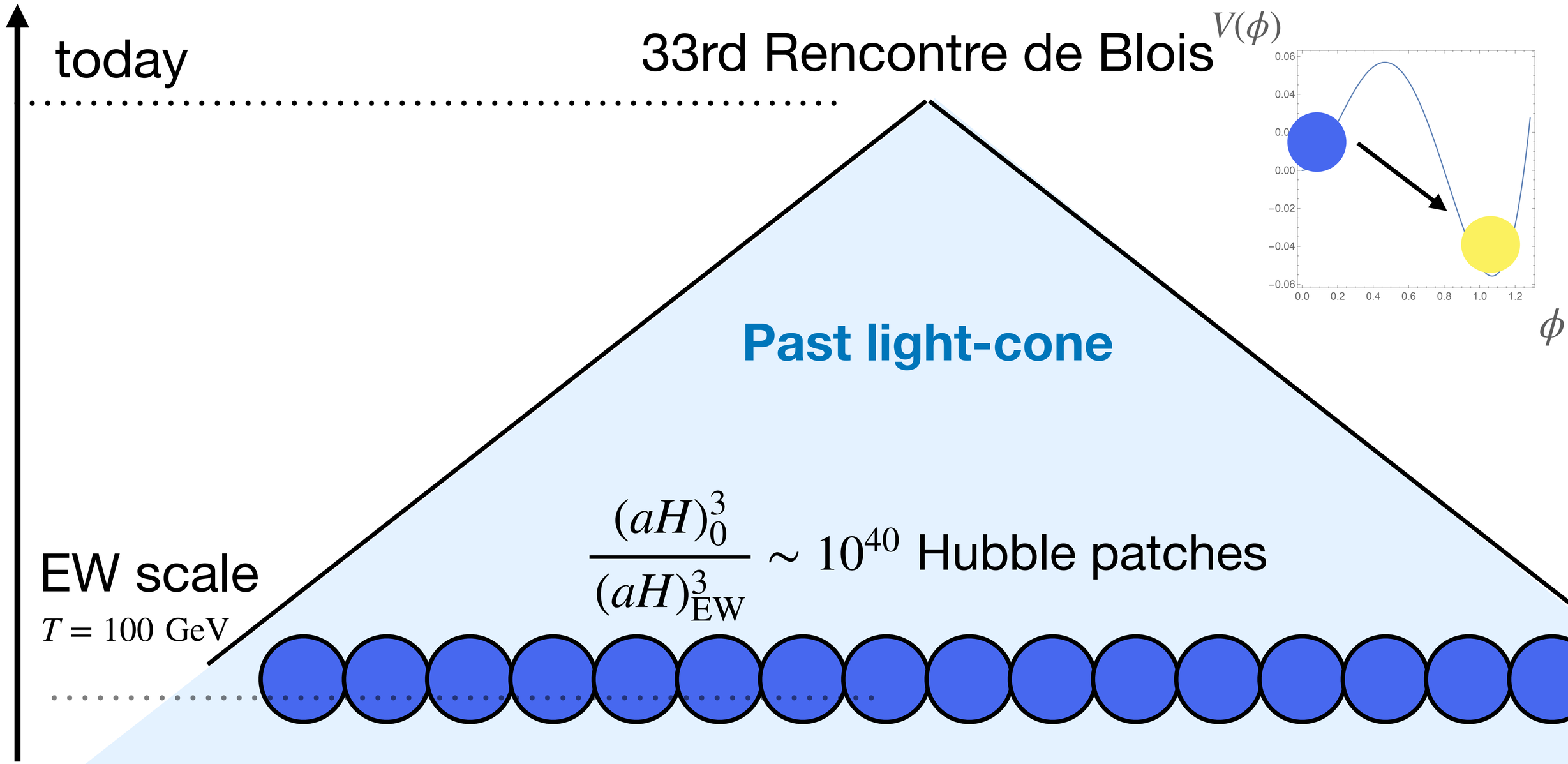
Past light-cone

$$\frac{(aH)_0^3}{(aH)_{\rm EW}^3} \sim 10^{40} \text{ Hubble patches}$$

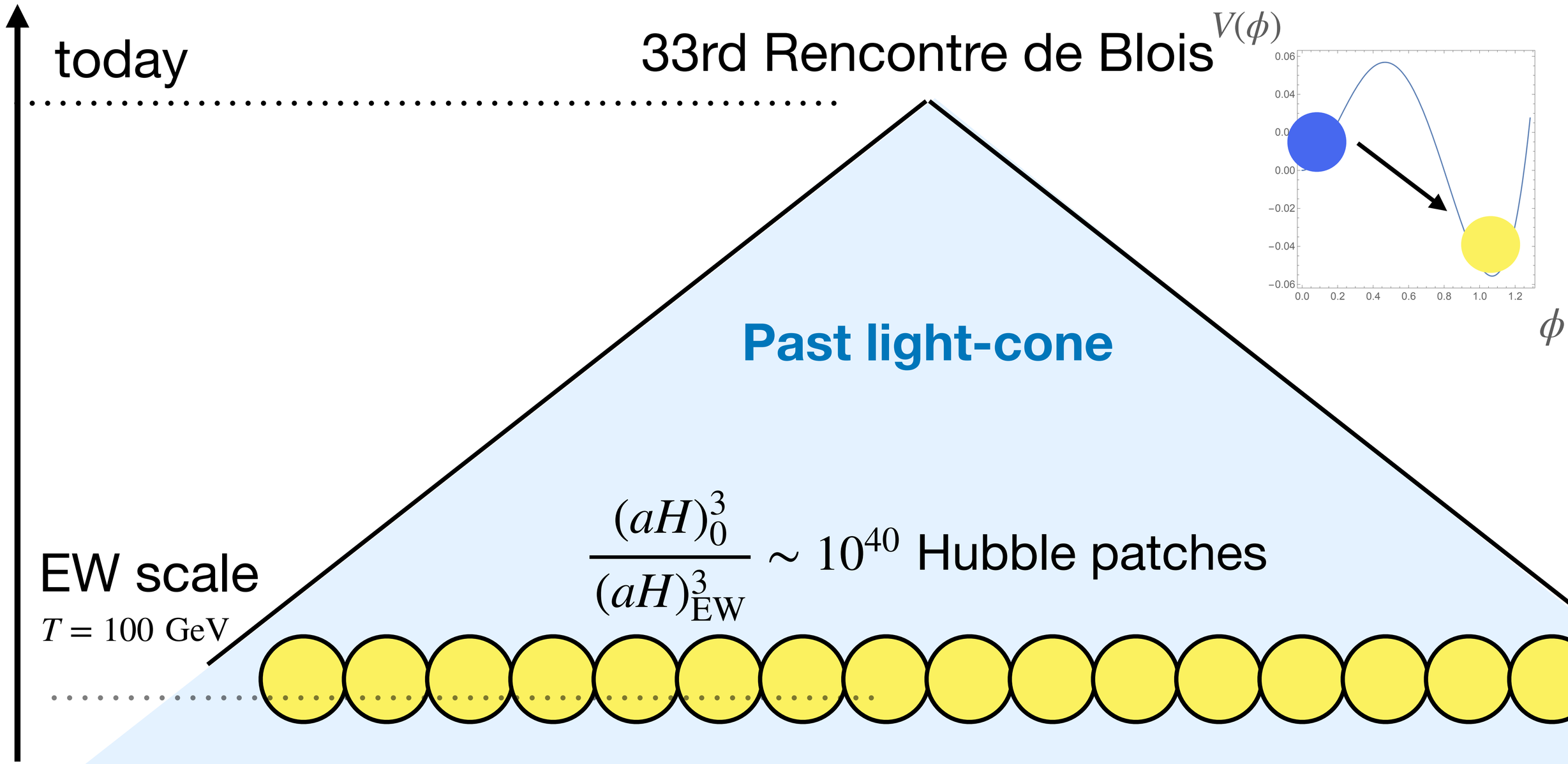
EW scale

$T = 100$ GeV

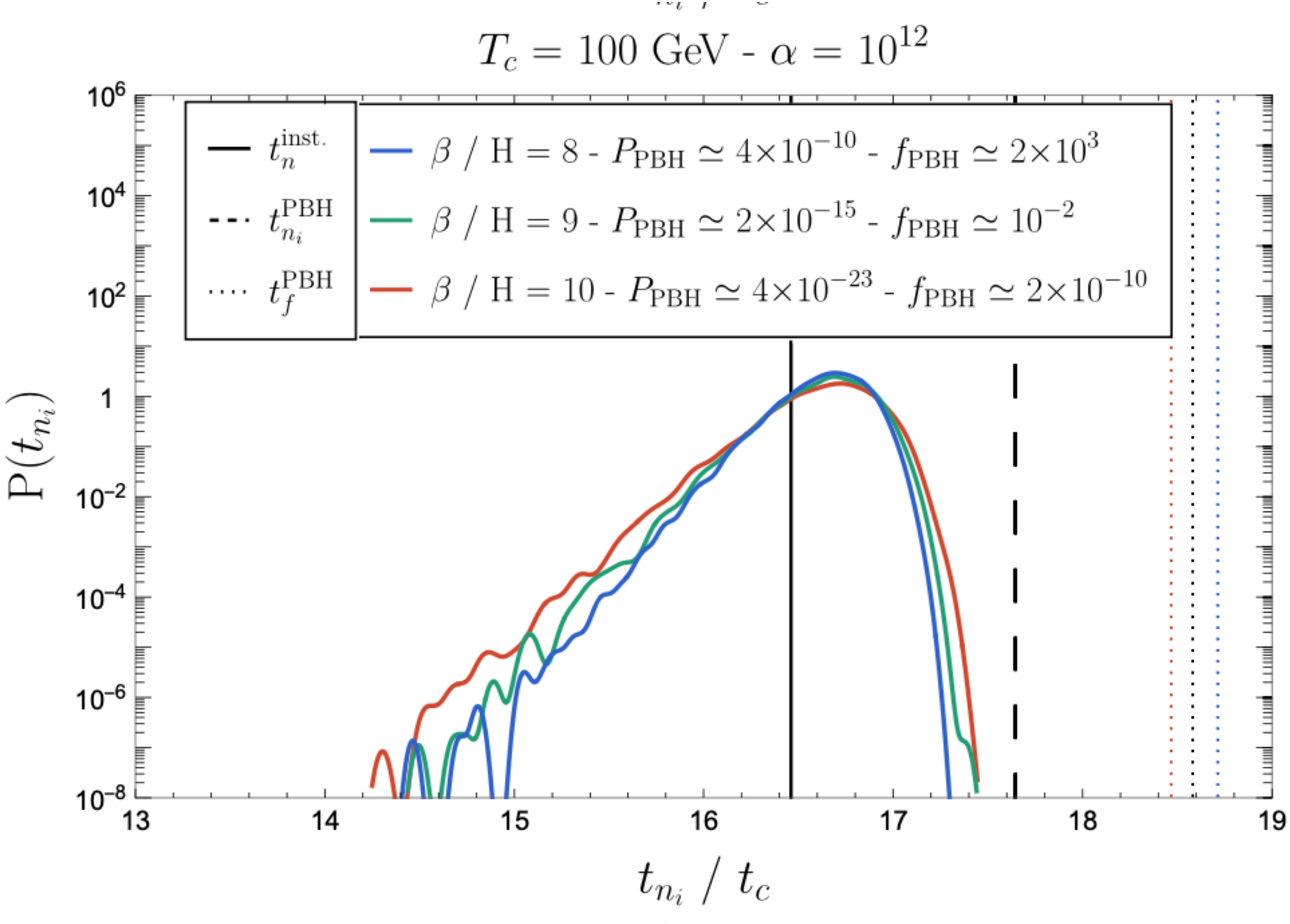
PBHs from fluctuation of the percolation time



PBHs from fluctuation of the percolation time



When phase transition takes place ?



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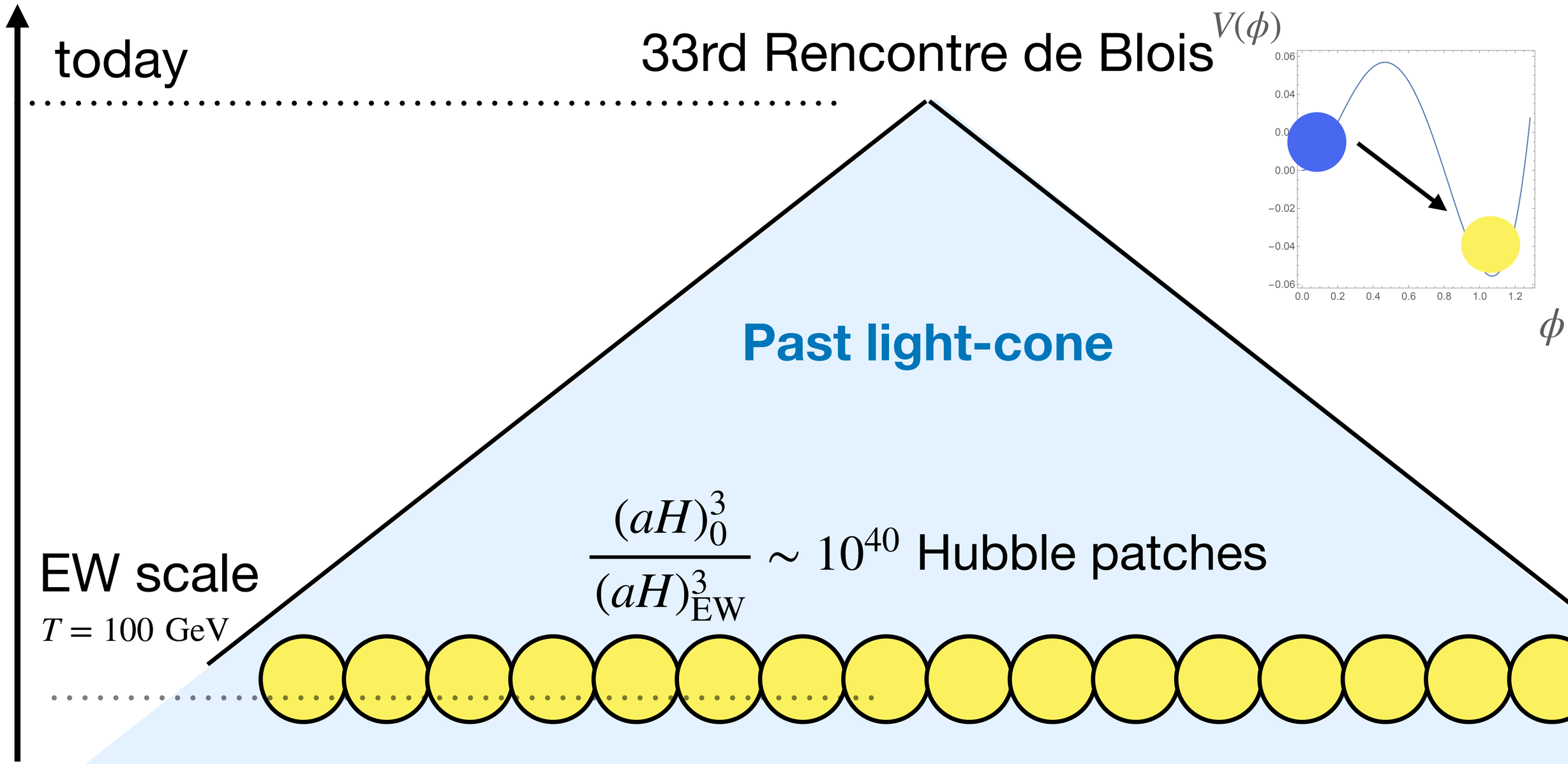

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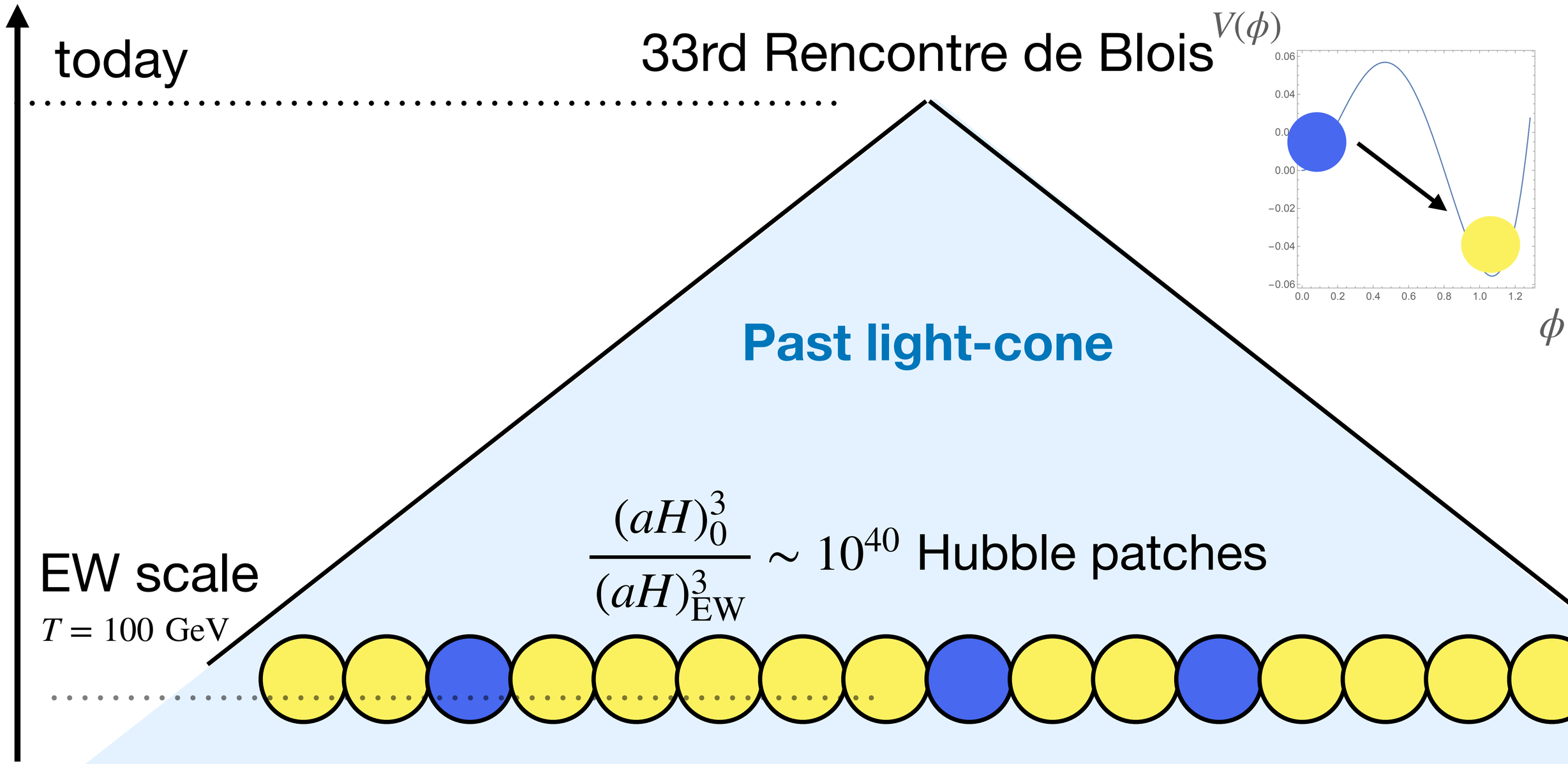

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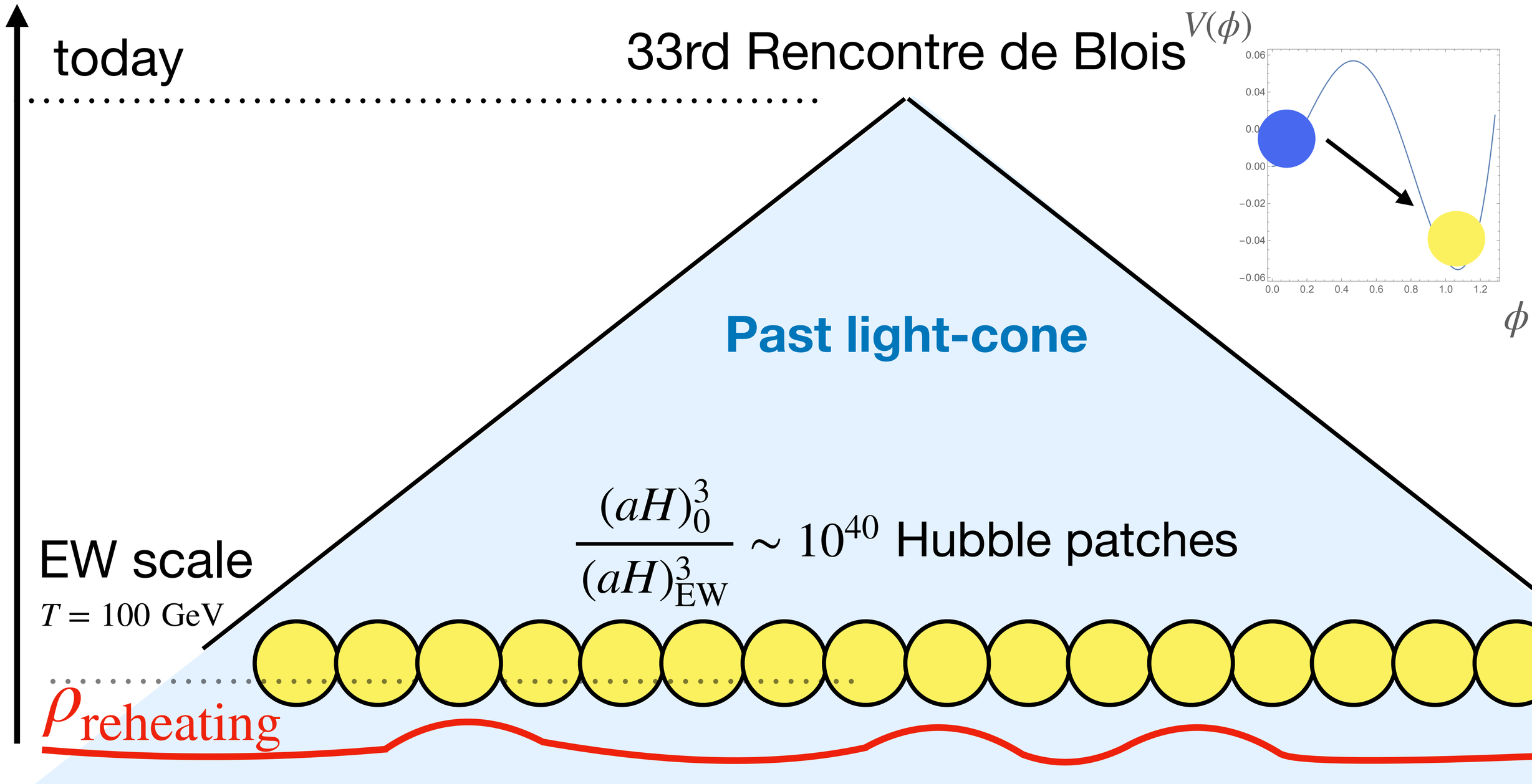

Supercooled 1stOPT

Supercooled 1stOPT = Hierarchical PT

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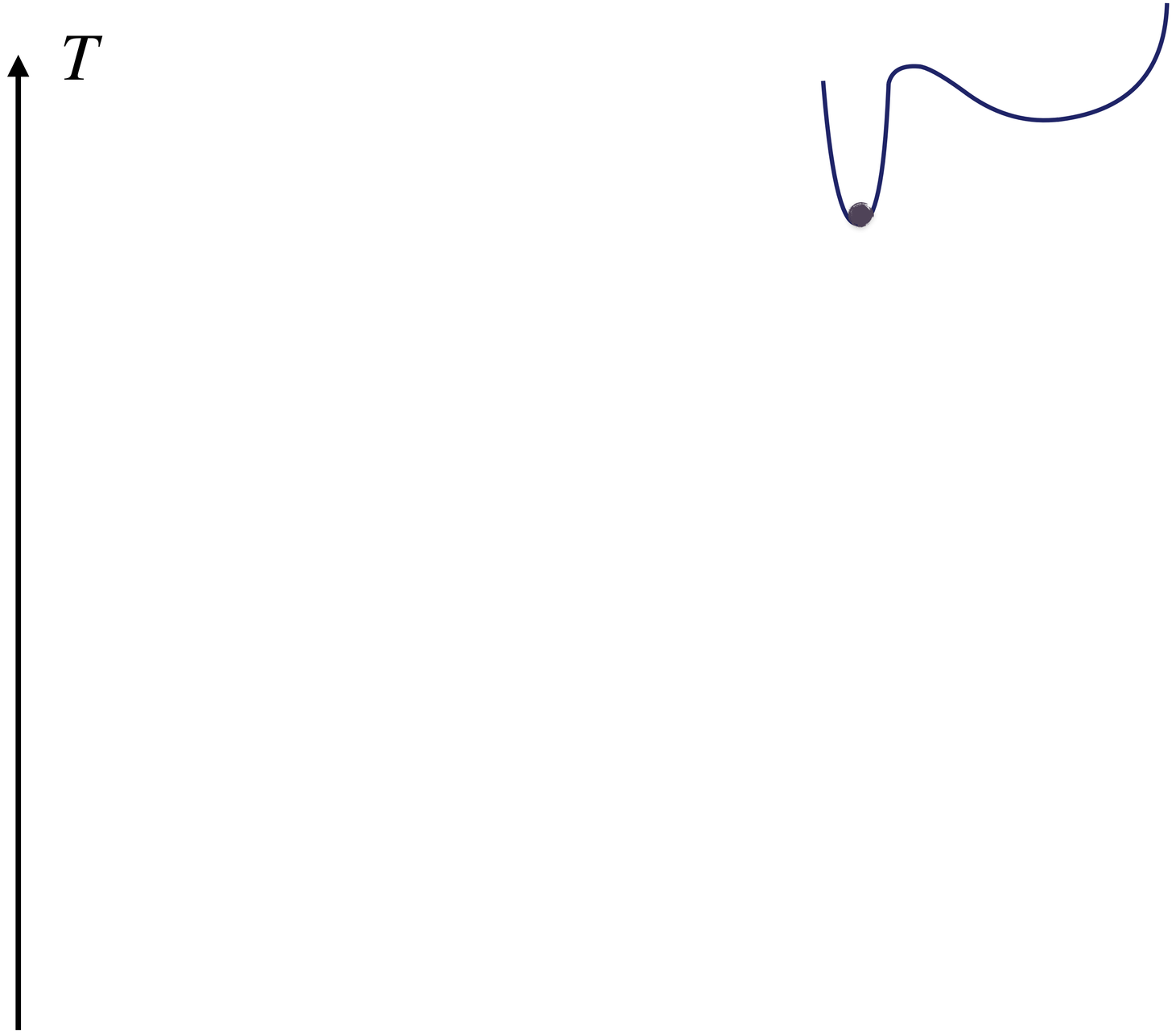

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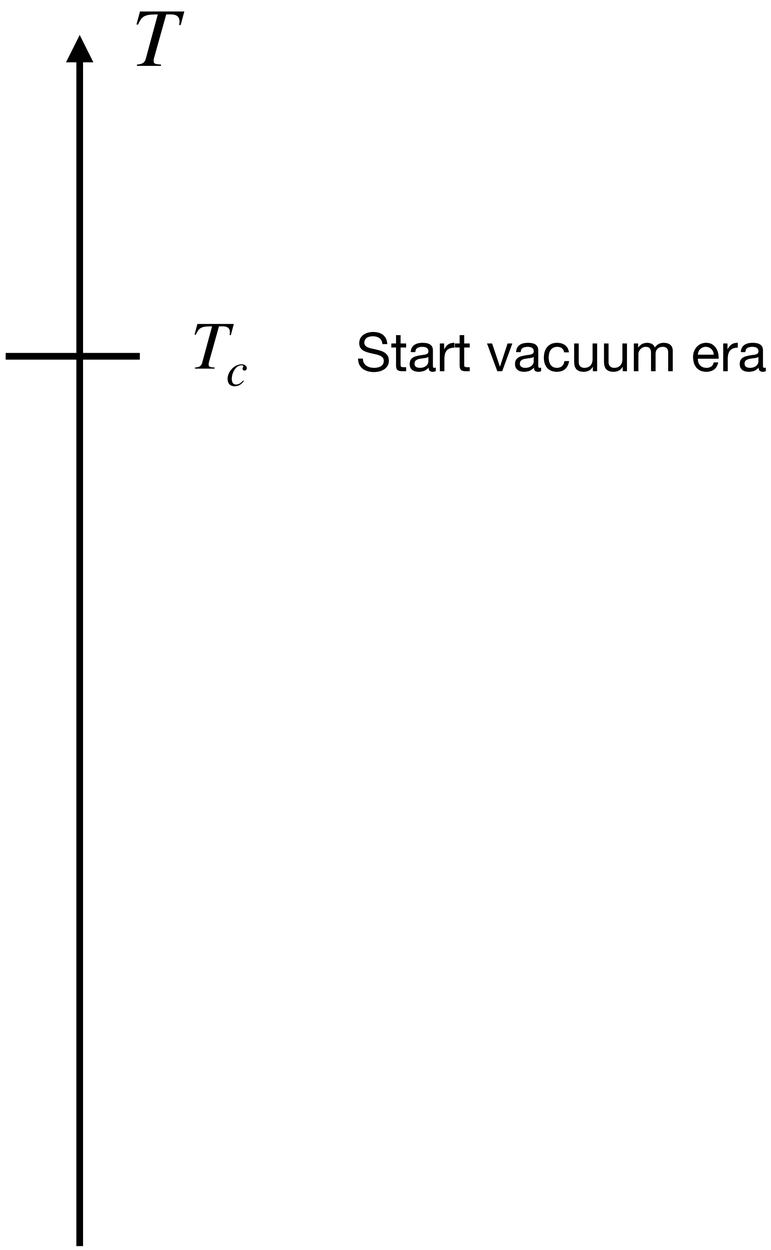
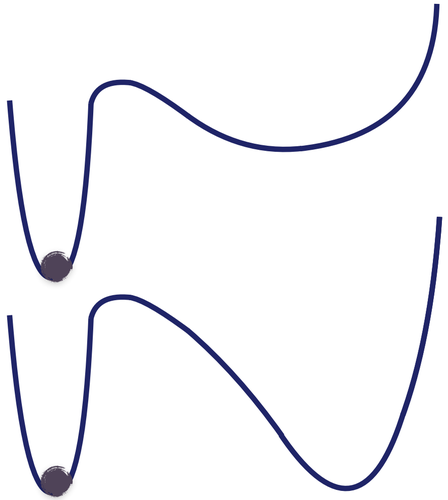


Start vacuum era



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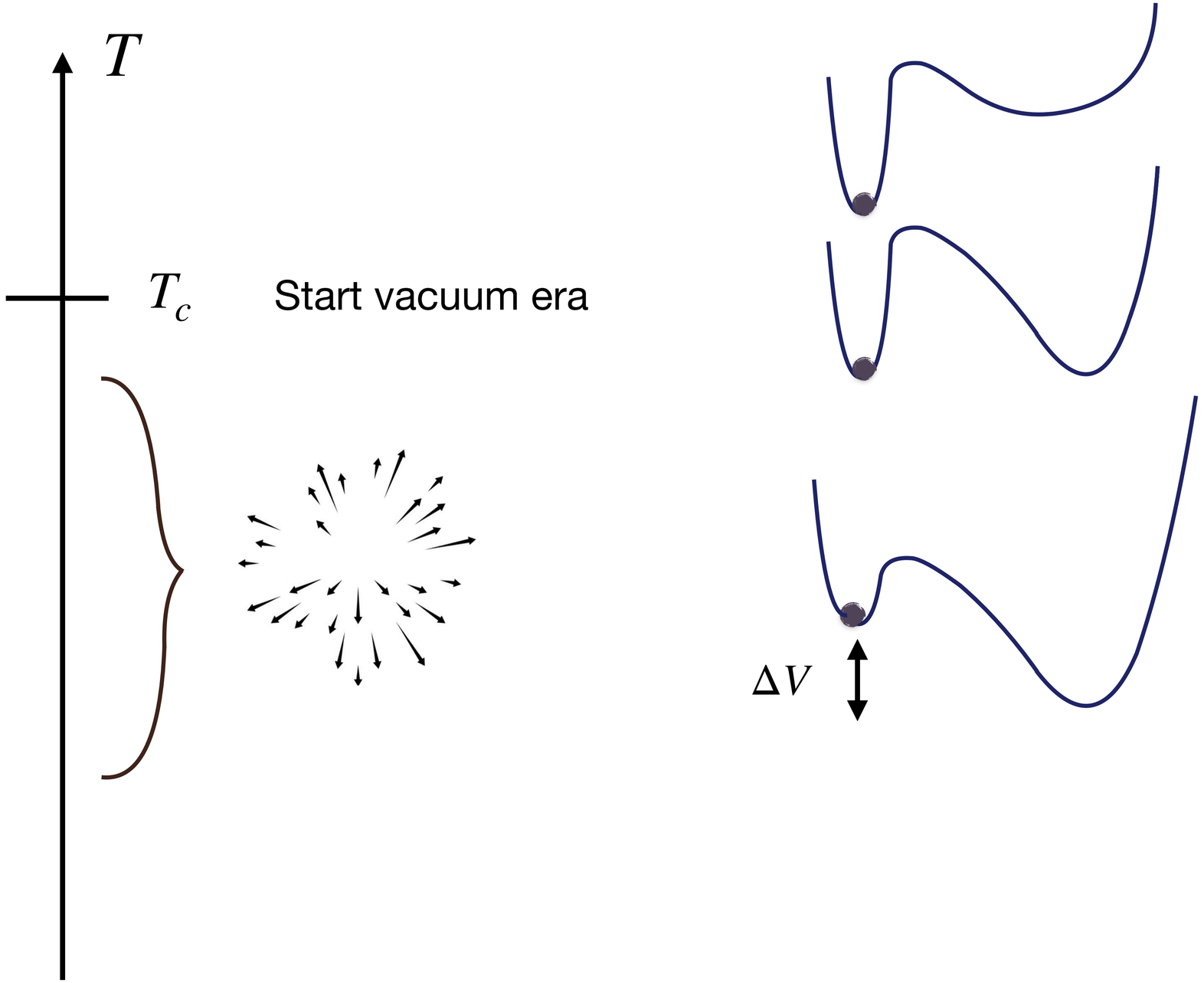

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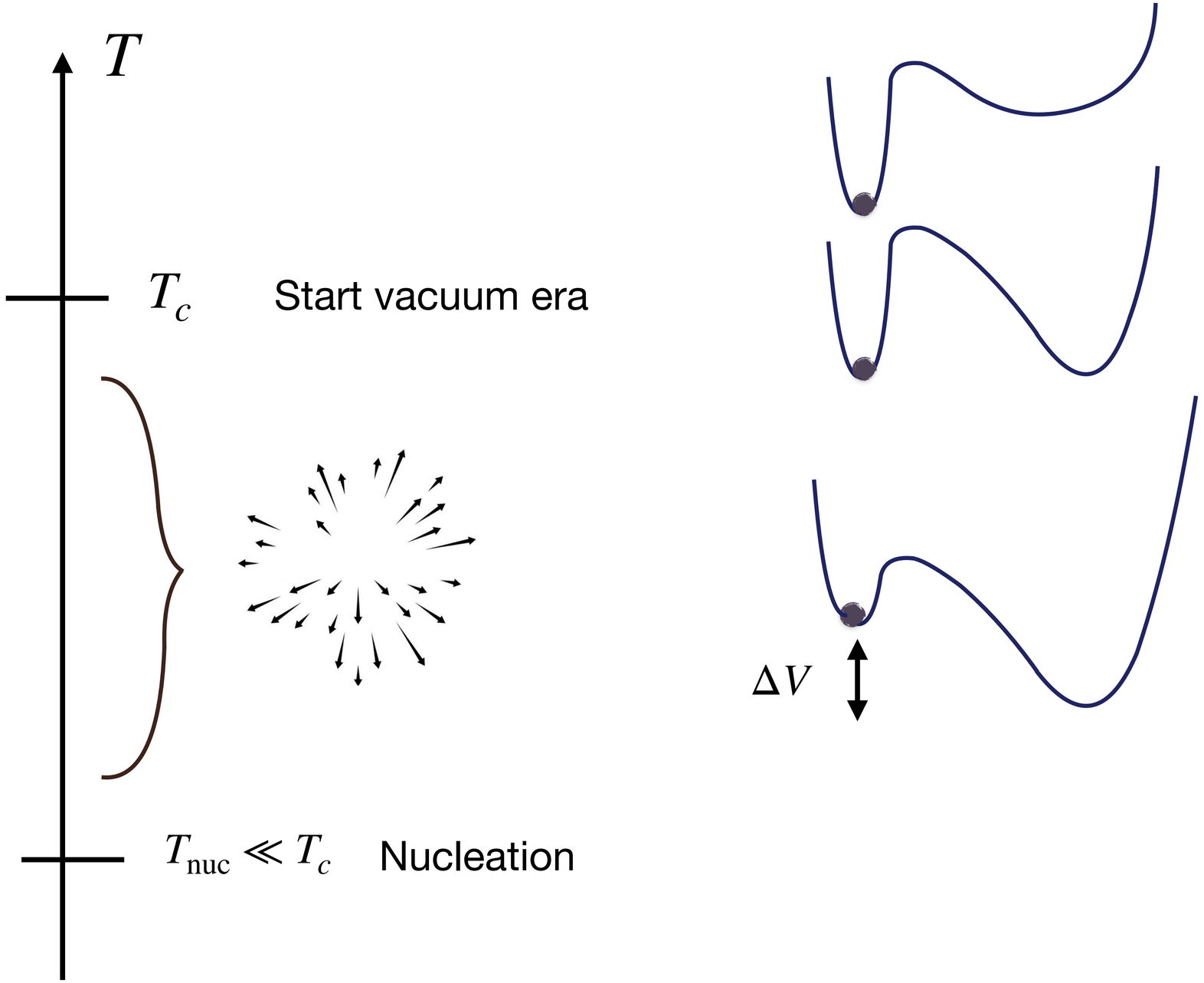

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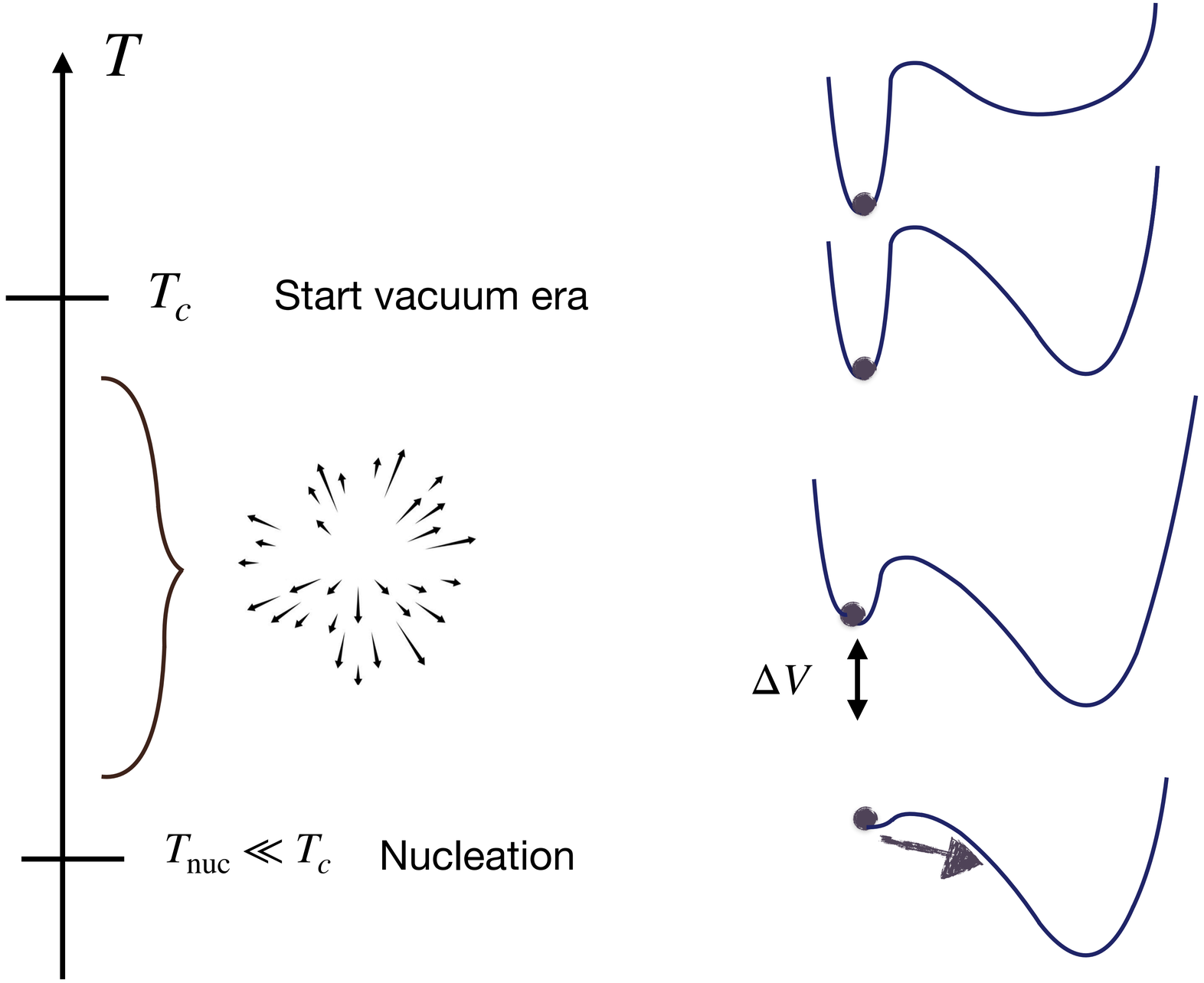

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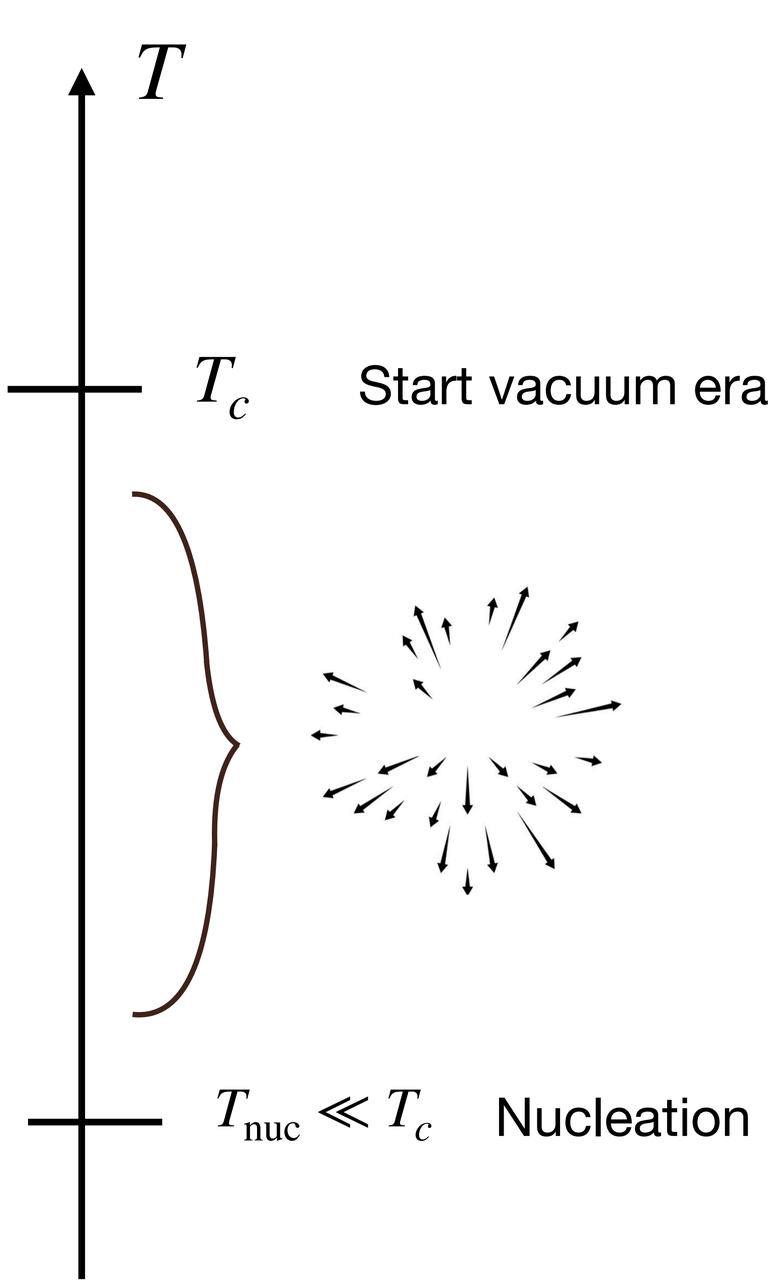

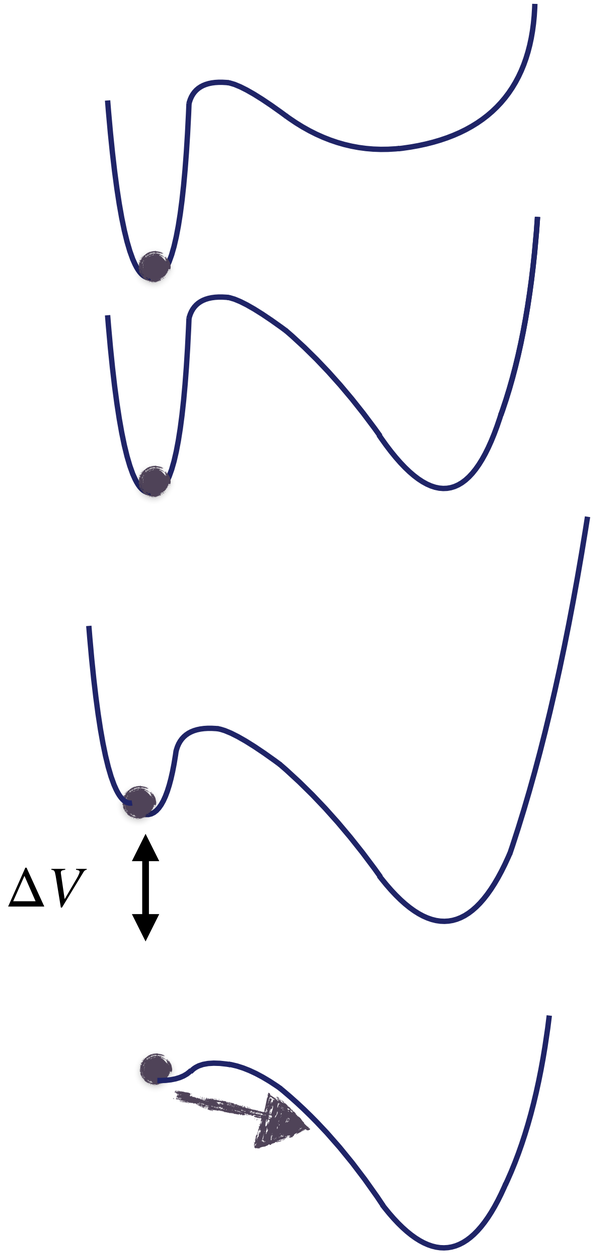

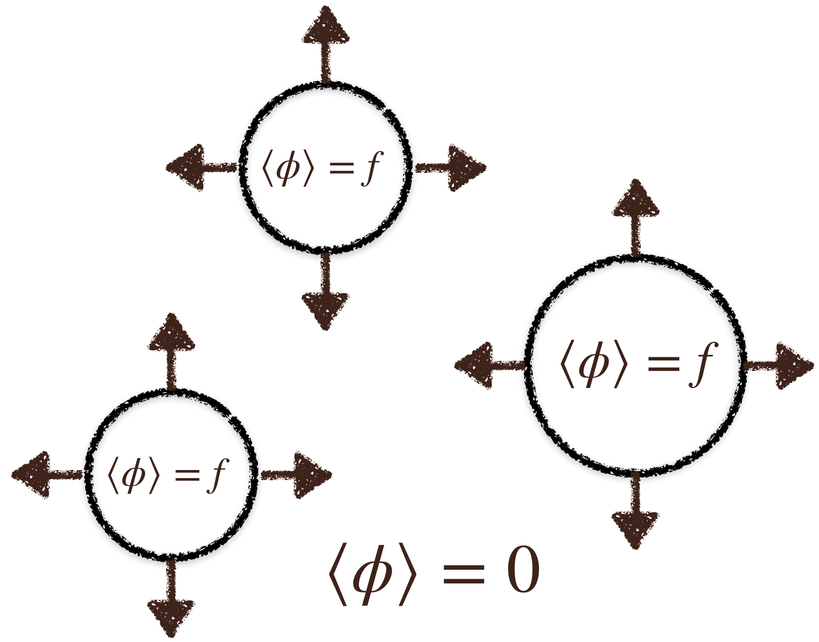

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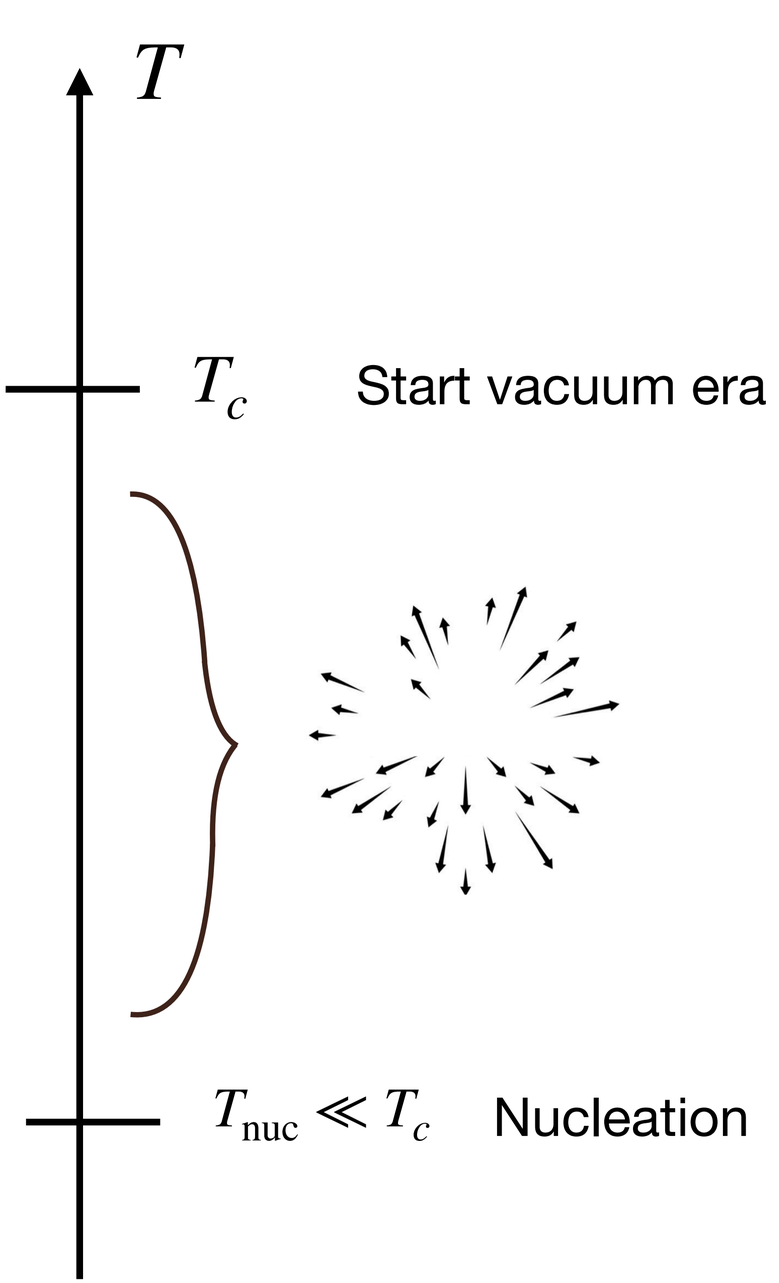

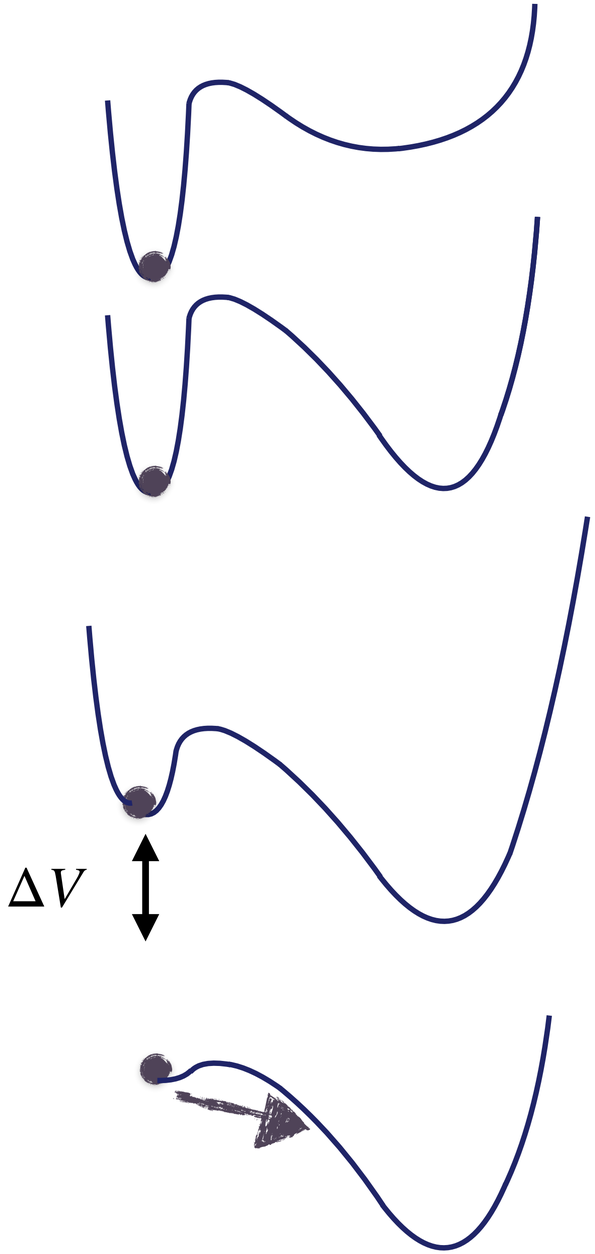

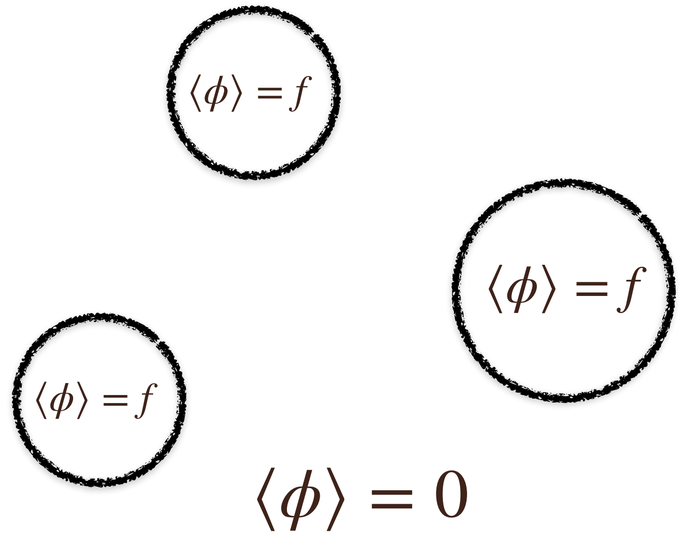

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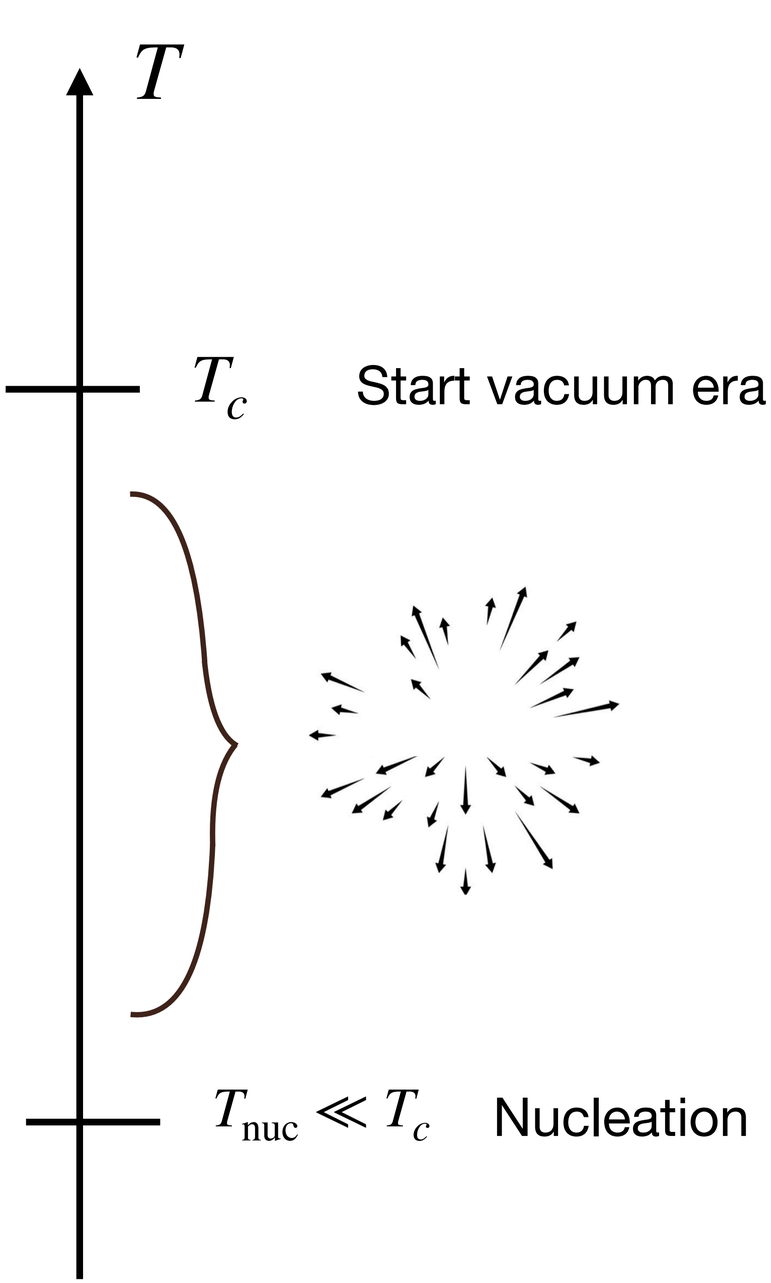

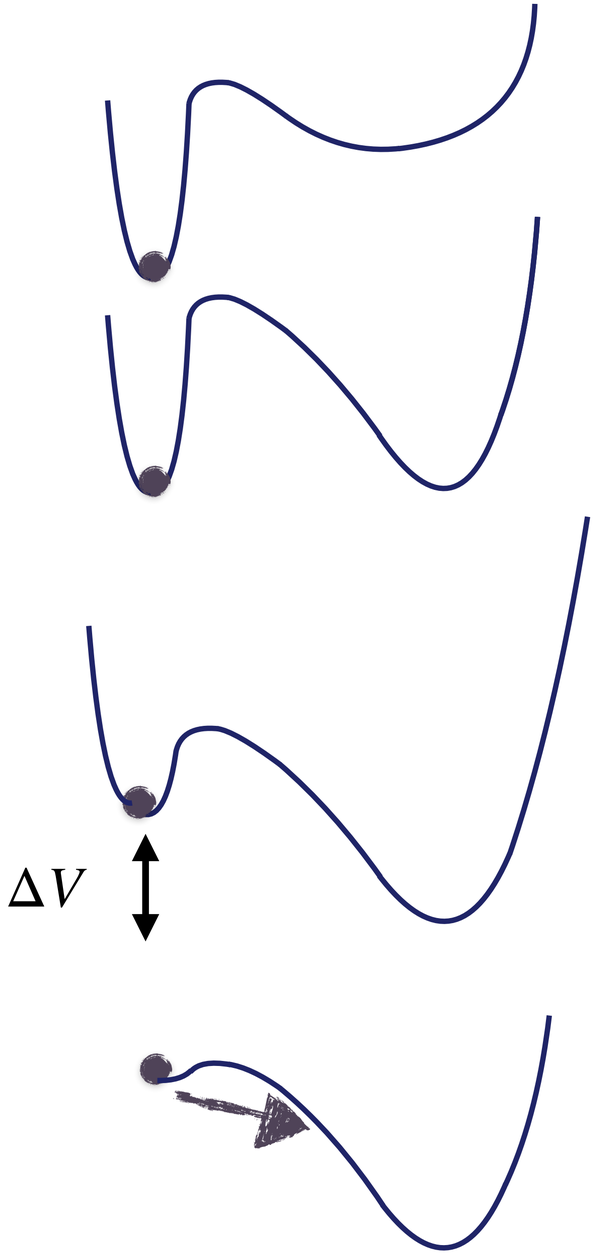

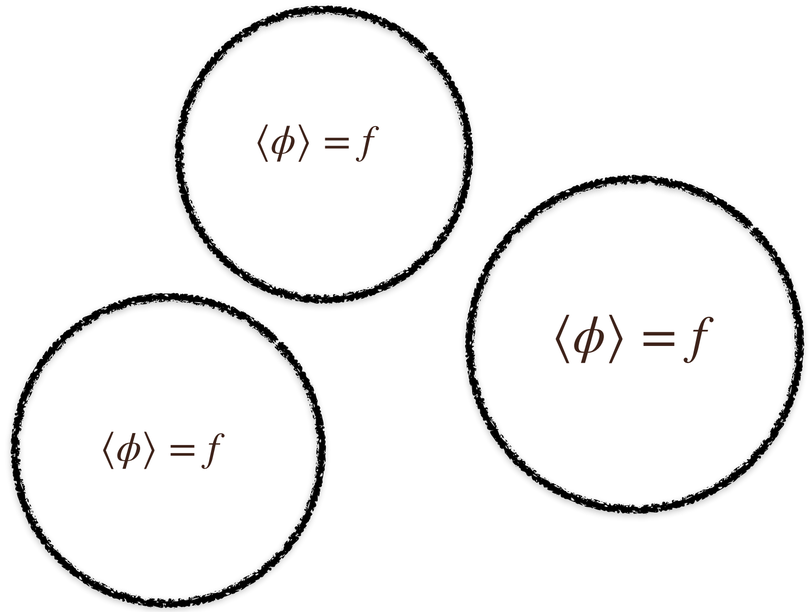

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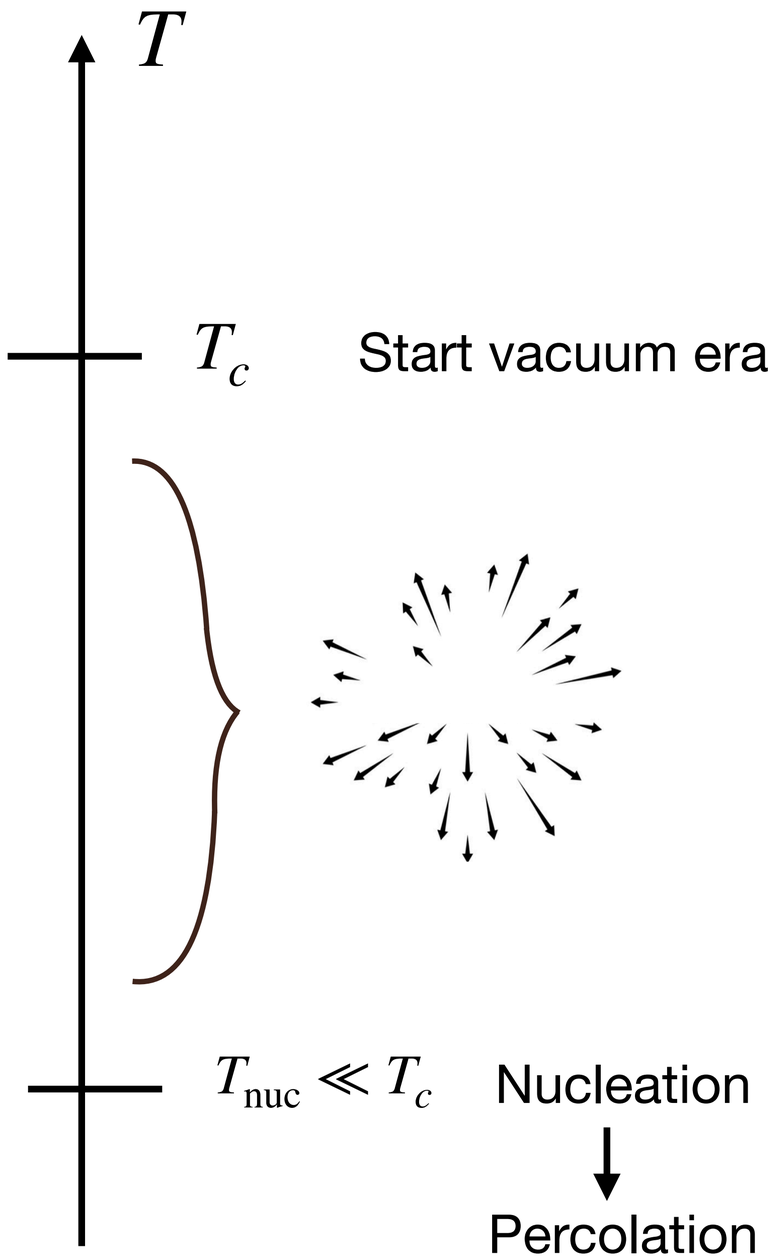
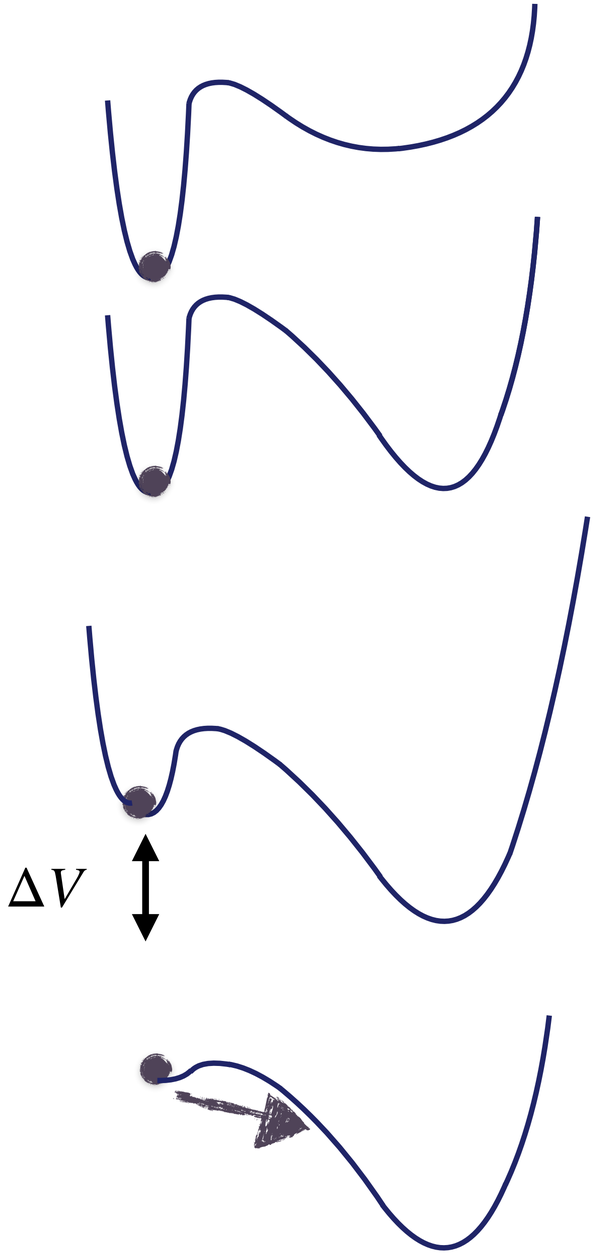
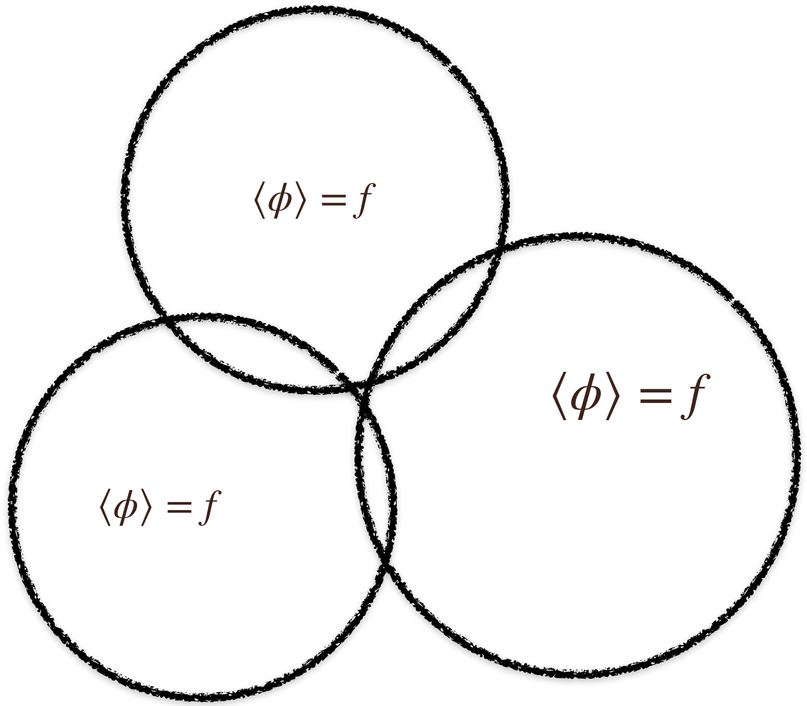






Supercooled 1stOPT = Hierarchical PT

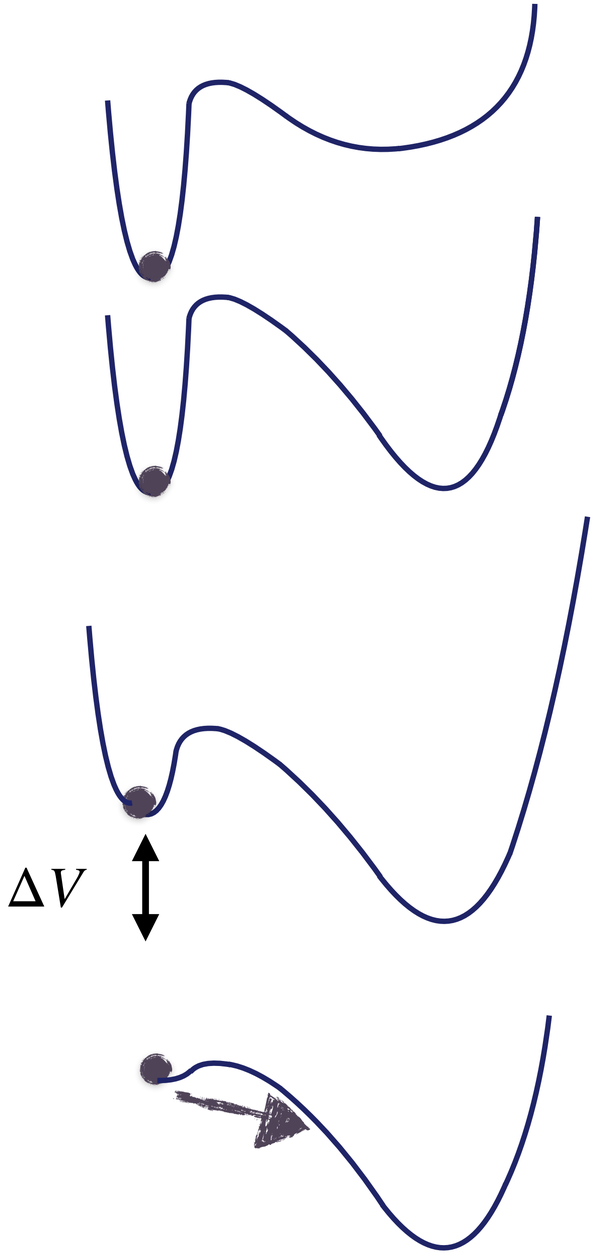
T

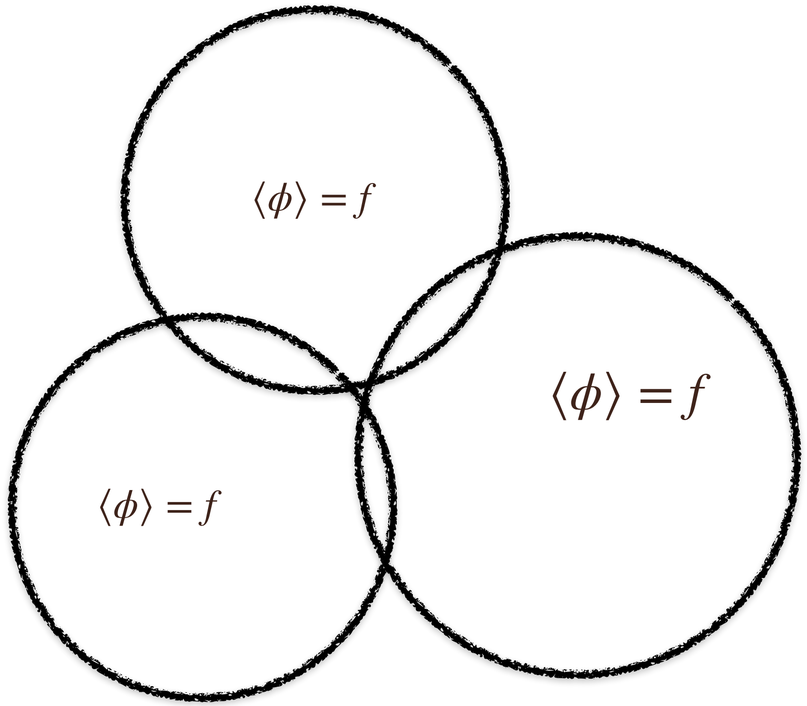
T_c Start vacuum era

Stochastic event

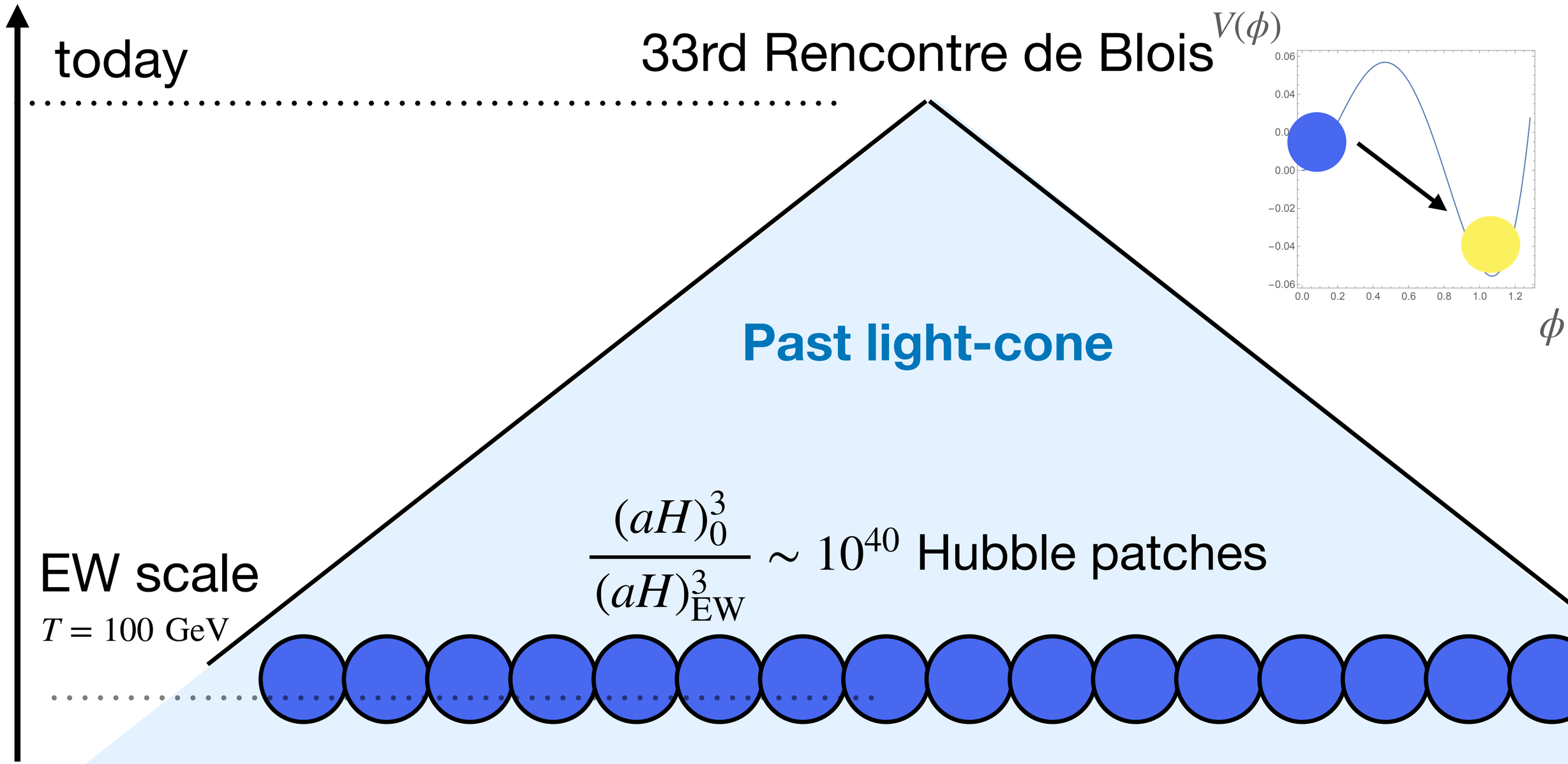
$T_{\text{nuc}} \ll T_c$ Nucleation

Percolation





PBHs from fluctuation of the percolation time



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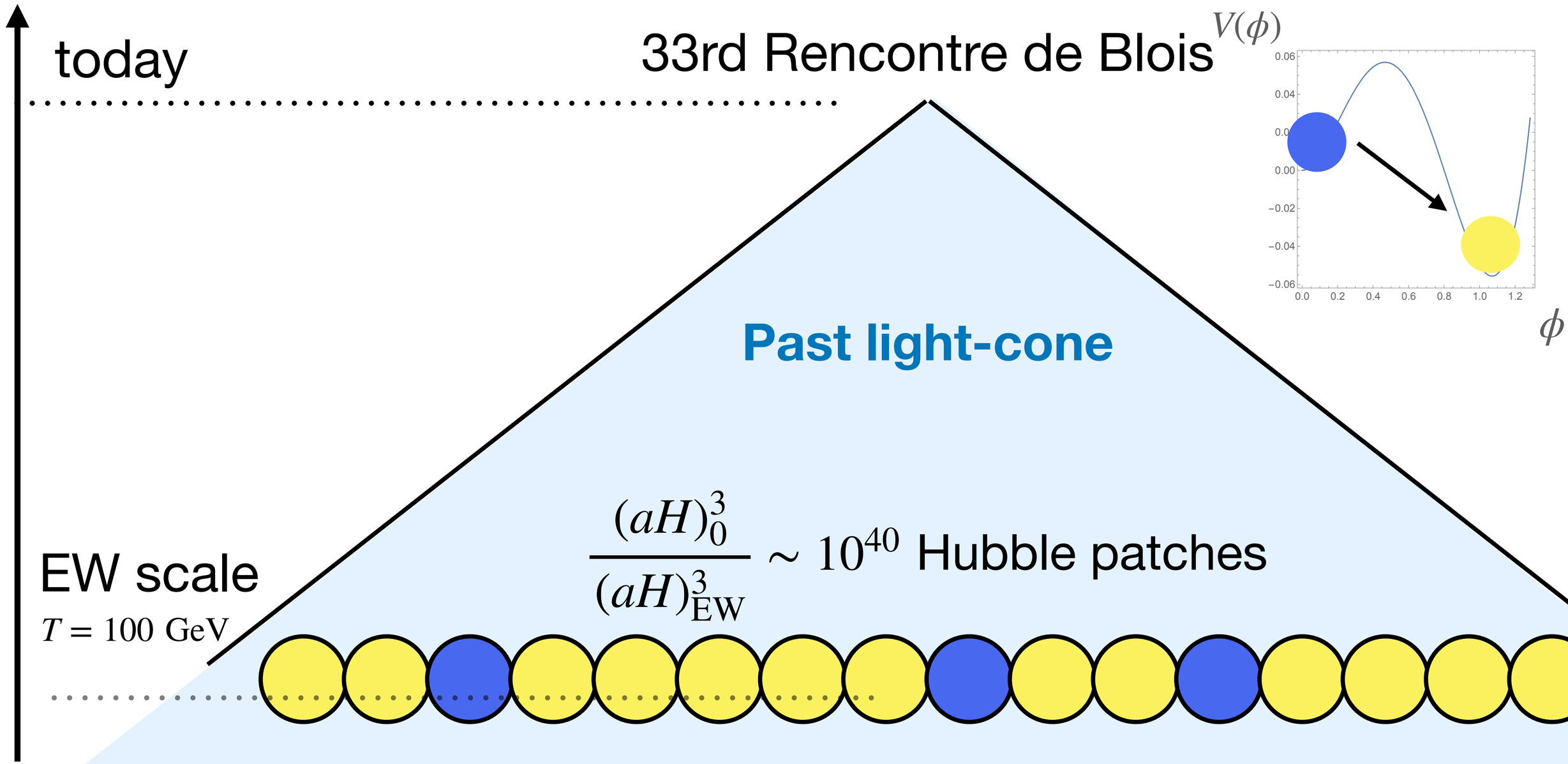

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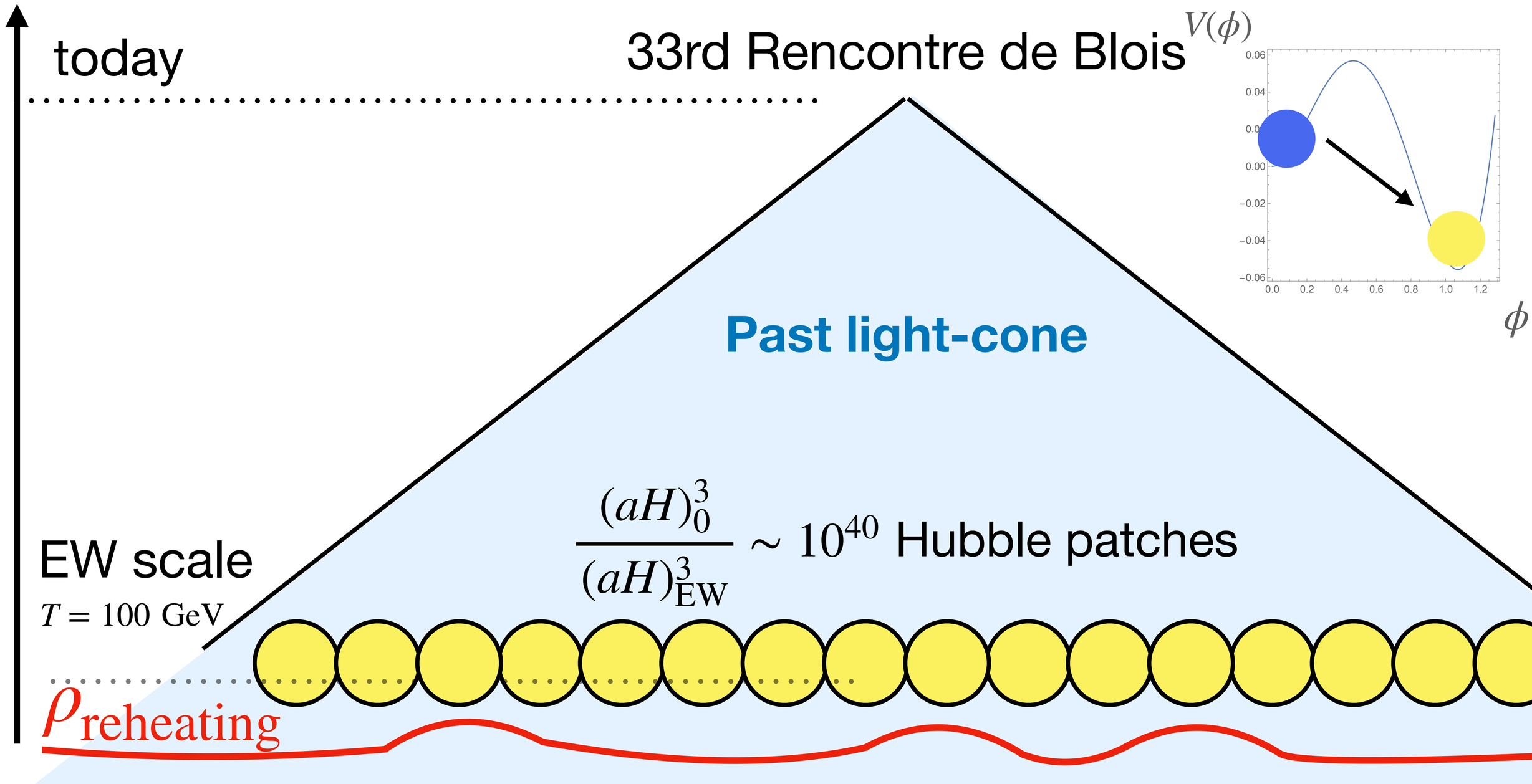

PBHs from fluctuation of the percolation time

t

today

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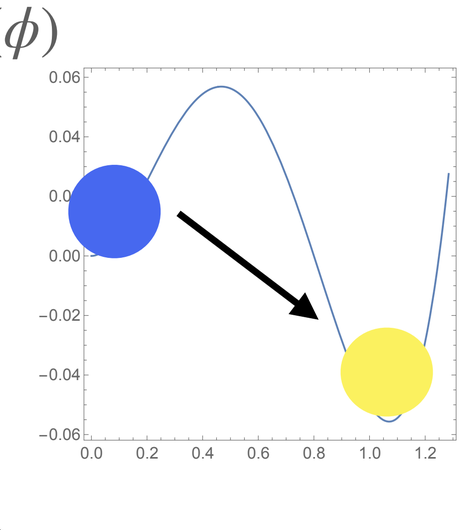
$$\delta = \frac{\rho_{\rm rad} - \bar{\rho}_{\rm rad}}{\bar{\rho}_{\rm rad}} > \delta_c = 0.45$$



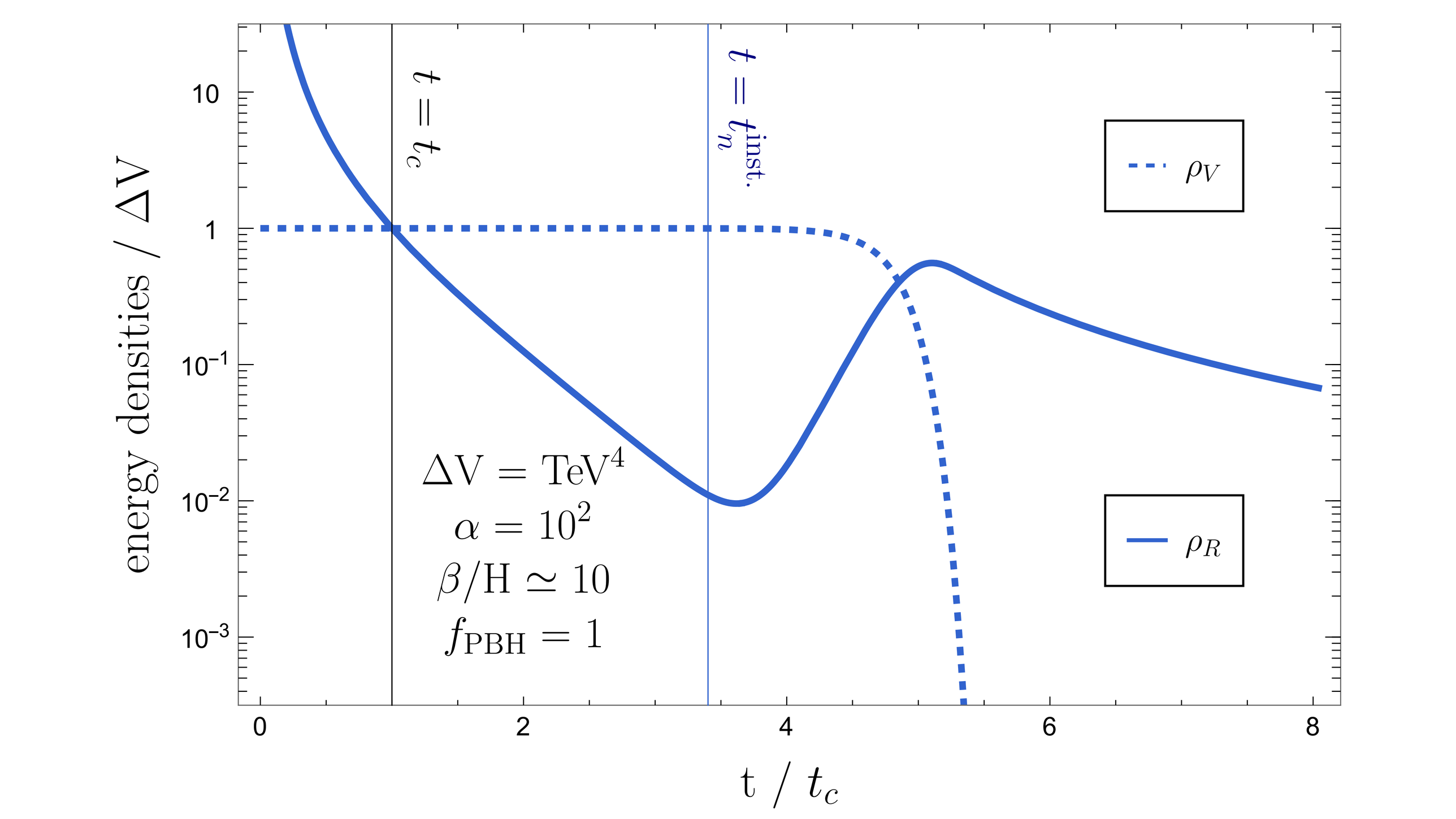
Past light-cone

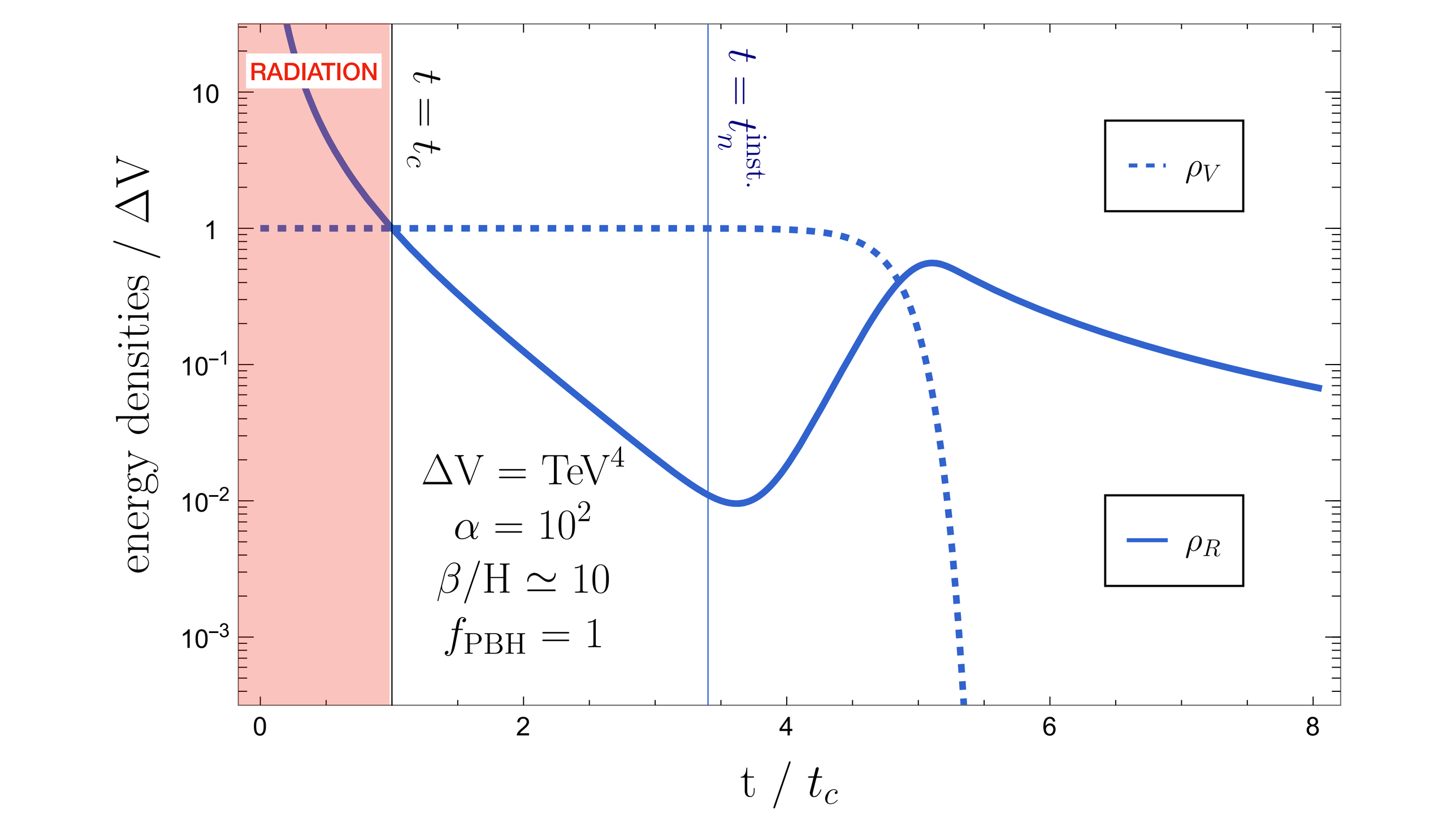
$$\frac{(aH)_0^3}{(aH)_{\rm EW}^3} \sim 10^{40} \text{ Hubble patches}$$

EW scale

$T = 100$ GeV

$\rho_{\rm reheating}$


energy densities / ΔV
t / t_c
$t = t_c$
$t = t_{\rm inst.}$
ρ_V
ρ_R
$\Delta V = \mathrm{TeV}^4$
$\alpha = 10^2$
$\beta/\mathrm{H} \simeq 10$
$f_{\rm PBH} = 1$
10
1
10^{-1}
10^{-2}
10^{-3}
0
2
4
6
8


RADIATION
$t = t_c$
$t = t_{\rm inst.} = t_n$
ρ_V
ρ_R
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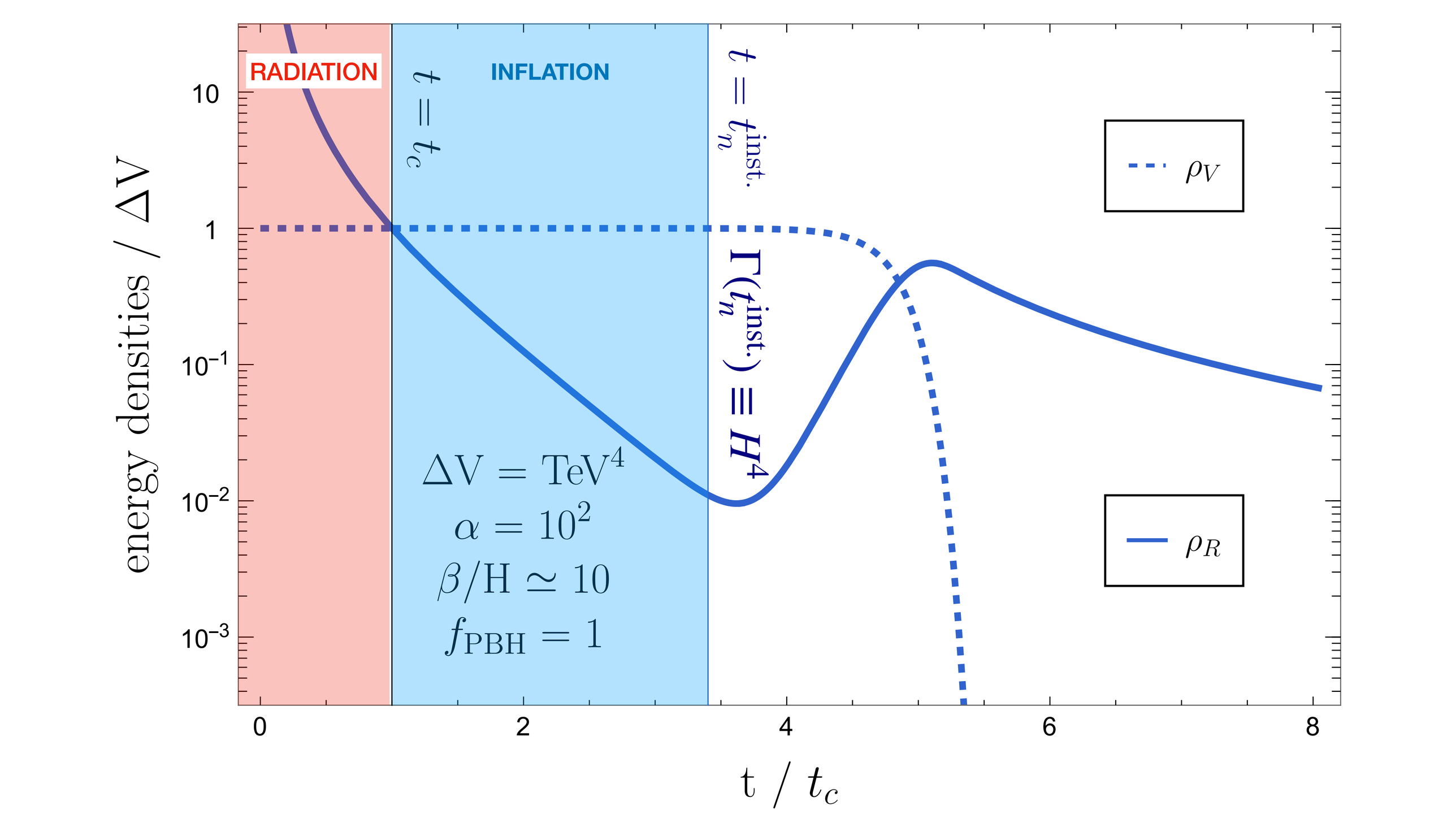
RADIATION
INFLATION
$t = t_c$
$t = t_n^{\rm inst.}$
$H^4 \equiv \Gamma(t_n^{\rm inst.})$
$\Delta V = {\rm TeV}^4$
$\alpha = 10^2$
$\beta/{\rm H} \simeq 10$
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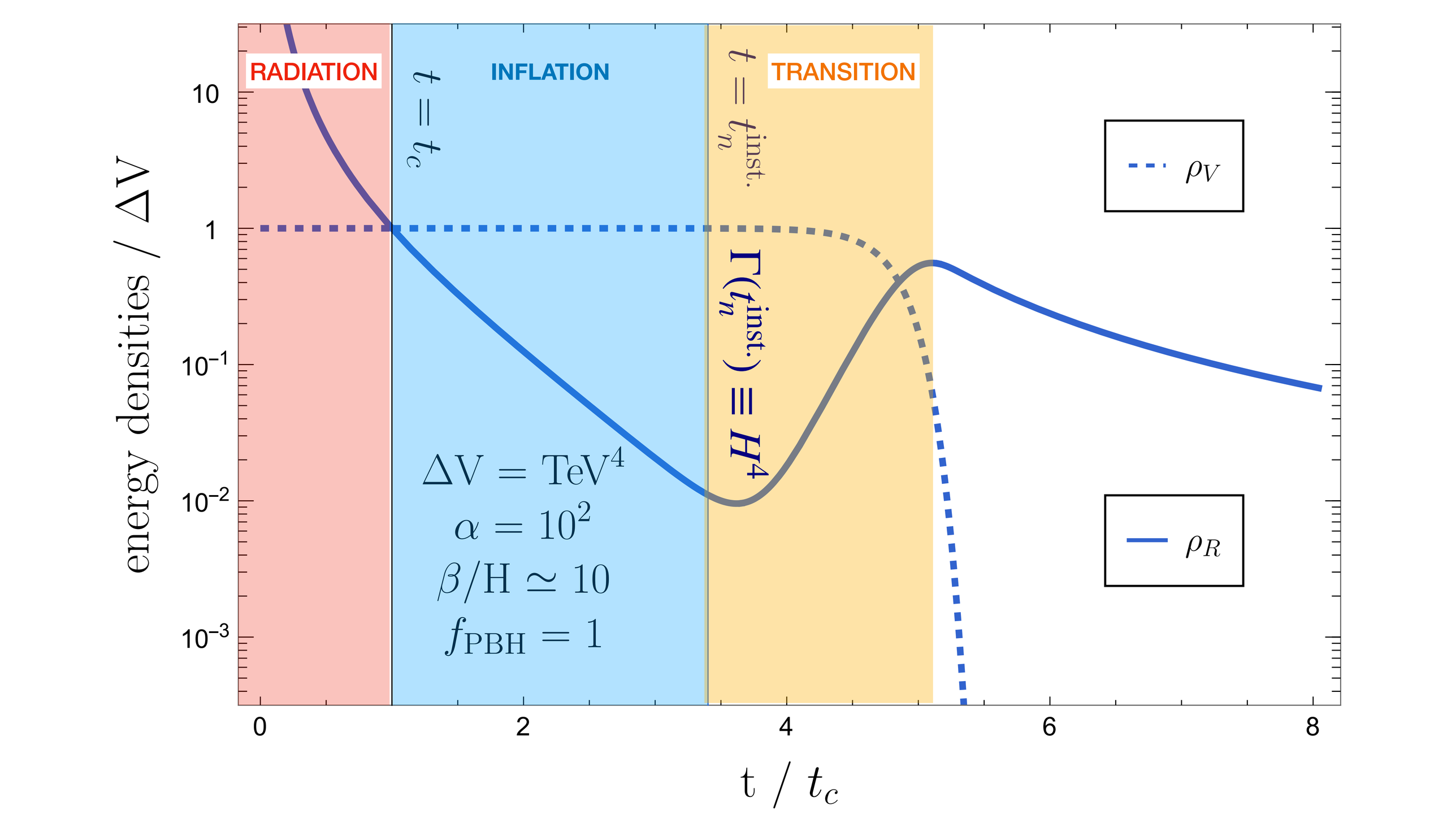
t / t_c


RADIATION
INFLATION
TRANSITION
$t = t_c$
$t = t_n^{\rm inst.}$
$\Gamma(t_n^{\rm inst.}) \equiv H^4$
$\Delta V = {\rm TeV}^4$
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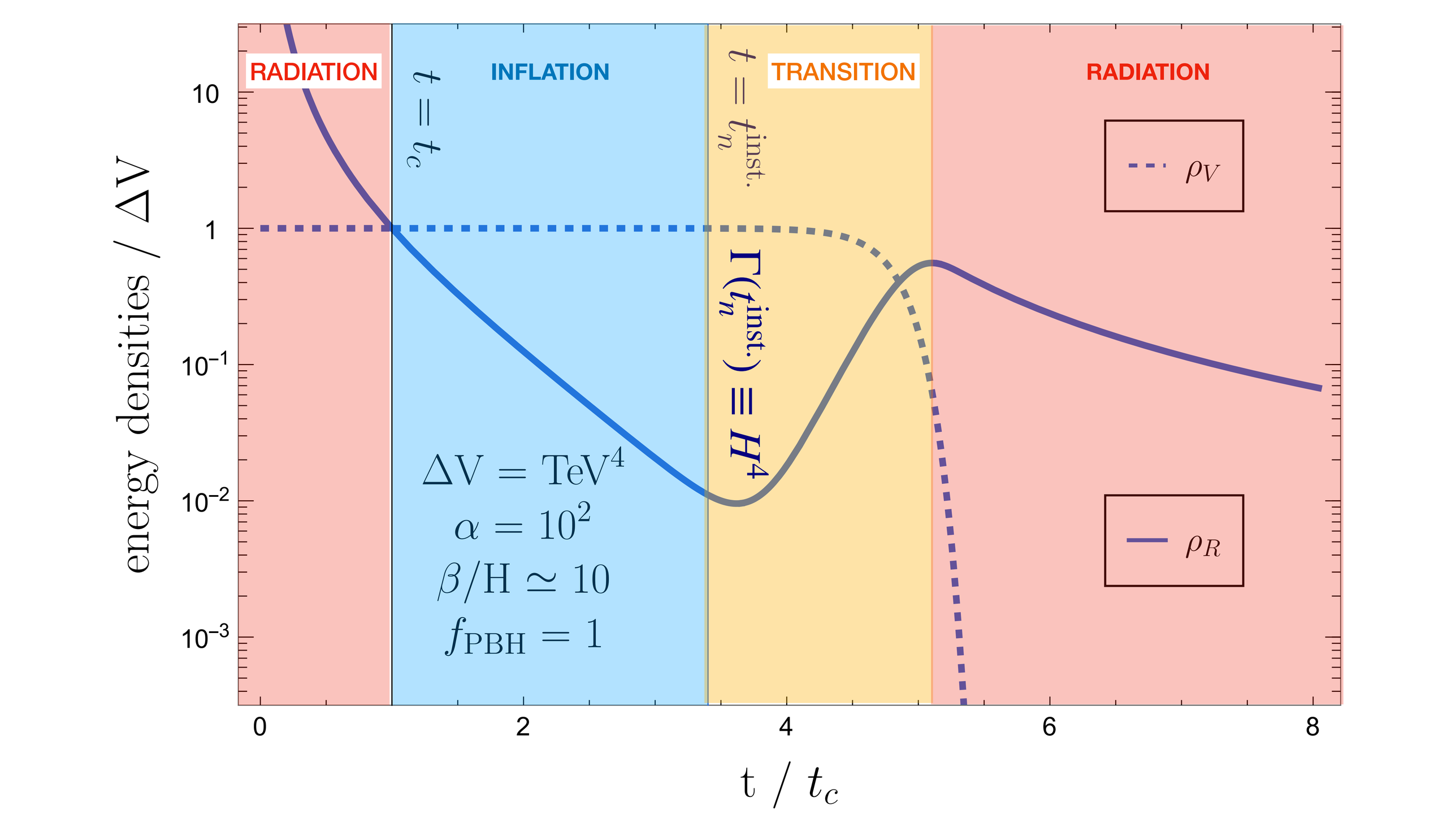
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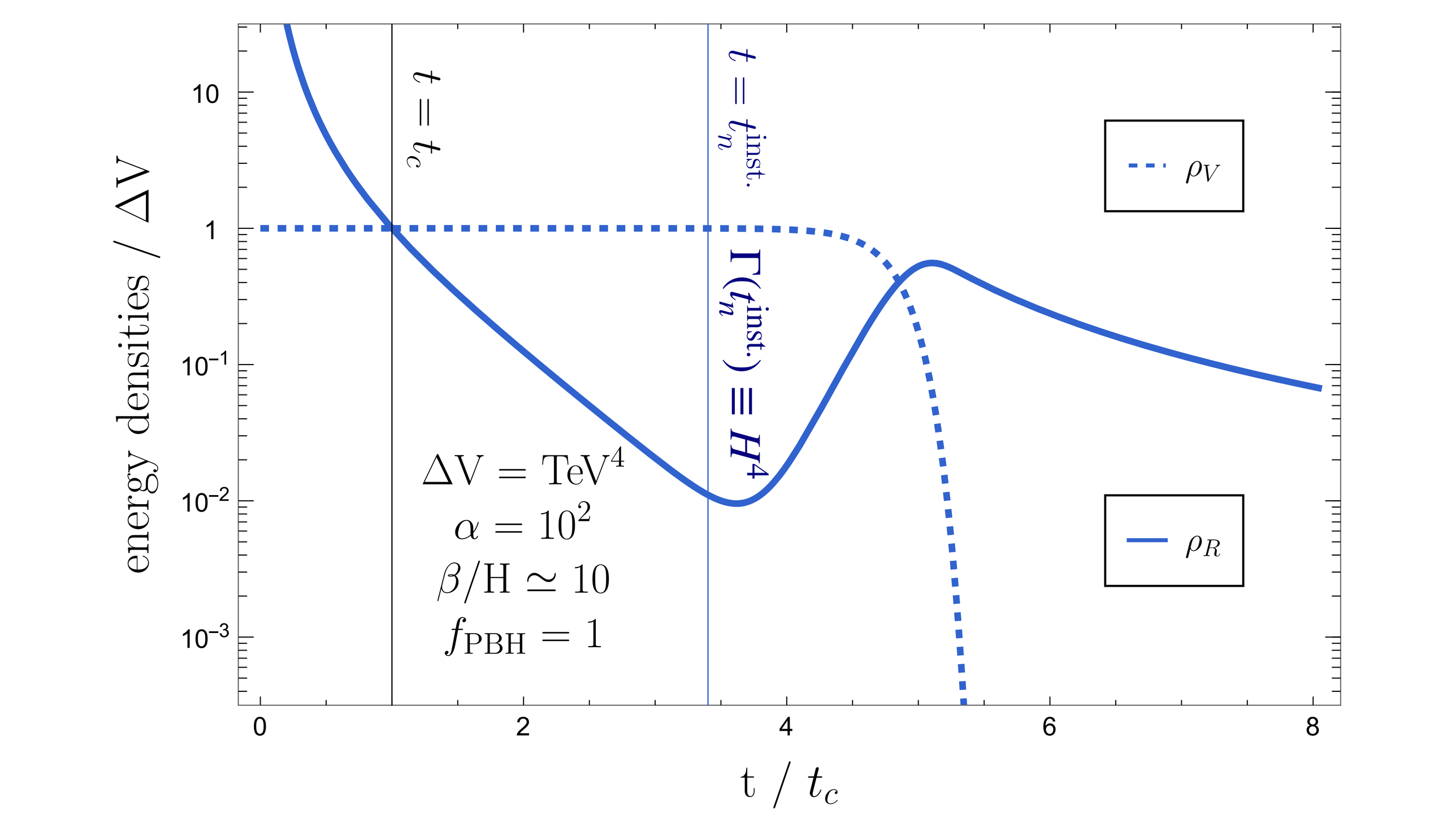
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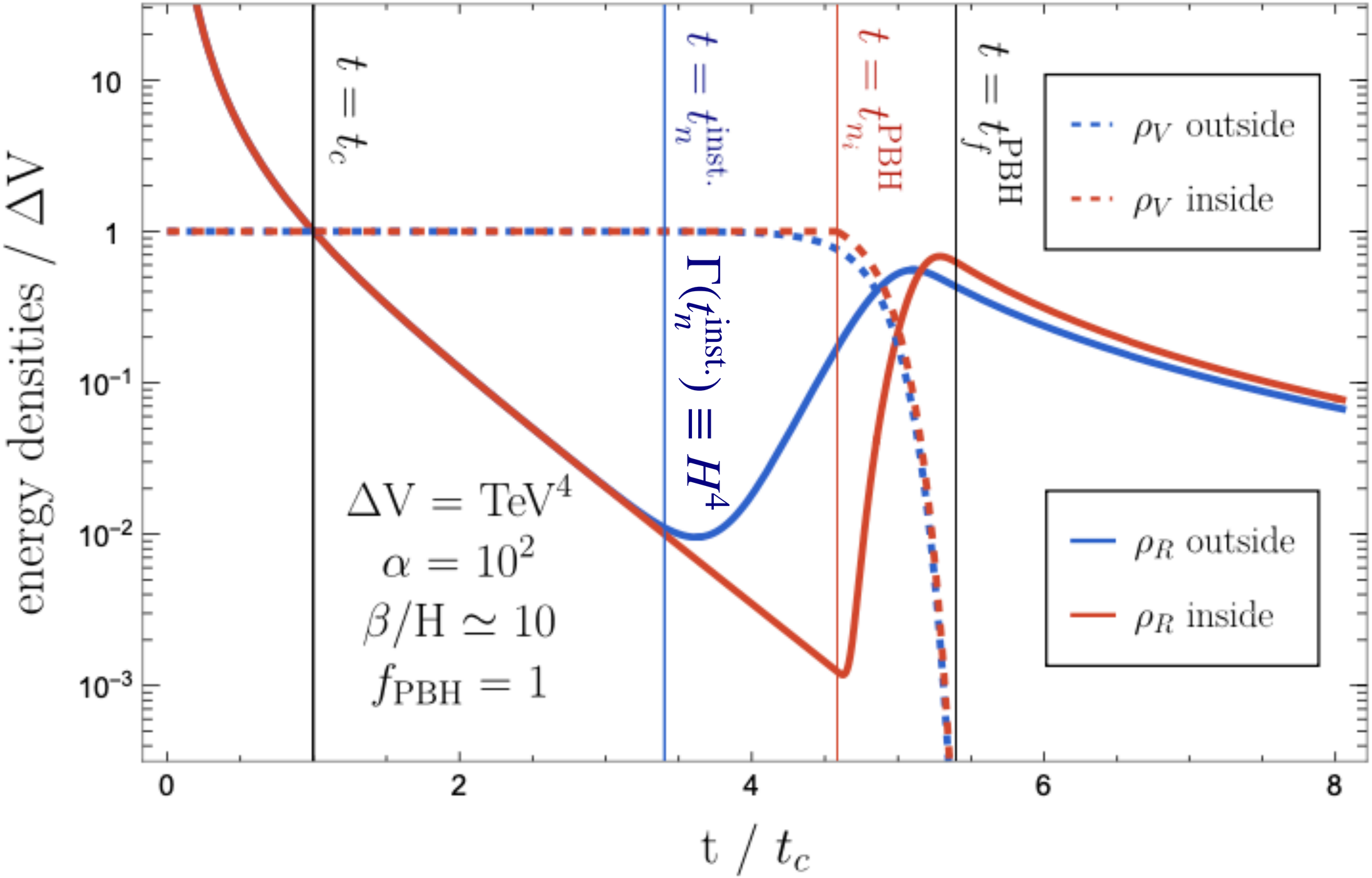
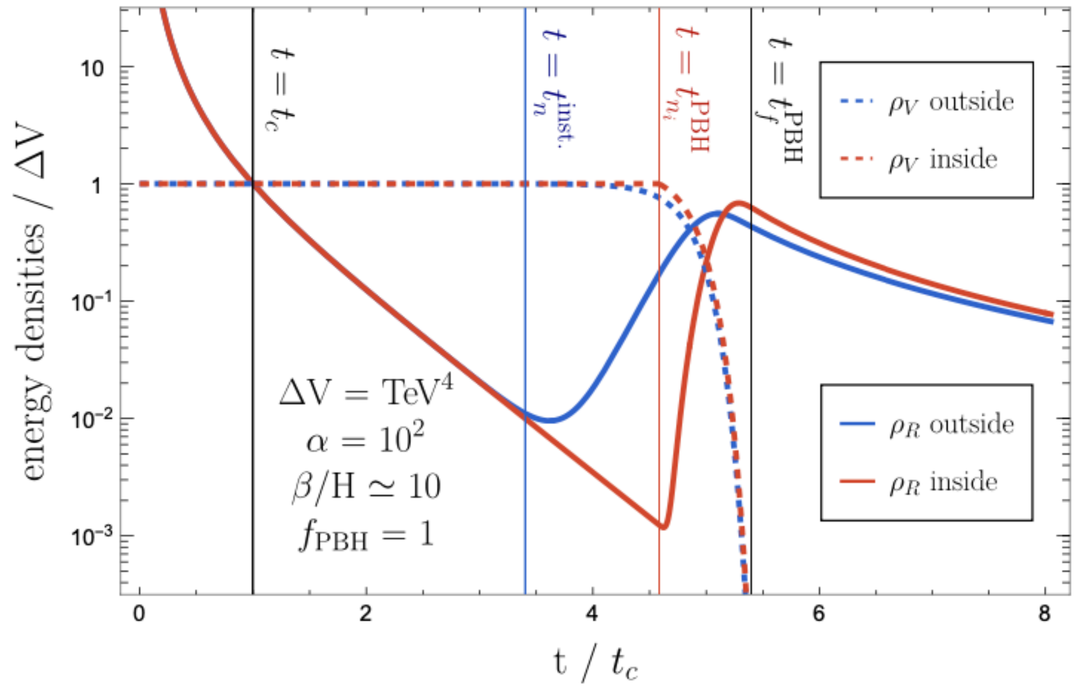

energy densities / ΔV
t / t_c
$t = t_c$
$t = t_n^{\rm inst.}$
$t = t_{n_i}^{\rm PBH}$
$t = t_f^{\rm PBH}$
$\Gamma(t_n^{\rm inst.}) \equiv H^4$
$\Delta V = {\rm TeV}^4$
$\alpha = 10^2$
$\beta/{\rm H} \simeq 10$
$f_{\rm PBH} = 1$
ρ_V outside
ρ_V inside
ρ_R outside
ρ_R inside
10
1
10^{-1}
10^{-2}
10^{-3}
0
2
4
6
8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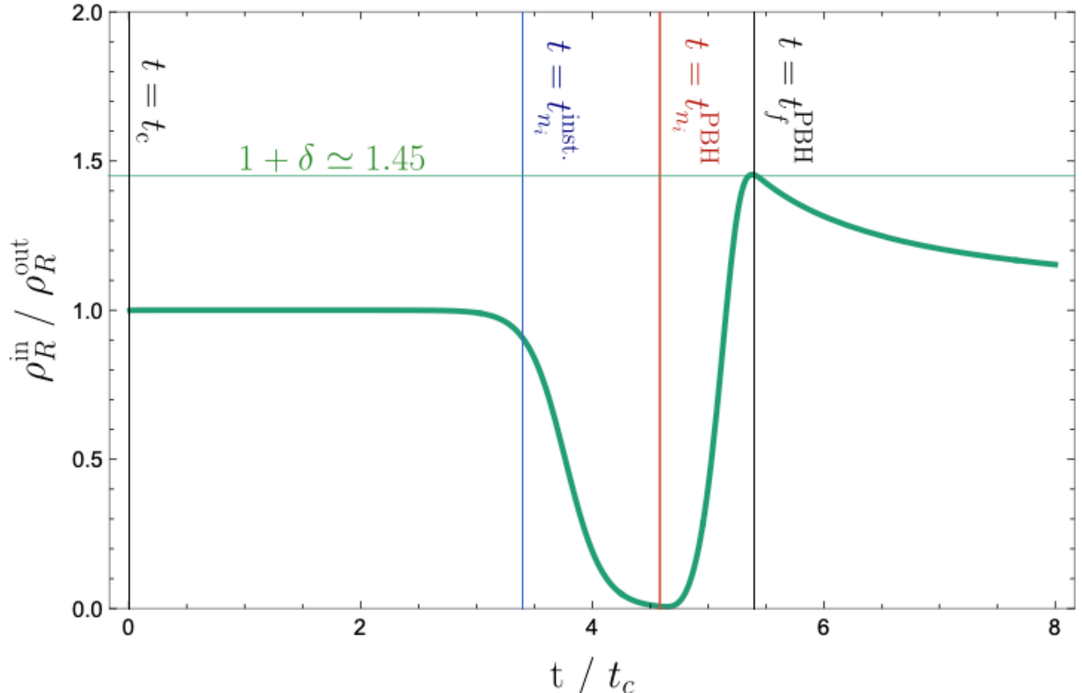
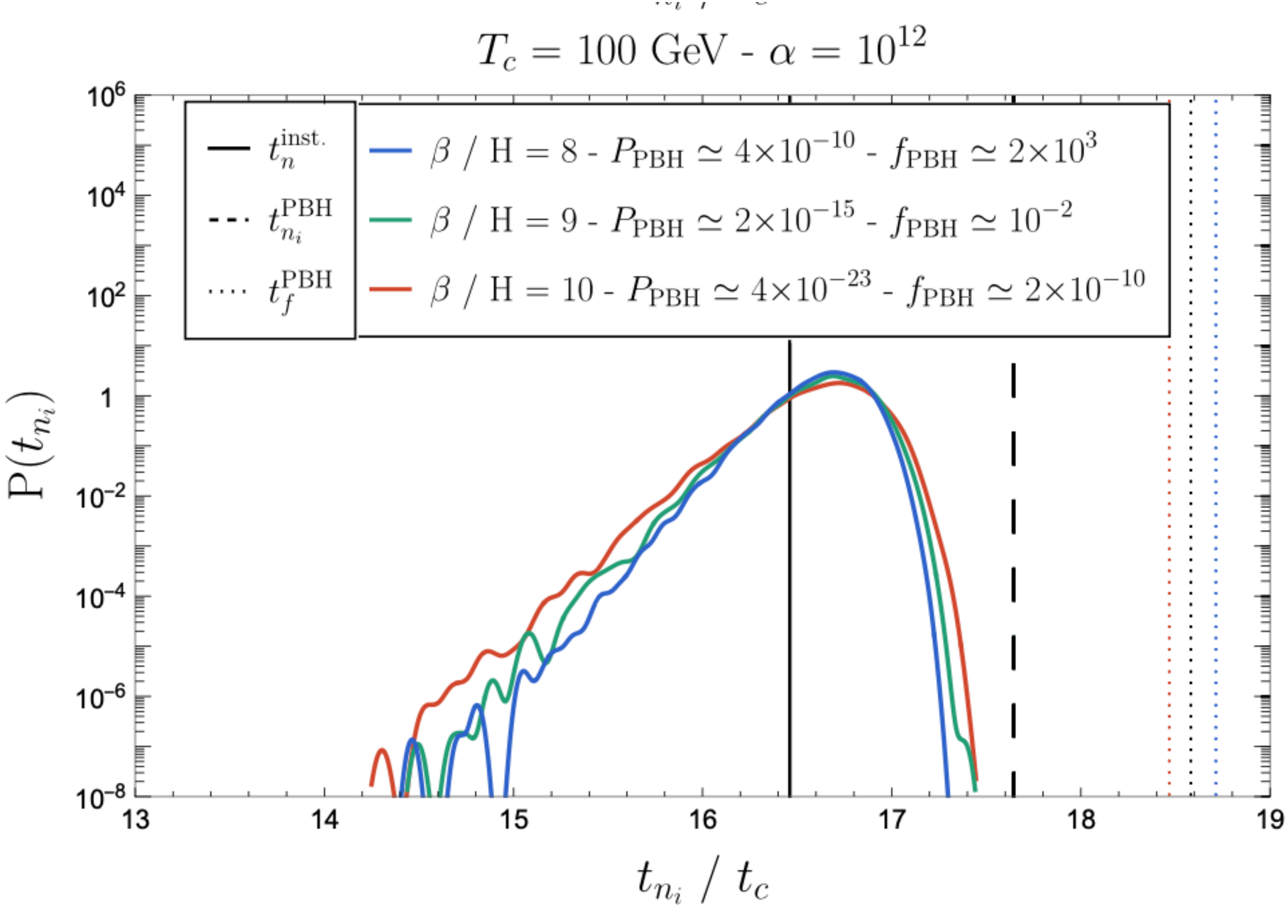
$\beta/{\rm H} \simeq 10$
$f_{\rm PBH} = 1$


$\rho_R^{\rm in} / \rho_R^{\rm out}$
t / t_c
$t = t_c$
$t = t_n^{\rm inst.}$
$t = t_{n_i}^{\rm PBH}$
$t = t_f^{\rm PBH}$
$1 + \delta \simeq 1.45$

The survival probability



PBH abundance

$$f_{\rm PBH} \equiv \frac{\rho_{\rm PBH}}{\rho_{\rm DM}} = P_{\rm PBH} \frac{M_{\rm PBH} \mathcal{N}_{\rm patches}}{\frac{4\pi}{3} H_0^{-3}} \frac{1}{\rho_{\rm DM,0}} = \frac{P_{\rm PBH}}{3 \times 10^{-11}} \left(\frac{T_c}{100\ {\rm GeV}} \right)$$

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$$F(t, t_{n_i}) = \exp\left[-\int_{t_{n_i}}^{t} dt^{'}\, \Gamma(t^{'})\, a^3(t^{'}) \times \frac{4\pi}{3} \left(\int_{t^{'}}^{t} \frac{d\tau}{a(\tau)} \right)^3 \right]$$

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$$\alpha \equiv \frac{\Delta V}{\frac{\pi^2}{30} g_* T_n^4}$$

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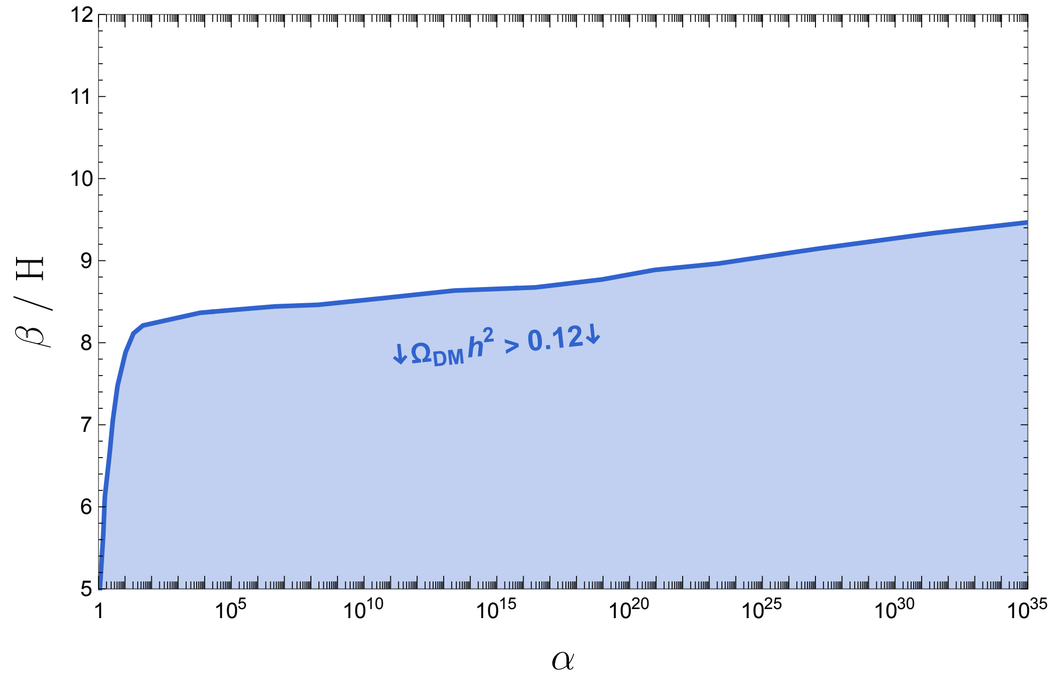

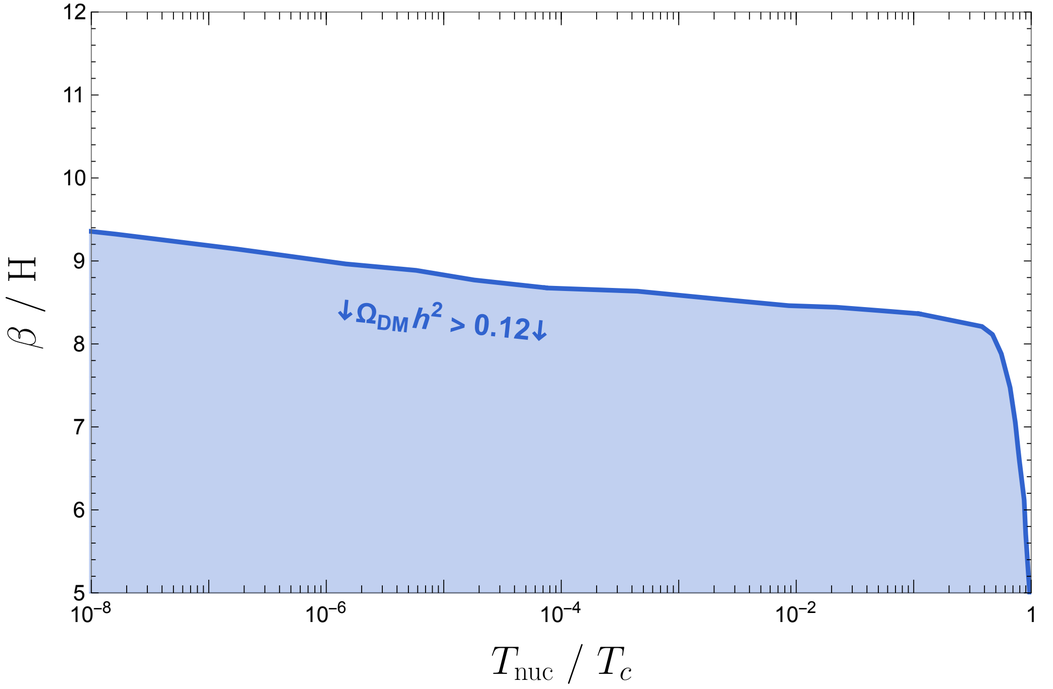

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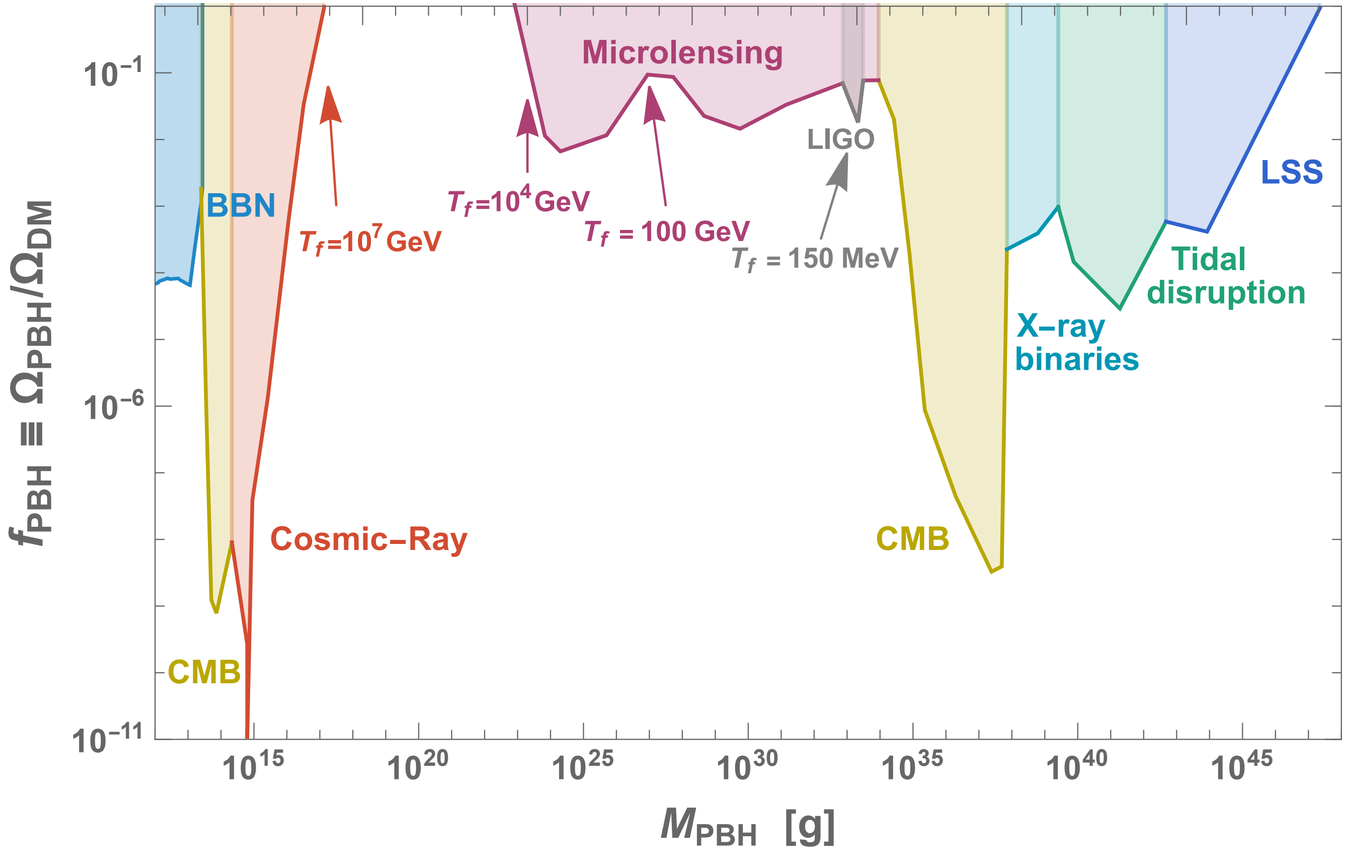

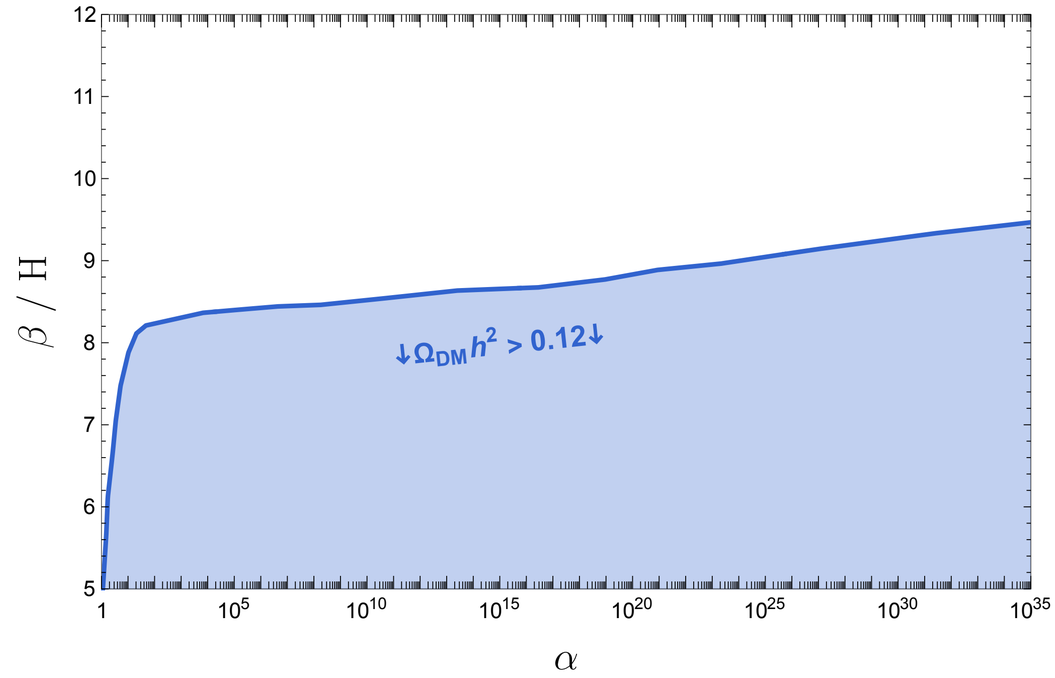

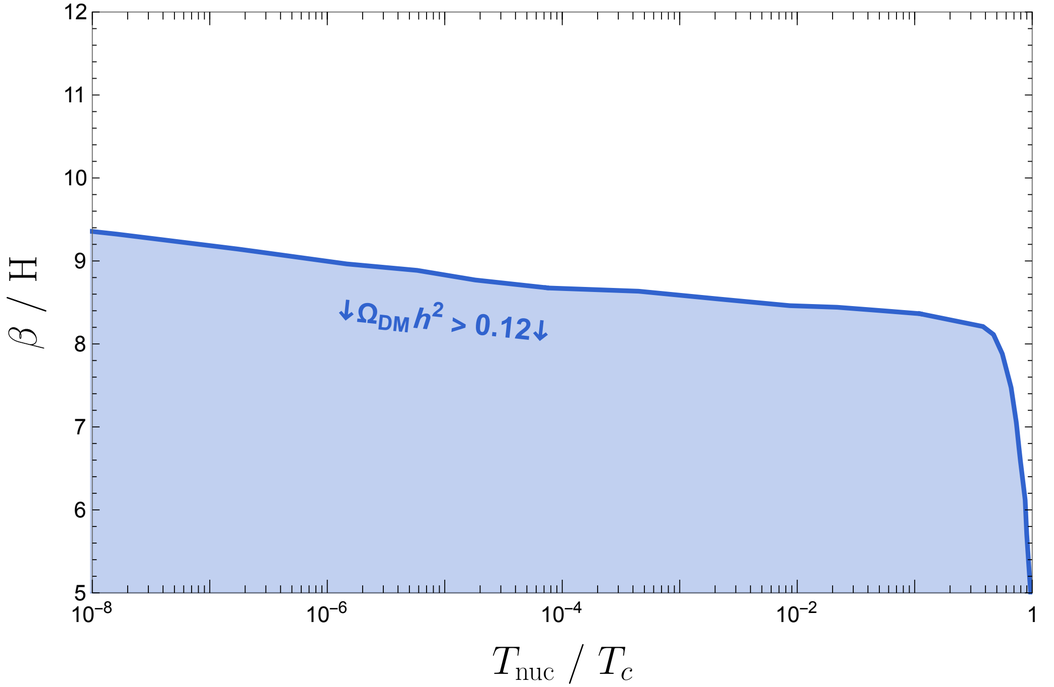

Supercooling from a nearly conformal sector

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Nearly-conformal dark $U(1)_D$:

$$\mathcal{L}_{\rm tree} = -\frac{1}{4}\left(F_{\mu\nu}\right)^2 + |D_\mu \Phi|^2 + \overline{\psi} \not{D}_\mu \psi - \left(y \Phi \overline{\psi}_L \psi_R + \text{h.c.}\right) - V_{\rm tree}(|\Phi|),$$

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$$V(\phi) = \beta_\lambda \frac{\phi^4}{4}\left[\log\left(\frac{\phi}{f}\right) - \frac{1}{4}\right]. \qquad \beta_\lambda = \frac{d\lambda}{d\log\phi} = \frac{1}{8\pi^2}\left(12 g_{\rm D}^4 + 12\lambda^4 + 4\lambda_{hs}^4 - 4y^4\right)$$

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1-loop Dolan-Jackiw corrections at finite-T:

$$V_T(\sigma,\ T) = V_{1-\text{loop}}^T + V_{\rm Daisy} = \frac{3T^4}{2\pi^2} J_B\left(\frac{m_V^2}{T^2}\right) + \frac{T}{12\pi}\left[m_V^3 - \left(m_V^2 + \Pi_V\right)^{3/2}\right].$$

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Thick-wall formula:

$$\frac{S_3}{T} \simeq \frac{A}{\log\left(\frac{M}{T}\right)} \qquad \text{with} \quad A = \frac{78}{g_{\rm D}^3} \quad \text{and} \quad M = 0.35\, g_{\rm D}\, f.$$

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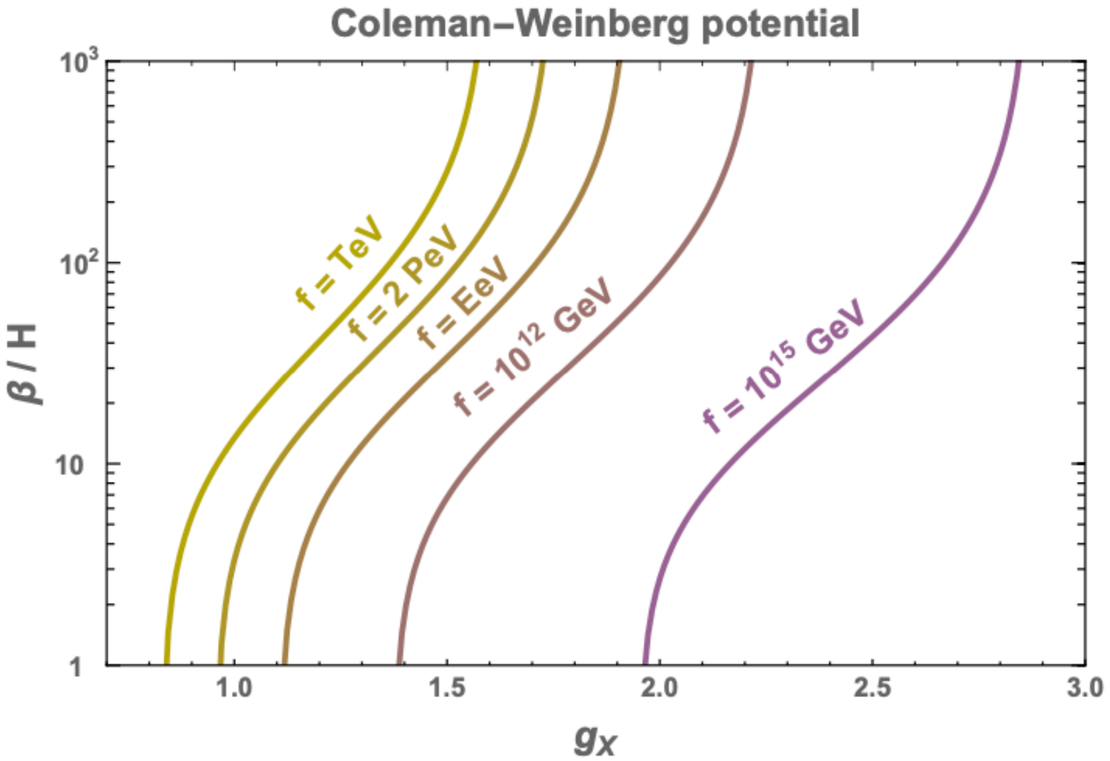

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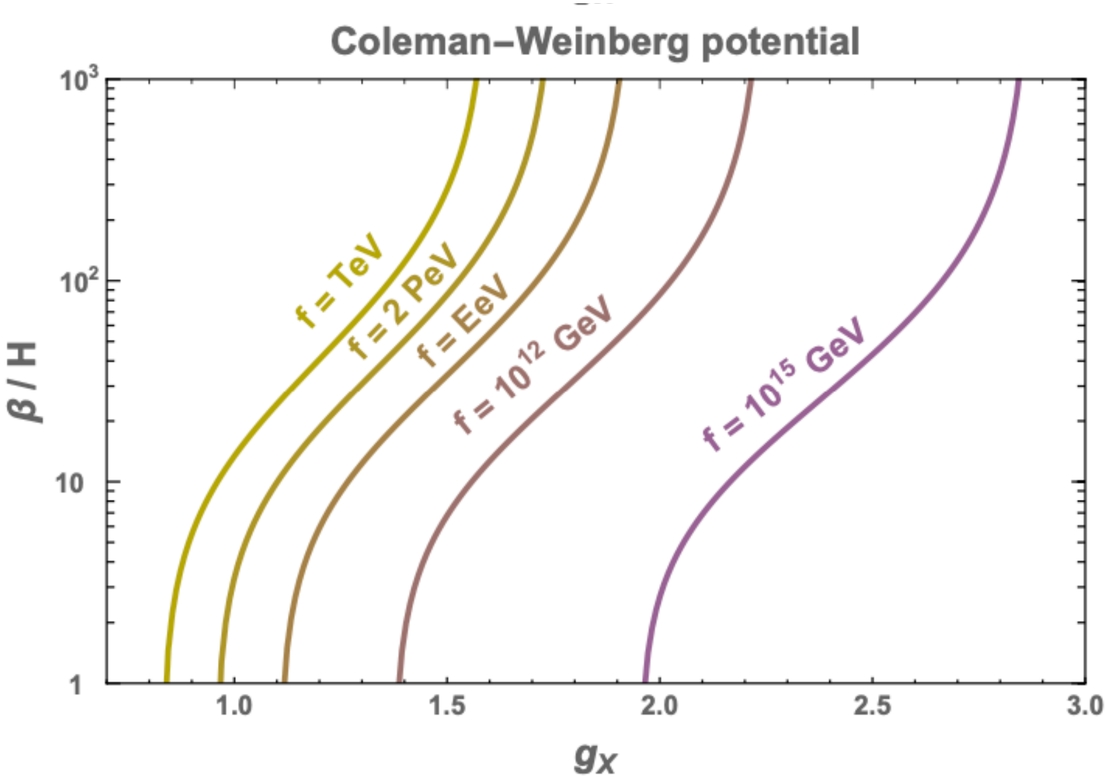
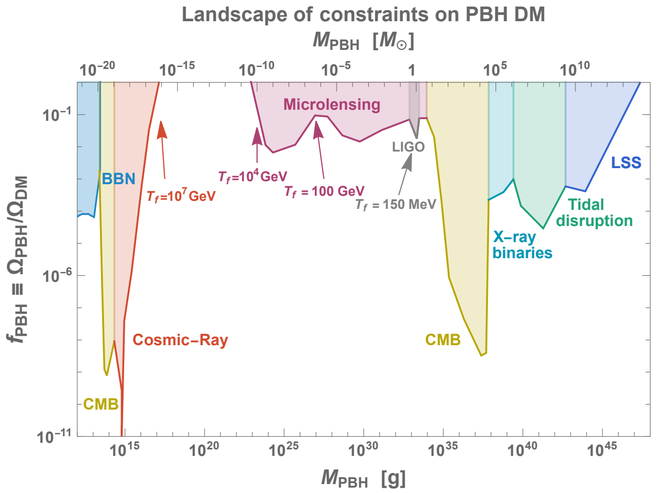


PBH DM



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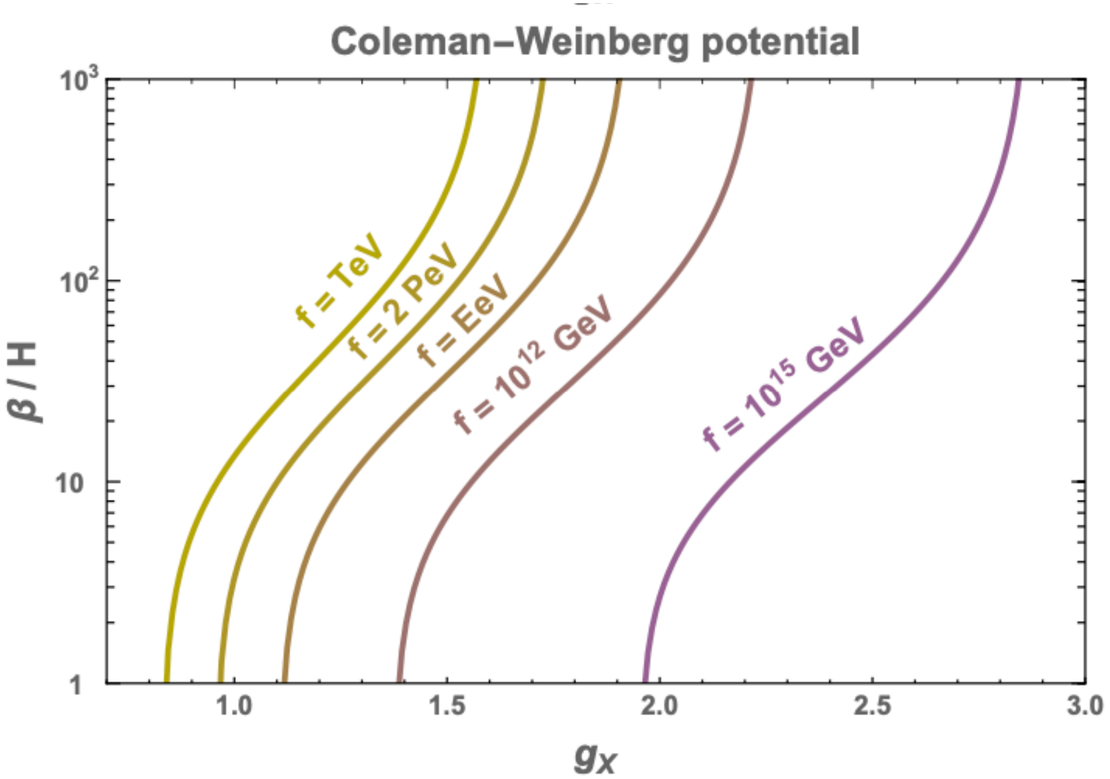

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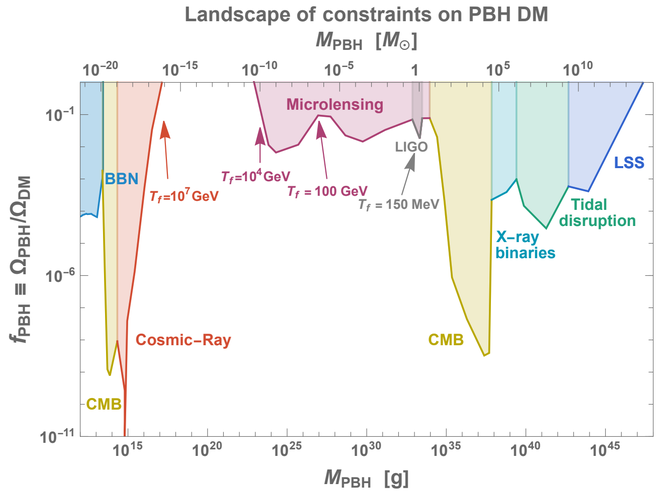
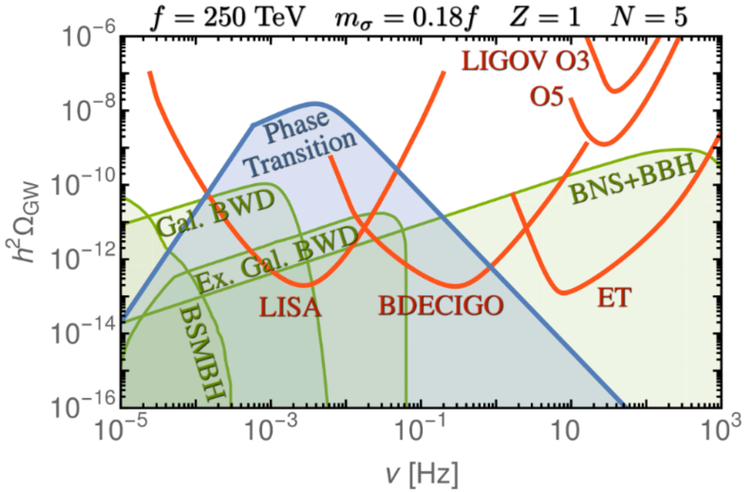


Large GW signal



Thanks