Post-Inflationary Higgs Dynamics from Spacetime Curvature

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Based on JHEP 08 (2025) 203 and JCAP 05 (2026) 053

Proyecto PID2022-139841NB-I00 financiado por:
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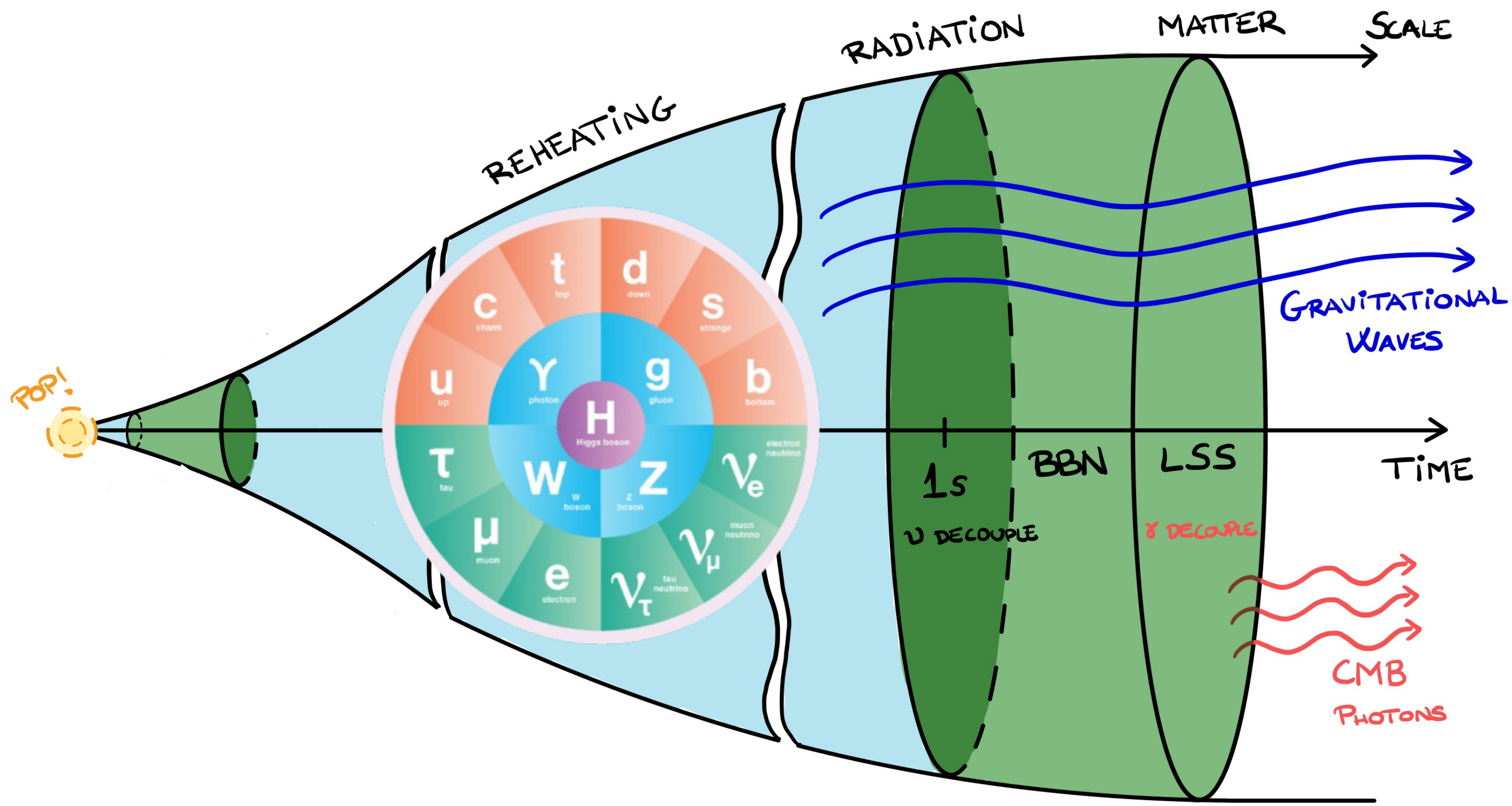
Fundación BBVA

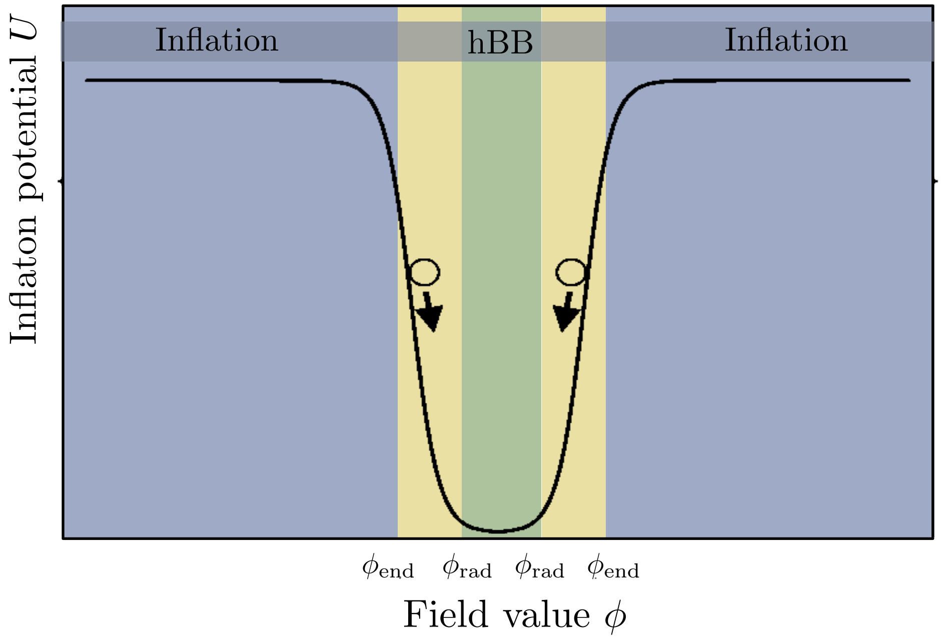
From inflation to the hot Big Bang

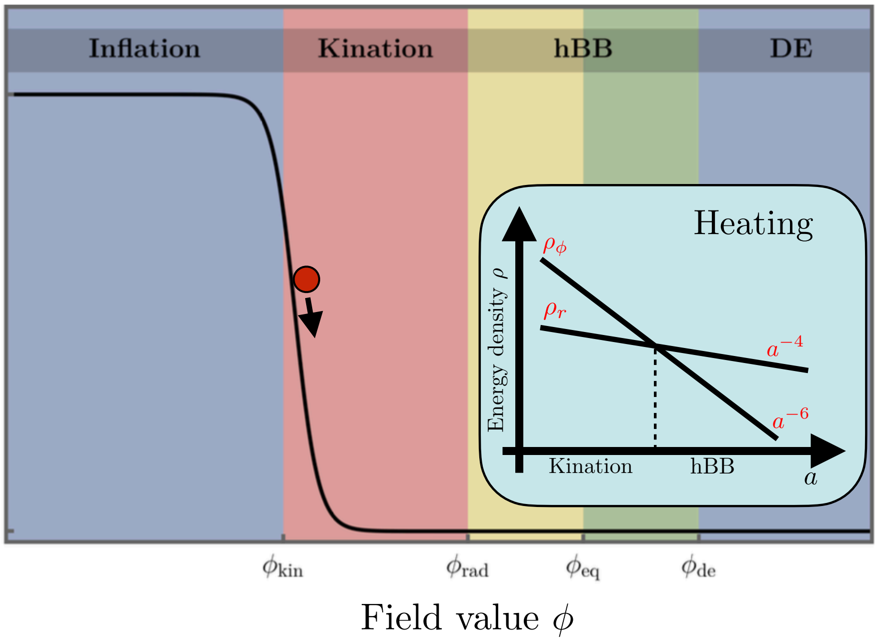
- Inflation leaves the Universe cold and empty
- The inflaton energy must be converted into SM particles



Adapted from G. Domenech

Oscillatory vs. Non-oscillatory





- Parametric resonance
- Highly efficient
- High heating temperature
- Full depletion required

For a review see B. Barman, N. Bernal, JR, Nucl.Phys.B 1018 (2025) 116996

- Gravitational particle production *
- Highly inefficient
- No SM heating before BBN
- No depletion required

For a review see e.g. D. Bettoni, JR, Galaxies 10 (2022) 1, 22

* Instant preheating not suitable with usual Higgs-portal couplings. See C. Wetterich and JR, Phys.Rev.D 96 (2017) 6, 063509

A simple scenario

- A single field ϕ for both inflation and dark energy (quintessential inflation)
- An unavoidable non-minimal coupling of the Higgs field H to gravity
- No additional degrees of freedom beyond the electroweak scale

$$\frac{\mathcal{L}}{\sqrt{-g}} = \frac{M_{\rm P}^2}{2} R - g^{\mu\nu}(D_\mu H)^\dagger (D_\nu H) - \lambda \left(H^\dagger H - \frac{v_{\rm EW}^2}{2} \right)^2 - \xi H^\dagger H R + \mathcal{L}_{\rm SM} + \mathcal{L}_\phi$$

Interesting outputs

- The Higgs field is safely stabilized during inflation (no isocurvature pert.)
- Appealing connection between SM parameters and (post-)inflationary era
- The Higgs field itself can be responsible for heating the Universe

G. Laverda, JR, JCAP 03 (2024) 033 & JHEP 05 (2024) 339

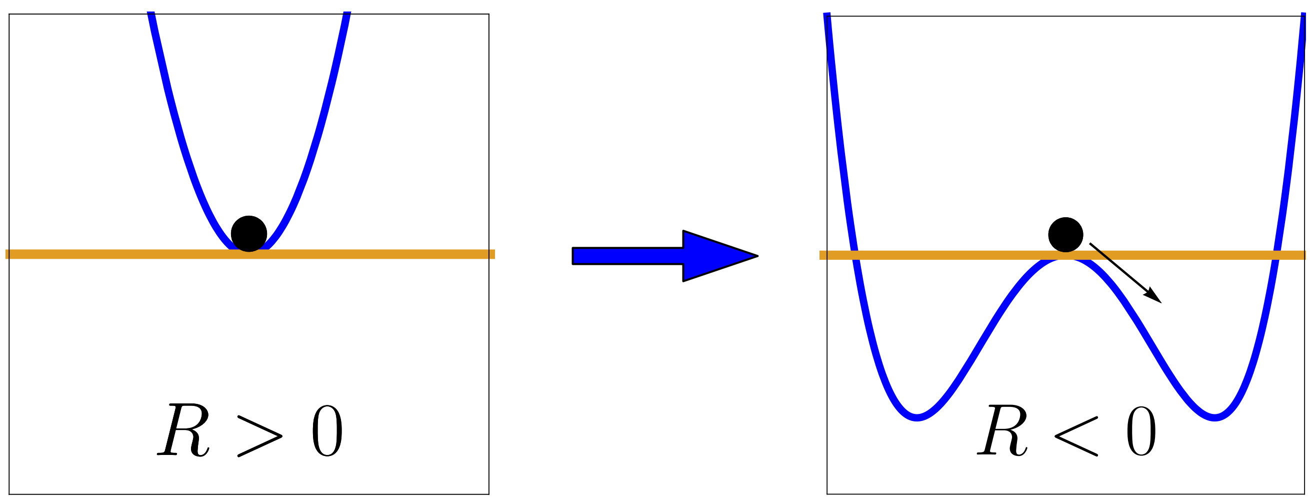
Hubble-induced transition

$$V_{\text{eff}}(H) = (\xi R + m_h^2) H^\dagger H + \lambda (H^\dagger H)^2$$

Energetically subdominant / Spectator field $R = 3(1 - 3w_\phi)\mathcal{H}^2$

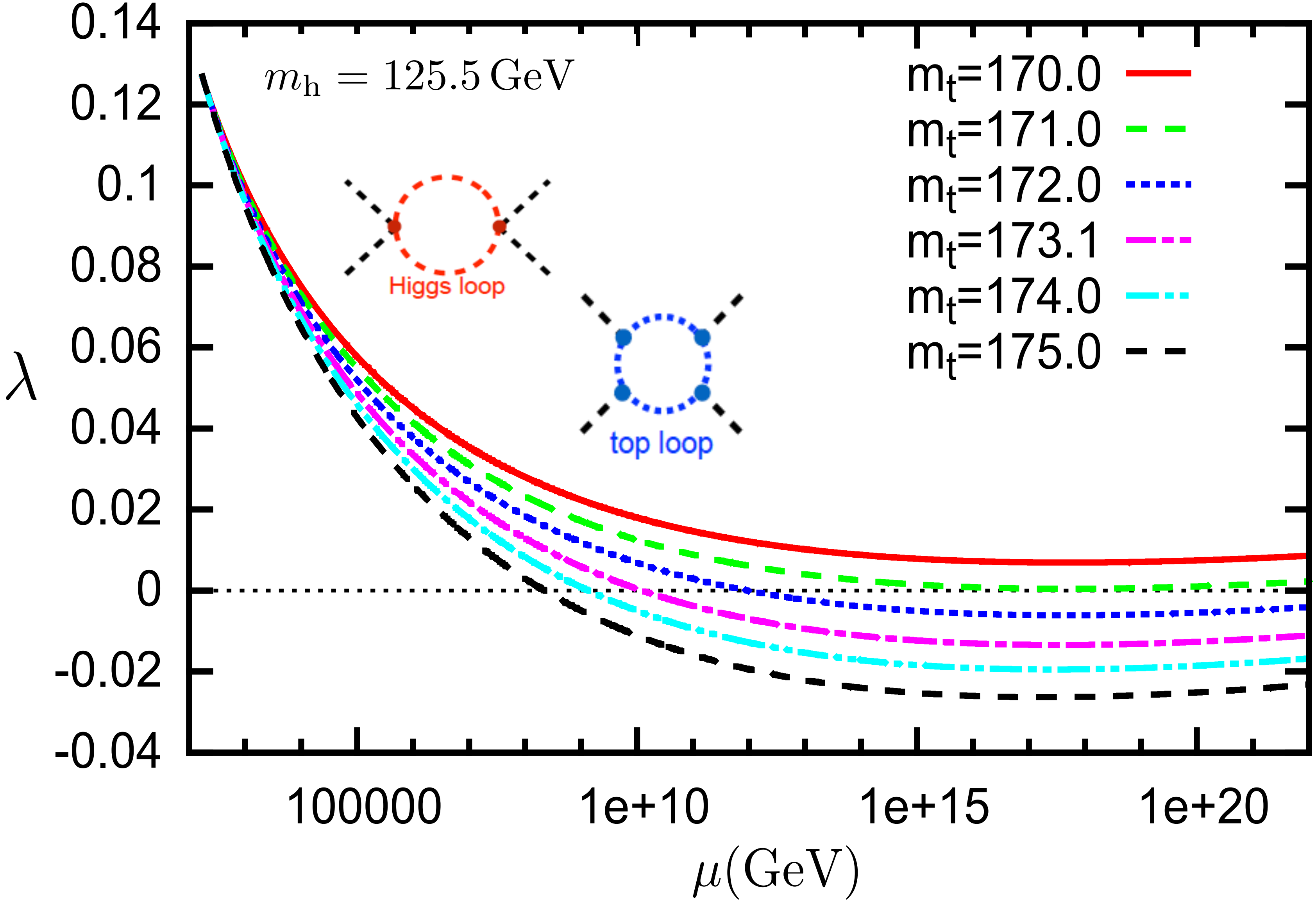
Negligible contribution to the effective Planck mass, $\xi h^2 \ll M_P^2$

Inflation $w_\phi = -1$ Kination $w_\phi = 1$

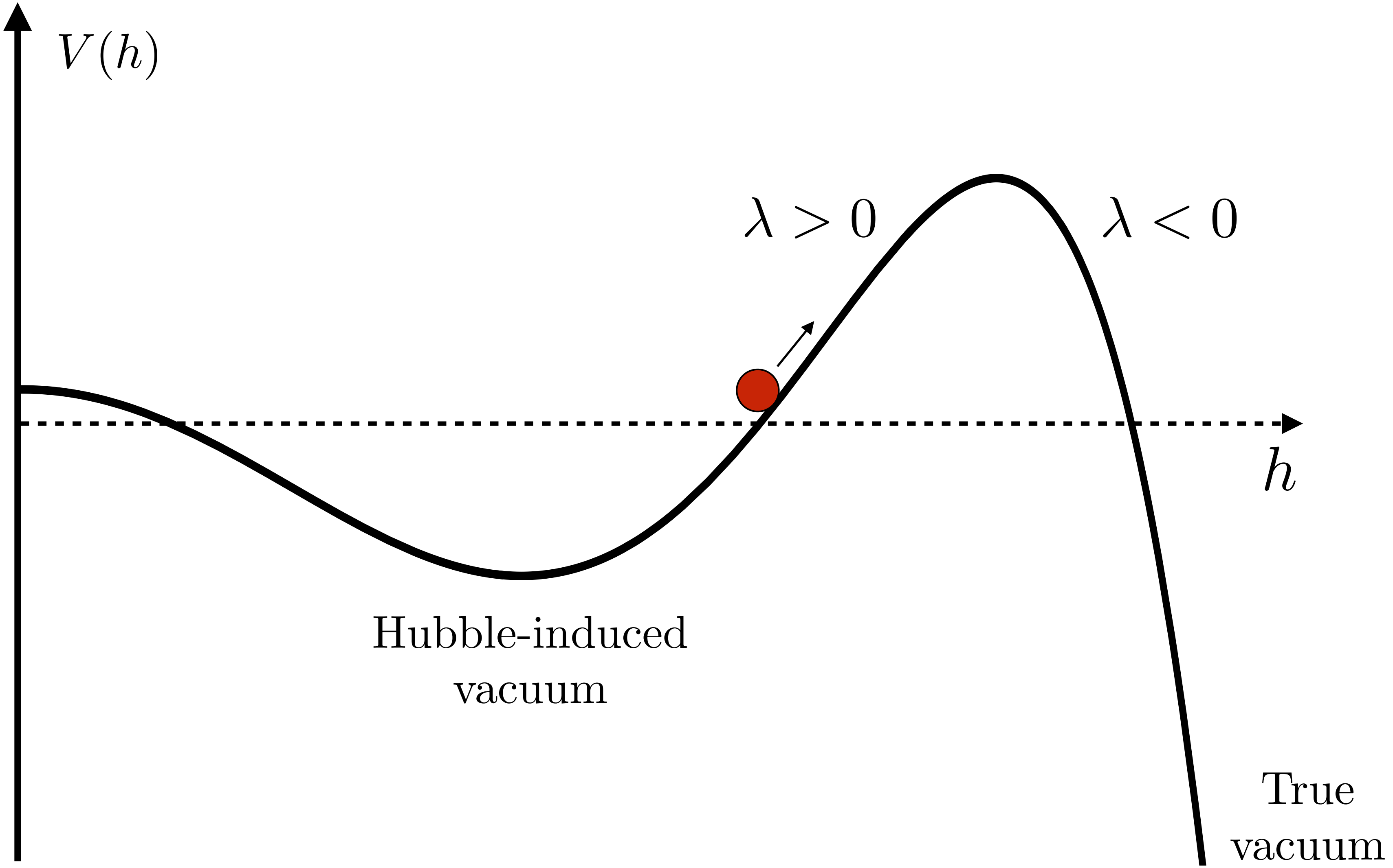


No isocurvature perturbations Tachyonic production

Standard Model running



Higgs effective potential



See also Ethan Milligan's talk

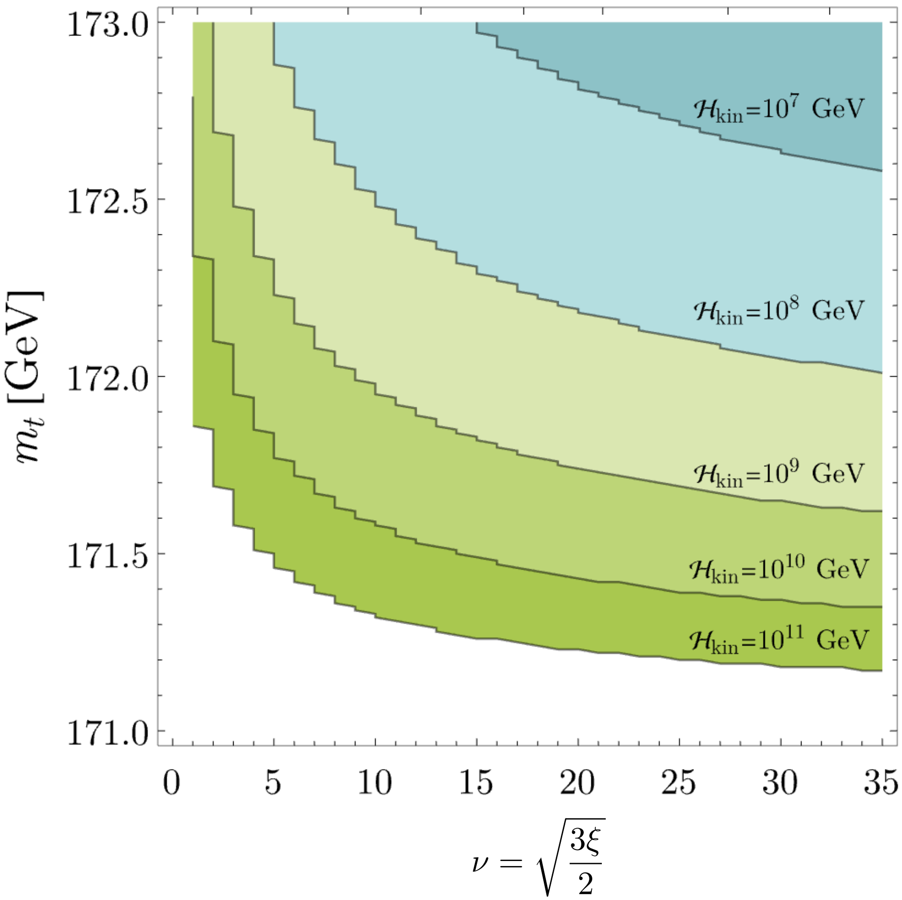
Scanning of parameter space

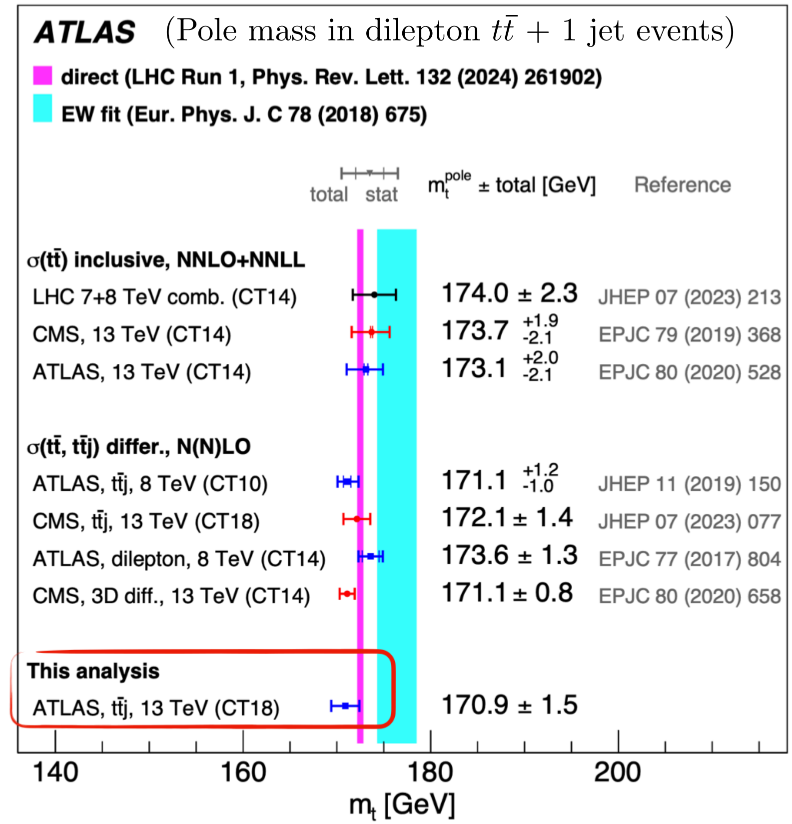
- Three-loop renormalisation-group running of the Higgs self-coupling
- Agnostic approach to top quark mass values, $m_t = 170 - 173$ GeV
- Wide range for non-minimal coupling parameter $\xi \sim 1 - 700$
- Wide range for the onset scale of kination $\mathcal{H}_{\rm kin} \sim 10^6 - 10^{15}$ GeV
- O(1000) 3+1-dimensional classical lattice simulations.
- Checking for existence and crossing of the barrier

$$\xi < \frac{y_\Lambda^4 \mu_\Lambda^2}{32\, e^{3/2} \pi^2\, \mathcal{H}^2}$$

$$\rho_{\rm tac}(\lambda(\mu), \xi) < V(h_{\rm max}(\xi, y_\Lambda, \mathcal{H}, \mu_\Lambda))$$

Stability constraints on the top mass



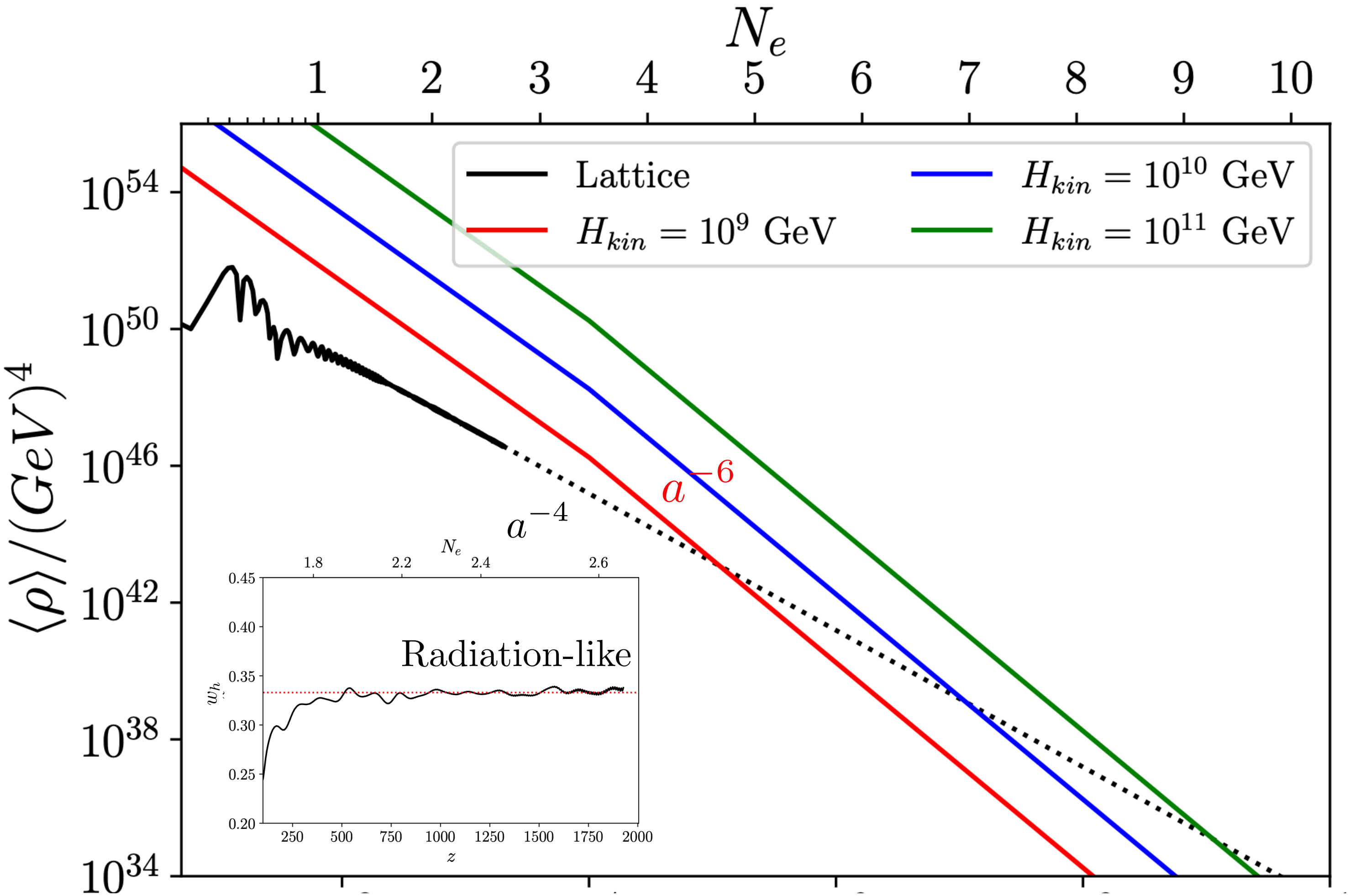


- Cosmology becomes a precision probe of Standard Model parameters
- Vacuum survival tends to prefer the low top-masses

G. Laverda, JR, JHEP 05 (2024) 339

Heating the Universe before BBN

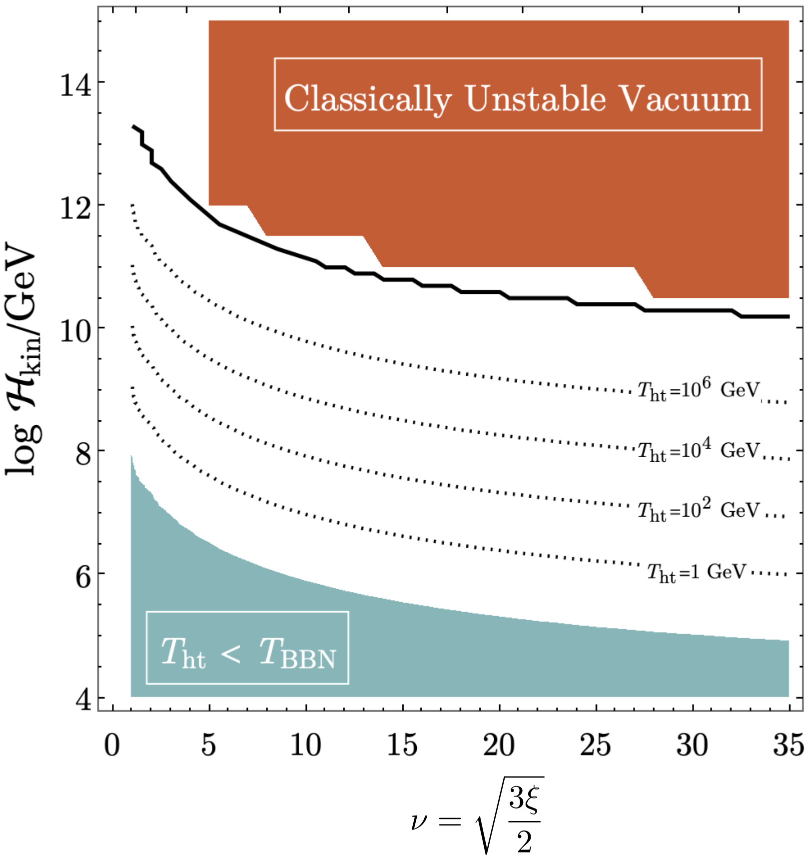
Explosive tachyonic Higgs production allows to heat the Universe.

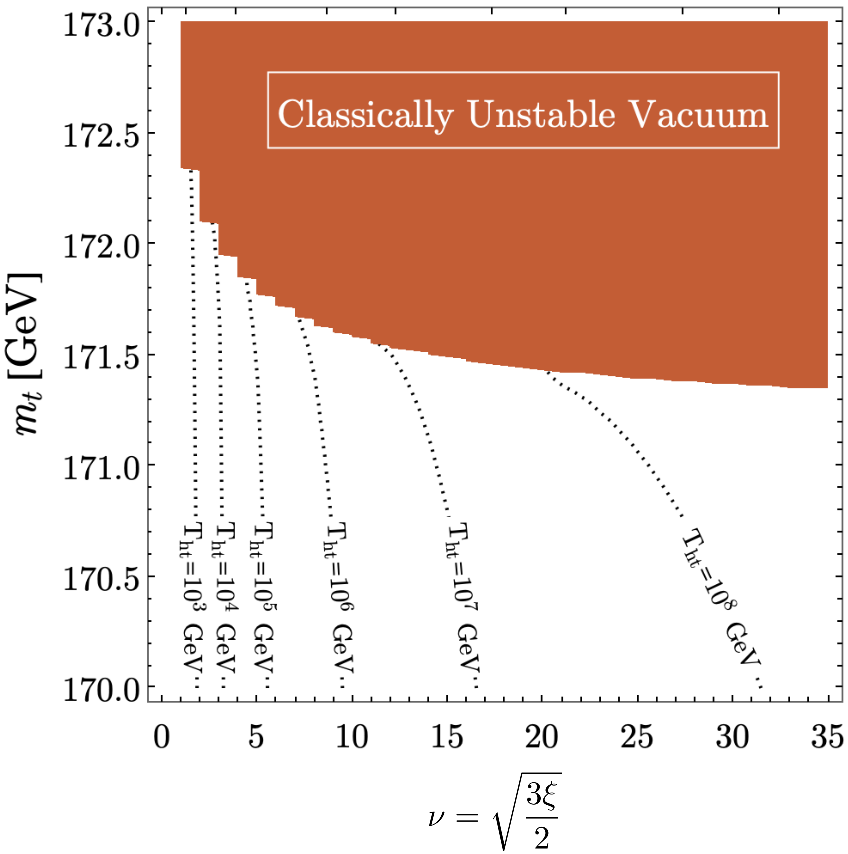


D.Bettoni, A. Lopez-Eiguren, JR, JCAP 01 (2022) 01, 002
G. Laverda, JR, JCAP 03 (2024) 033

Heating the Universe before BBN

- Reheating and vacuum stability pull in opposite directions.
- Heating requires strong instabilities, vacuum survival requires control.





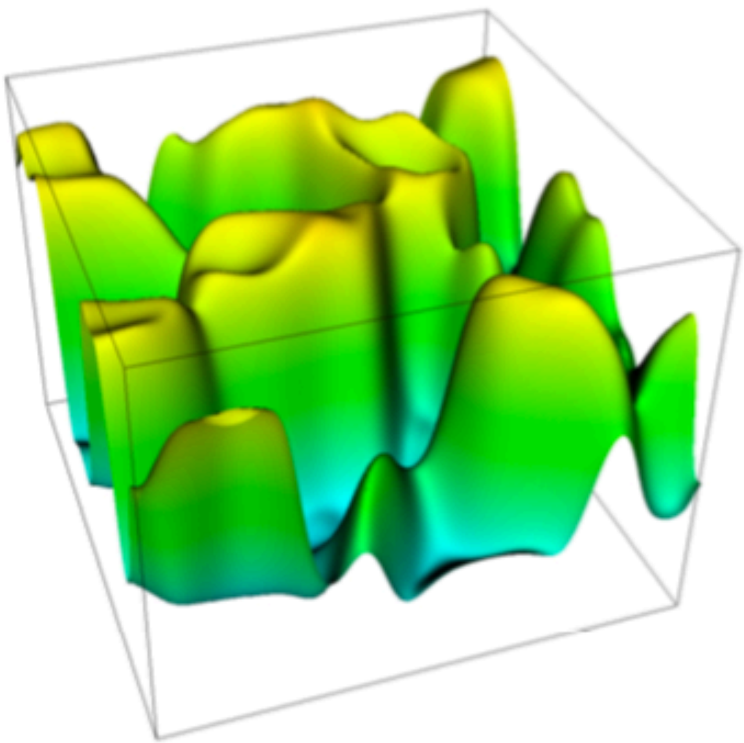
$$T_{\rm ht} \simeq 2.7 \times 10^8\,{\rm GeV} \left(1 + \frac{z_{\rm rad}}{\nu}\right)^{-3/4} \left(\frac{\rho^{\chi}_{\rm rad}/\rho^{\phi}_{\rm rad}}{10^{-8}}\right)^{3/4} \left(\frac{H_{\rm kin}}{10^{11}\,{\rm GeV}}\right)^{1/2}$$

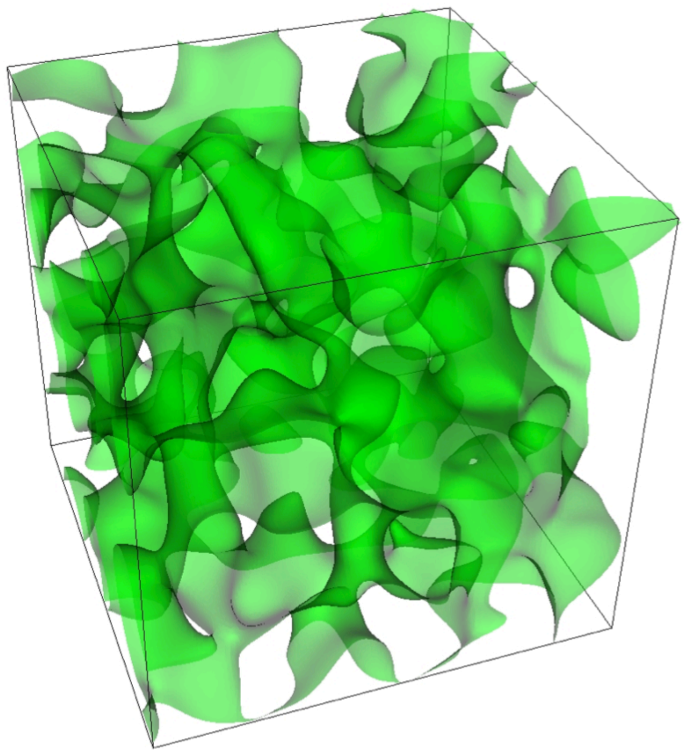
G. Laverda, JR, JHEP 05 (2024) 339

Gradients are large!

$$(h_{ij}^{TT})'' + 2H(h_{ij}^{TT})' - \frac{\nabla^2 h_{ij}^{TT}}{a^2} \simeq \frac{2a^2}{M_P^2}\Pi_{ij}^{TT}$$

$$\Pi_{ij} = \partial_i\chi\partial_j\chi - \xi\partial_i\partial_j\chi^2$$

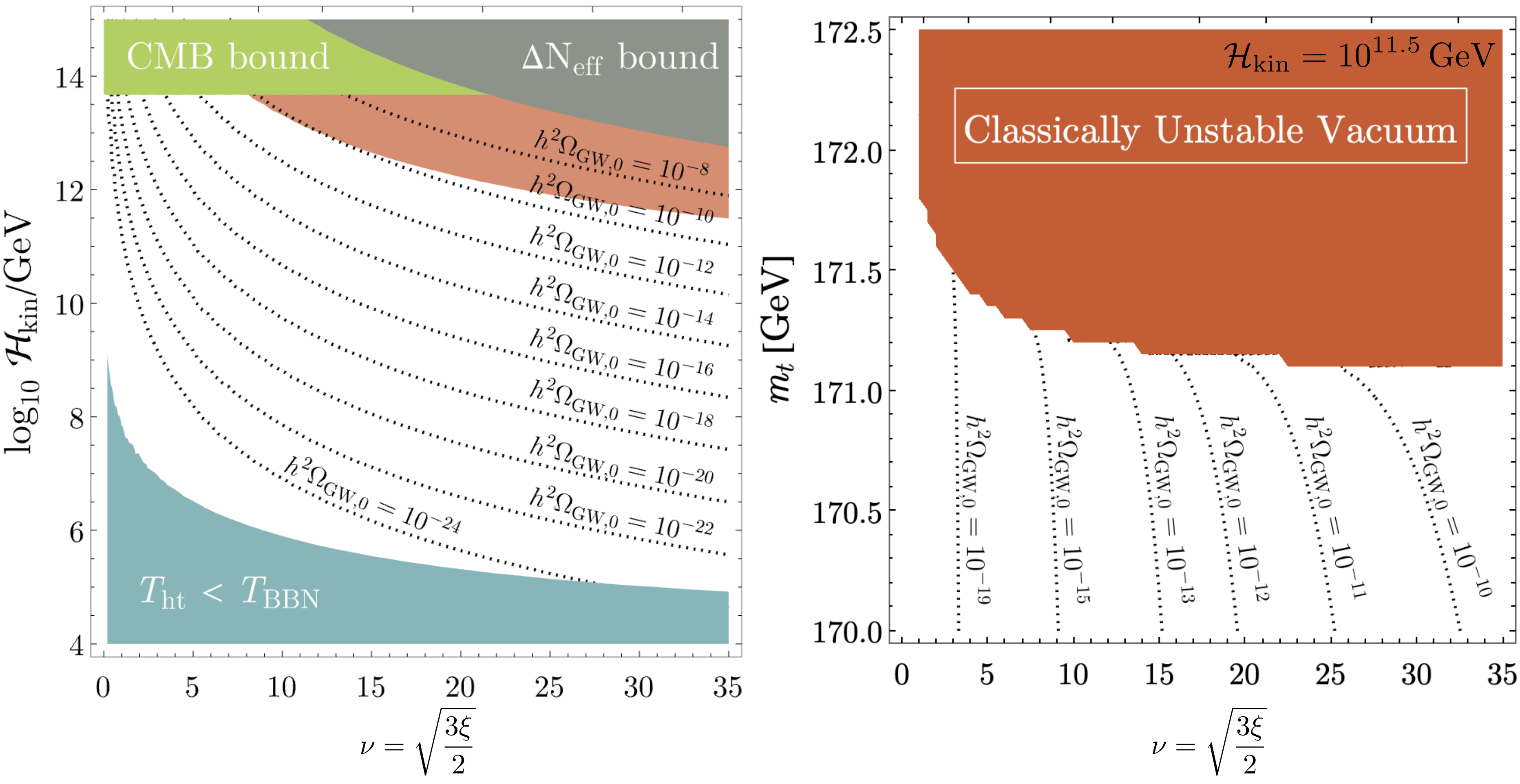




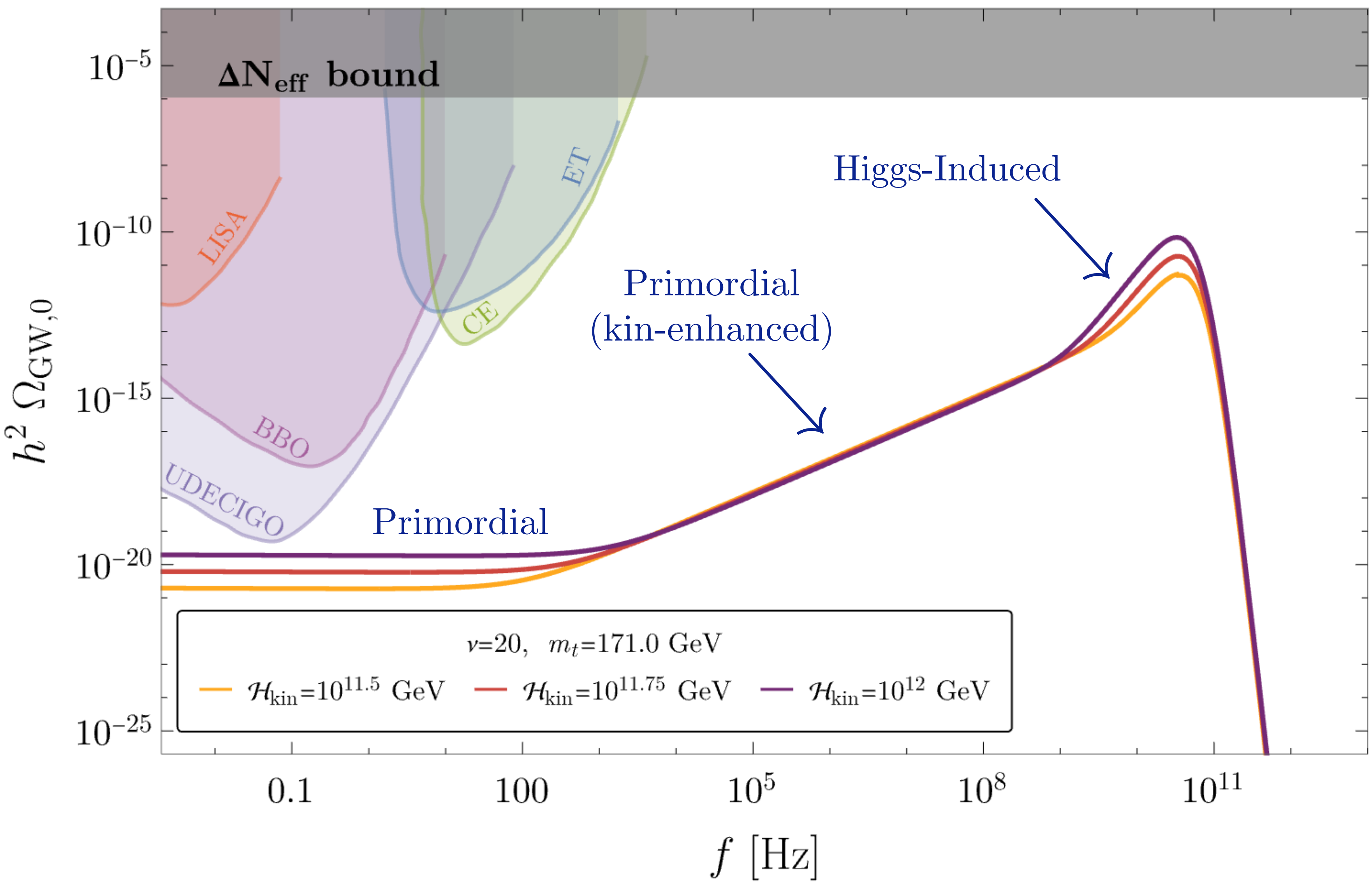
D. Bettoni, G. Domènech, J. Rubio, JCAP 02 (2019) 034
D. Bettoni, A López-Eiguren, G. Laverda, JR, JCAP 03 (2025) 027

GW energy density

$$\Omega_{\mathrm{GW},0}(\mathcal{H}_{\mathrm{kin}},\nu,m_t) = 1.67\times 10^{-5}h^{-2}\left(\frac{100}{g_*^{\mathrm{ht}}}\right)^{1/3}\times\bar{\Omega}_{\mathrm{GW}}$$



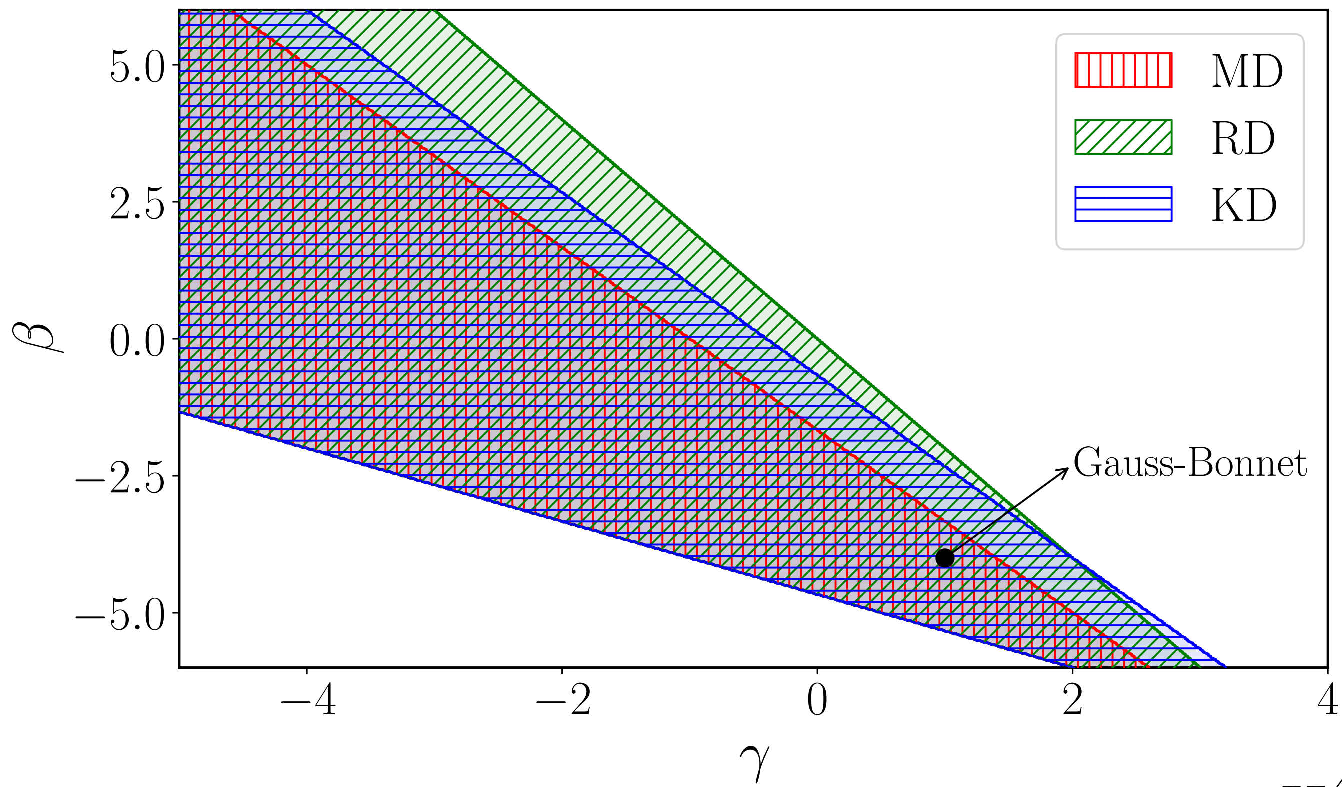
GW spectra



ΔN_eff bound
LISA
BBO
UDECIGO
CE
ET
Higgs-Induced
Primordial
(kin-enhanced)
Primordial
ν=20, m_t=171.0 GeV
ℋ_kin=10^11.5 GeV
ℋ_kin=10^11.75 GeV
ℋ_kin=10^12 GeV
10^−5
10^−10
10^−15
10^−20
10^−25
0.1
100
10^5
10^8
10^11
h^2 Ω_GW,0
f [Hz]

Beyond kination: Gravitational EFT

$$\frac{\Delta\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}\xi R\chi^2 - \left(\alpha R^2 + \beta R_{\mu\nu}R^{\mu\nu} + \gamma R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}\right)\frac{\chi^2}{\Lambda^2} + \ldots$$



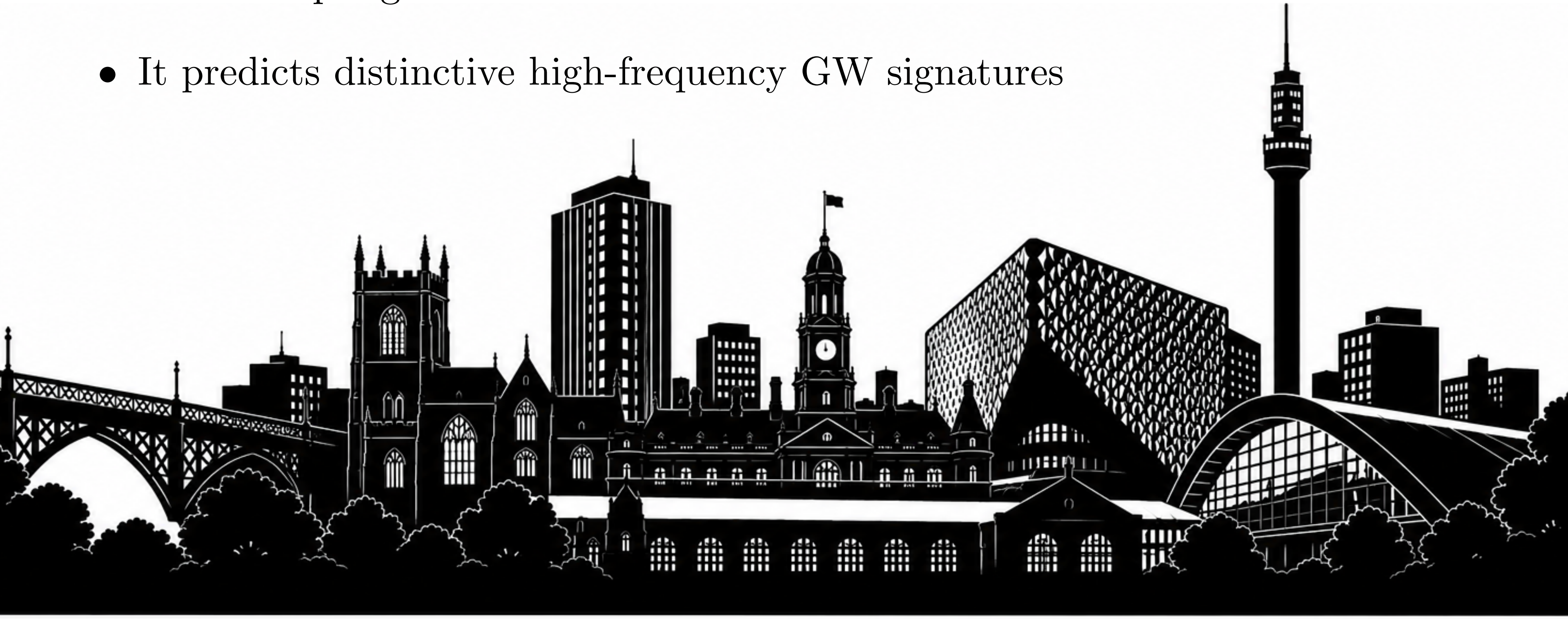
$$M_{\text{eff}}^2 = M^2 + 3\xi(1-3w)H^2 + C(\alpha,\beta,\gamma,\omega)\frac{H^4}{\Lambda^2}$$

Higher-order operators may become relevant during radiation domination

G. Laverda, T. Mendes, JR, JCAP 05 (2026) 053

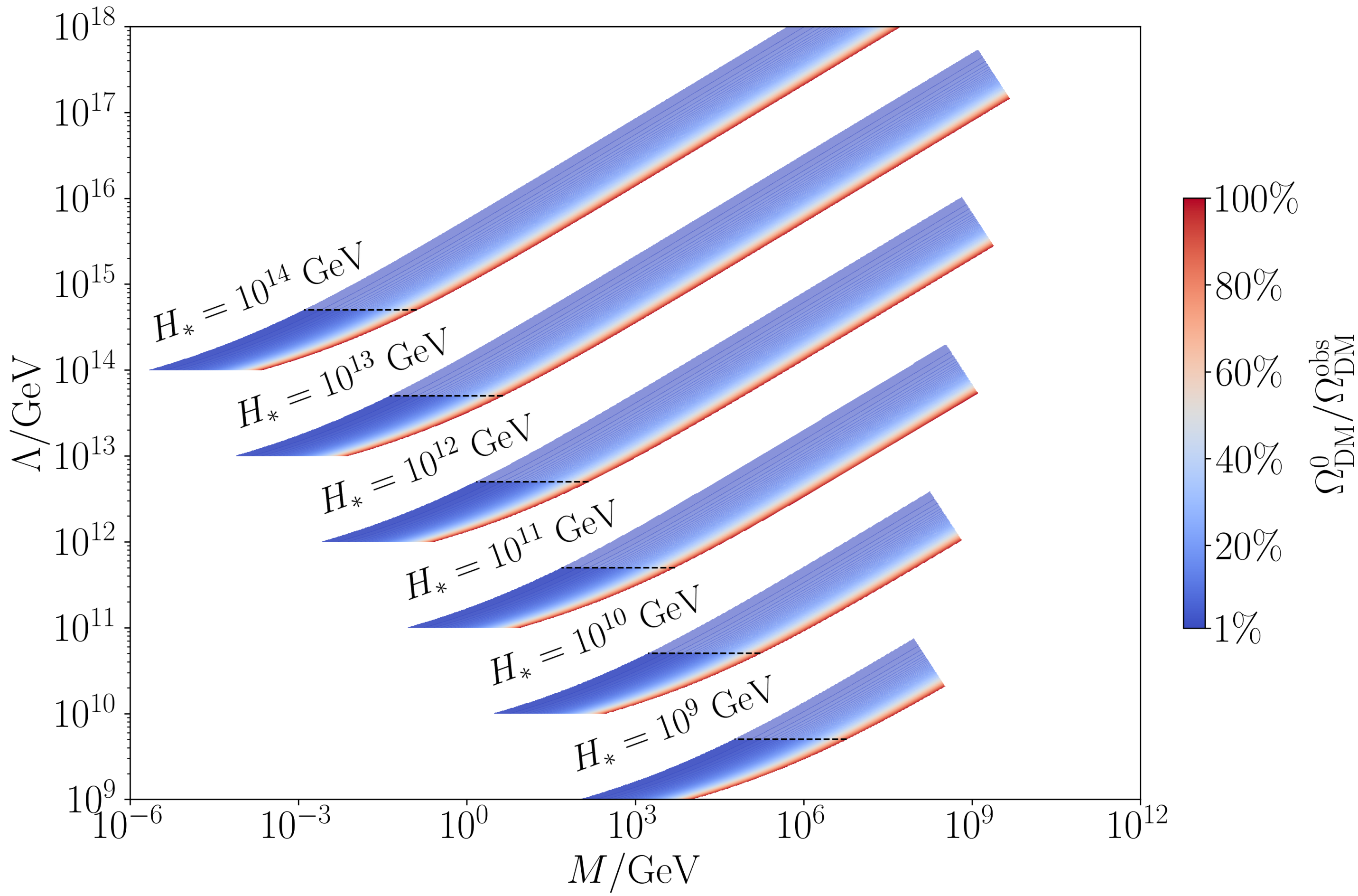
Conclusions

- Time-dependent spacetime curvature can trigger phase transitions via Hubble-induced instabilities.
- Specific cosmological transitions (e.g. inflation $\rightarrow$ kination) naturally destabilize the Higgs and other spectator fields.
- This mechanism enables efficient reheating before BBN without requiring direct couplings to new sectors.
- It predicts distinctive high-frequency GW signatures



Backup slides

Hitting the right DM abundance



$$\Omega^0_{\rm DM} \sim \mathcal{C}(\nu, \kappa_*) \left(\frac{H_*}{M_P}\right)^{5/2} \left(\frac{M}{H_*}\right) \nu^{5/2} \exp\left[\alpha(\kappa_*)\,\nu\right] \qquad \nu \propto \frac{H_*}{\Lambda}$$

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Tachyonic particle production

$$Y \equiv \frac{a}{a_{\rm kin}} \frac{h}{h_*} \qquad \vec{y} \equiv a_{\rm kin} h_* \vec{x} \qquad z \equiv a_{\rm kin} h_* \tau \qquad h_* \equiv \sqrt{6\xi} H_{\rm kin}$$

Spinodal/Tachyonic instability

$$S_\chi = \int d^3\vec{y}\, dz \left[\frac{1}{2}(Y')^2 - \frac{1}{2}|\nabla Y|^2 + \frac{1}{2}M_{\rm eff}^2(z) Y^2 - V(Y)\right]$$

$$M_{\rm eff}^2(z) \equiv (4\nu^2 - 1)\mathcal{H}^2 \qquad \nu \equiv \sqrt{\frac{3\xi}{2}}$$

- The field is *not* classical but rather quantum.
- A homogeneous component description is *completely inaccurate*.

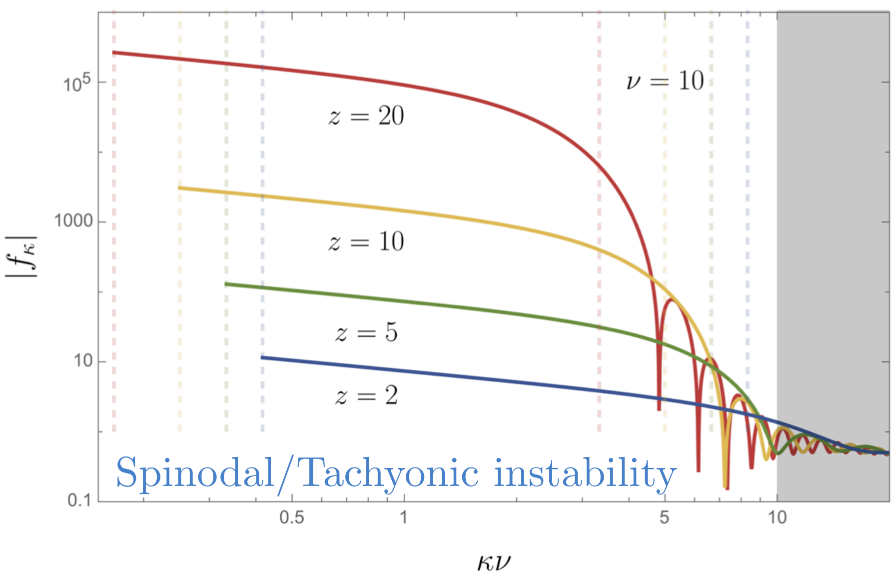
D. Bettoni, JR, JCAP 01 (2020) 002

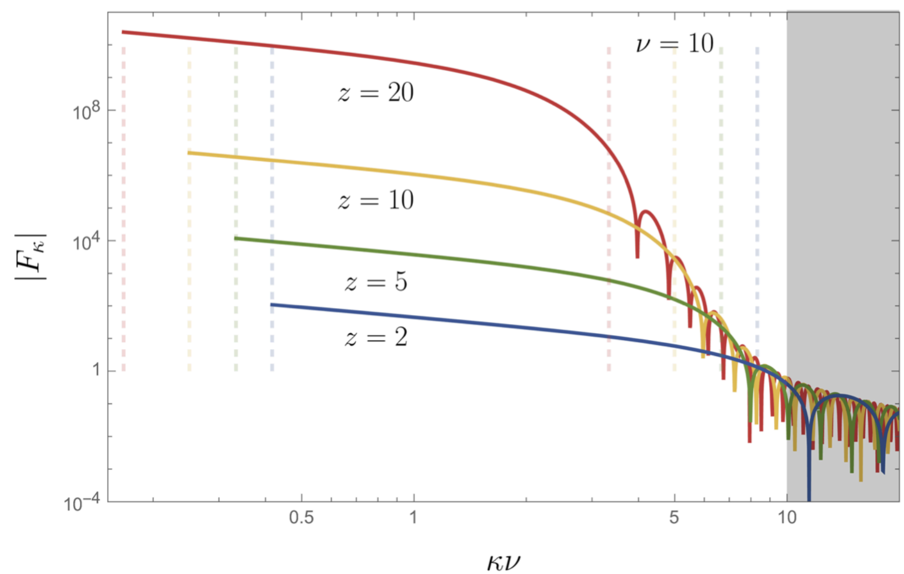
Classicalization

- The field is *not* classical but rather quantum.
- A homogeneous component description is *completely inaccurate*.

$$f''_\kappa + (\kappa^2 - M^2_{\text{eff}}(z))f_\kappa = 0$$

$$F_\kappa(z) = \text{Re}(f^*_\kappa f'_\kappa)$$





$$\Delta Y^2_\kappa \, \Delta\Pi^2_\kappa = |F_\kappa(z)|^2 + \frac{1}{4} \geq \frac{1}{4}\left|\langle[Y_\kappa(z),\ \Pi^\dagger_\kappa(z)]\rangle\right|^2$$

- Following dynamics needs non-analytical techniques.
- High occupation numbers → Classical Lattice Simulations

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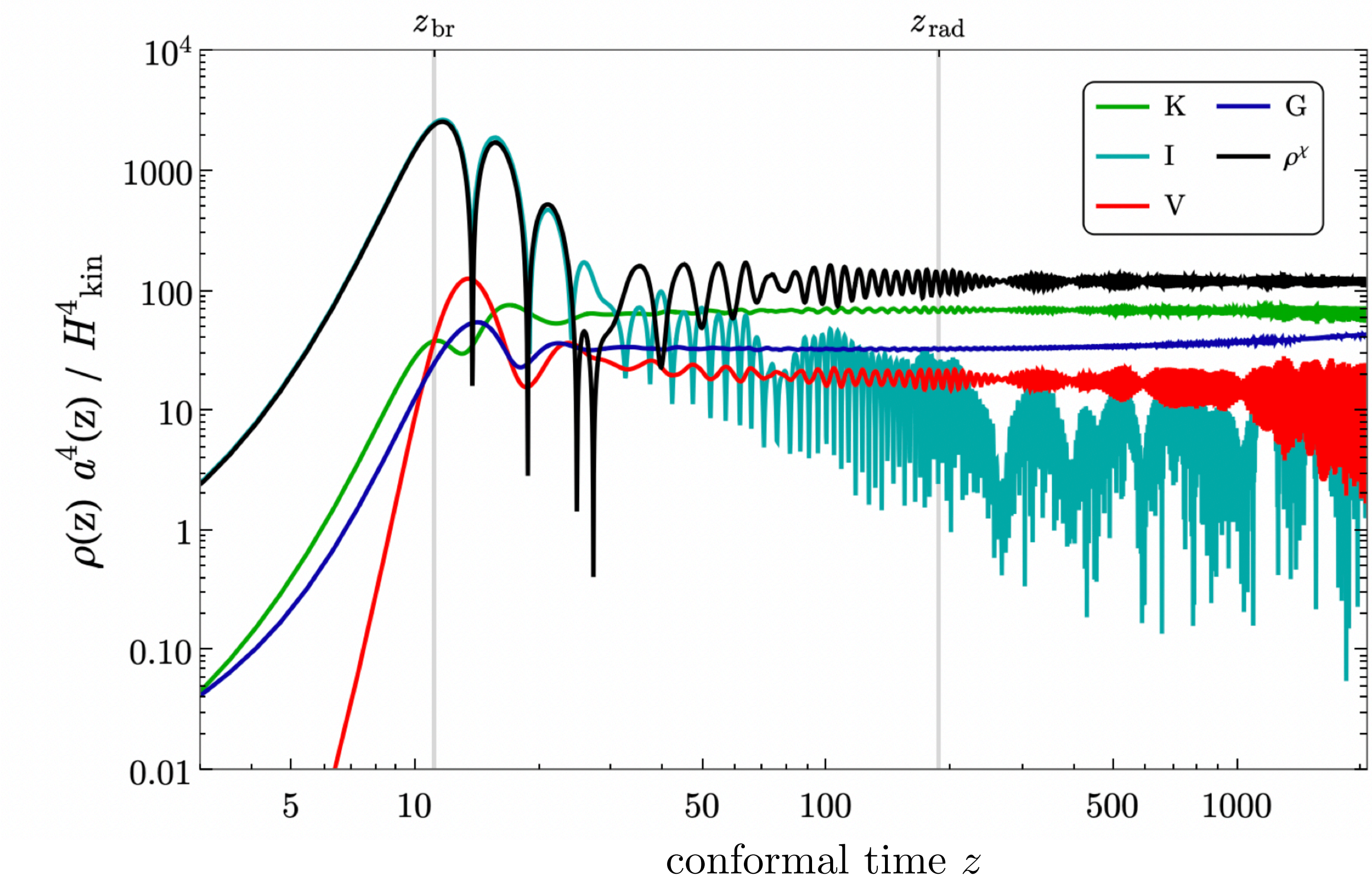
Energy distribution



Lattice-based fitting formulas: O(100) 3+1 classical lattice simulations

$$\rho_{\rm tac}(\lambda(\mu),\xi) = 16\,\mathcal{H}^4_{\rm kin}\ \exp\left(\beta_1(\lambda) + \beta_2(\lambda)\,\nu + \beta_3(\lambda)\ln\nu\right) \qquad \nu = \sqrt{\frac{3\xi}{2}}$$

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Gradients are crucial

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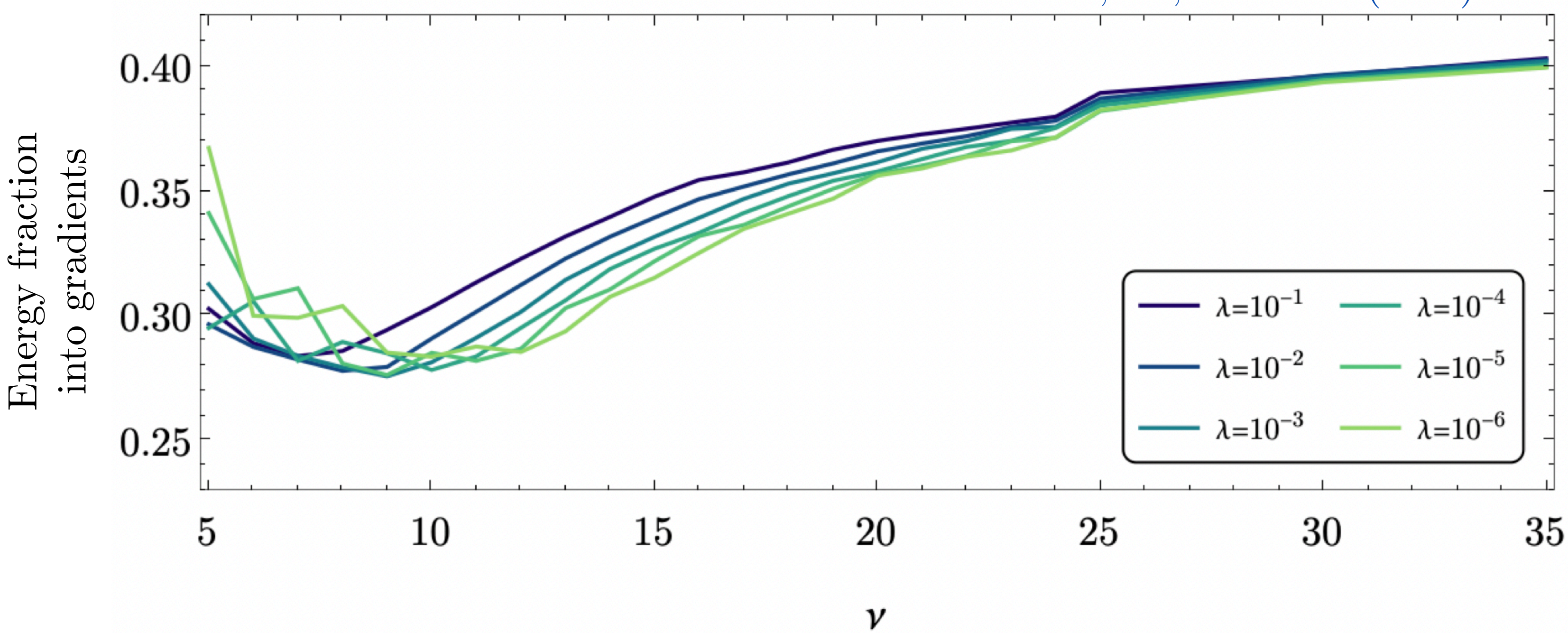

Radiation-like products for arbitrary potential

$$w_\chi = \frac{1}{3} + \frac{2}{3}\frac{(n-2)}{(n+1) + \langle(\nabla\chi/a)^2\rangle/\langle V\rangle} \qquad V \propto \chi^{2n}$$

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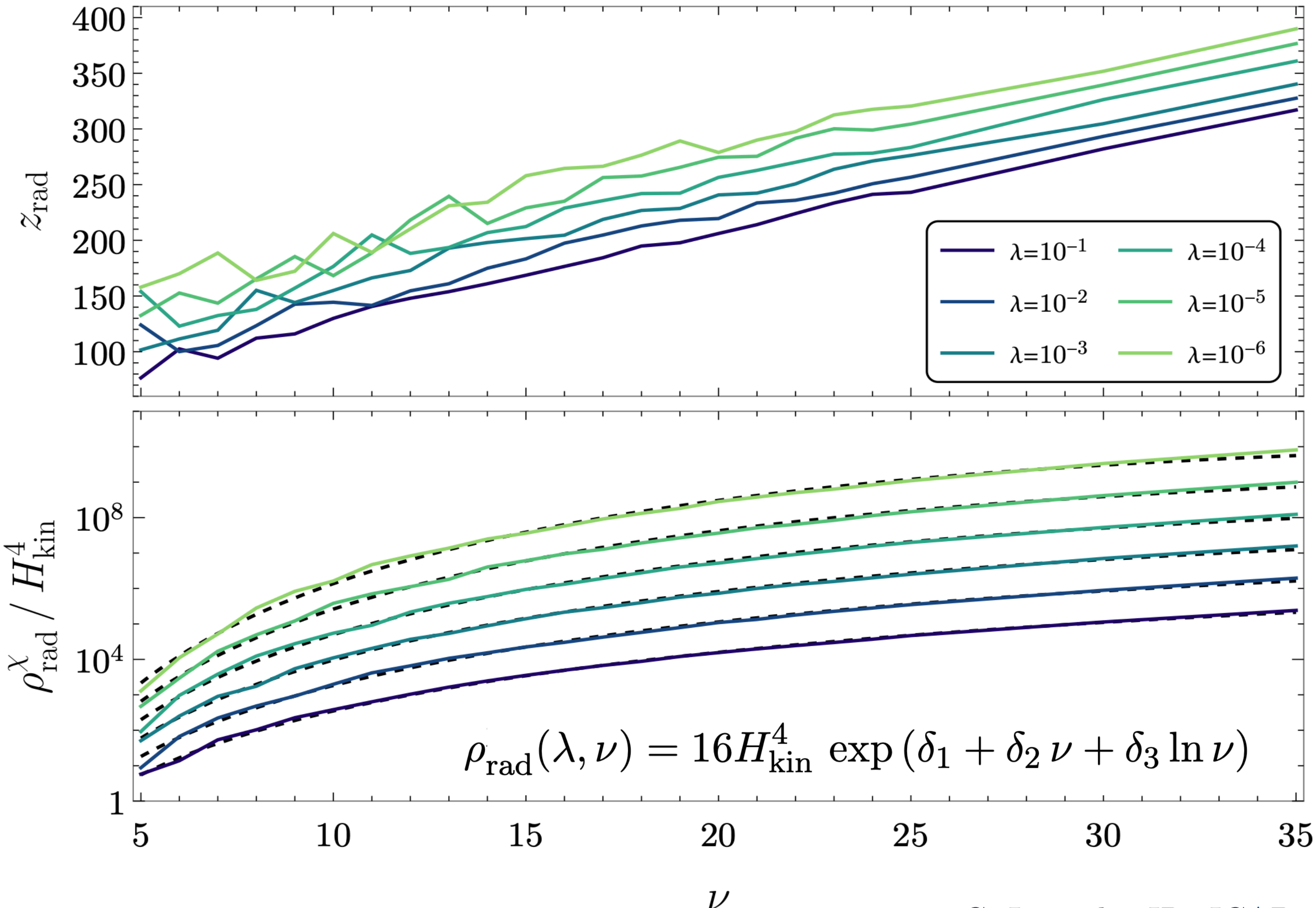
Onset of radiation domination

Lattice-based fitting formulas: O(100) 3+1 classical lattice simulations



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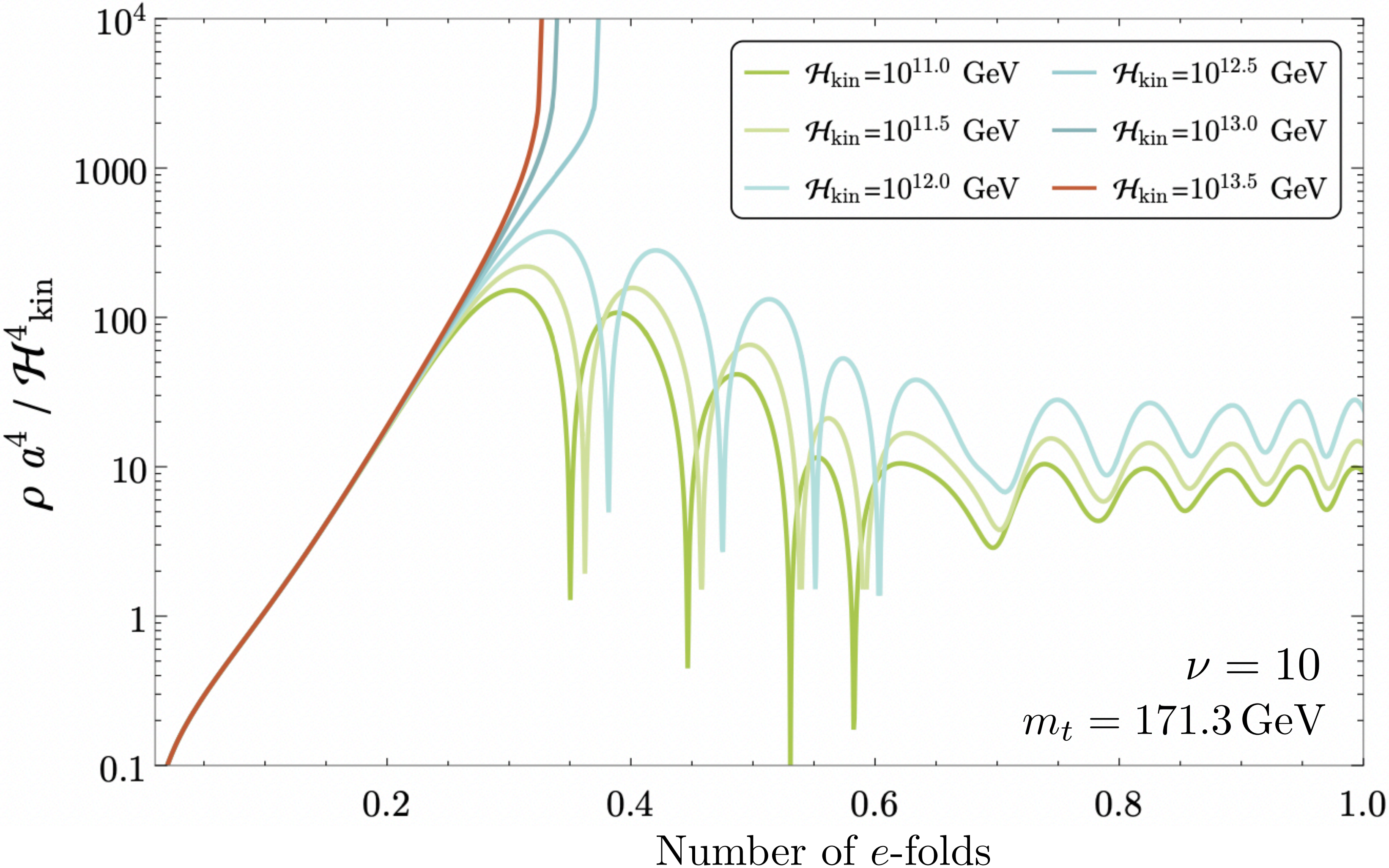
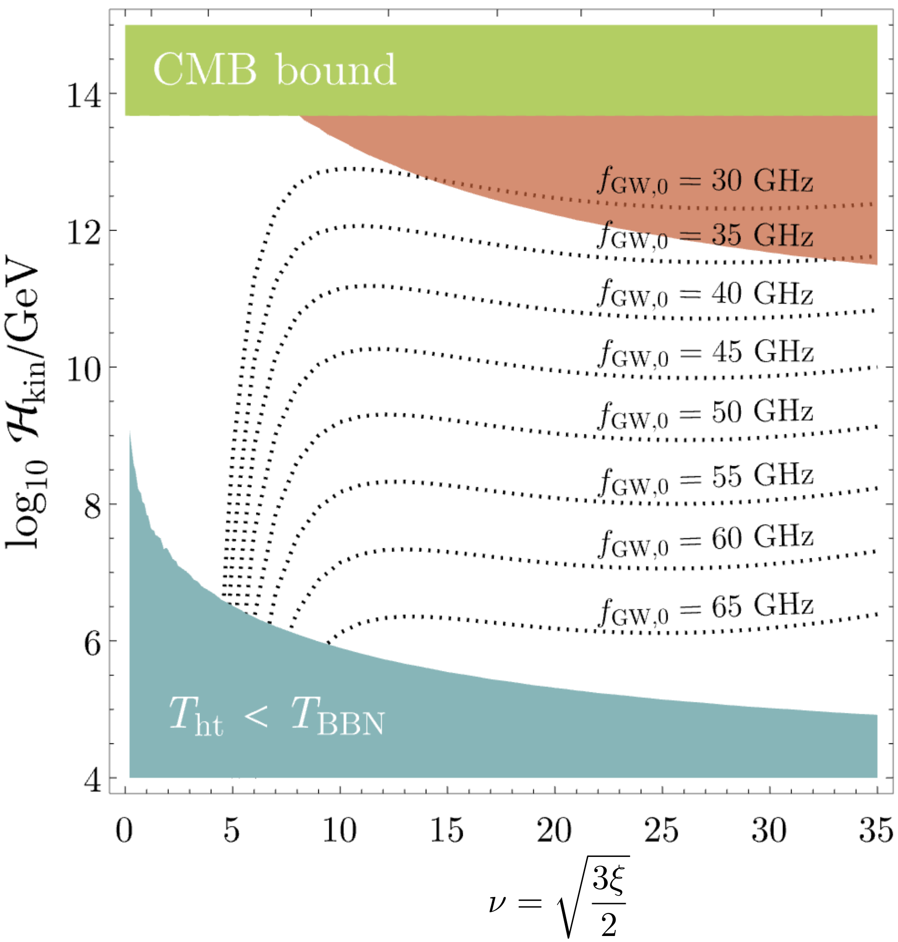
Vacuum stability during kination

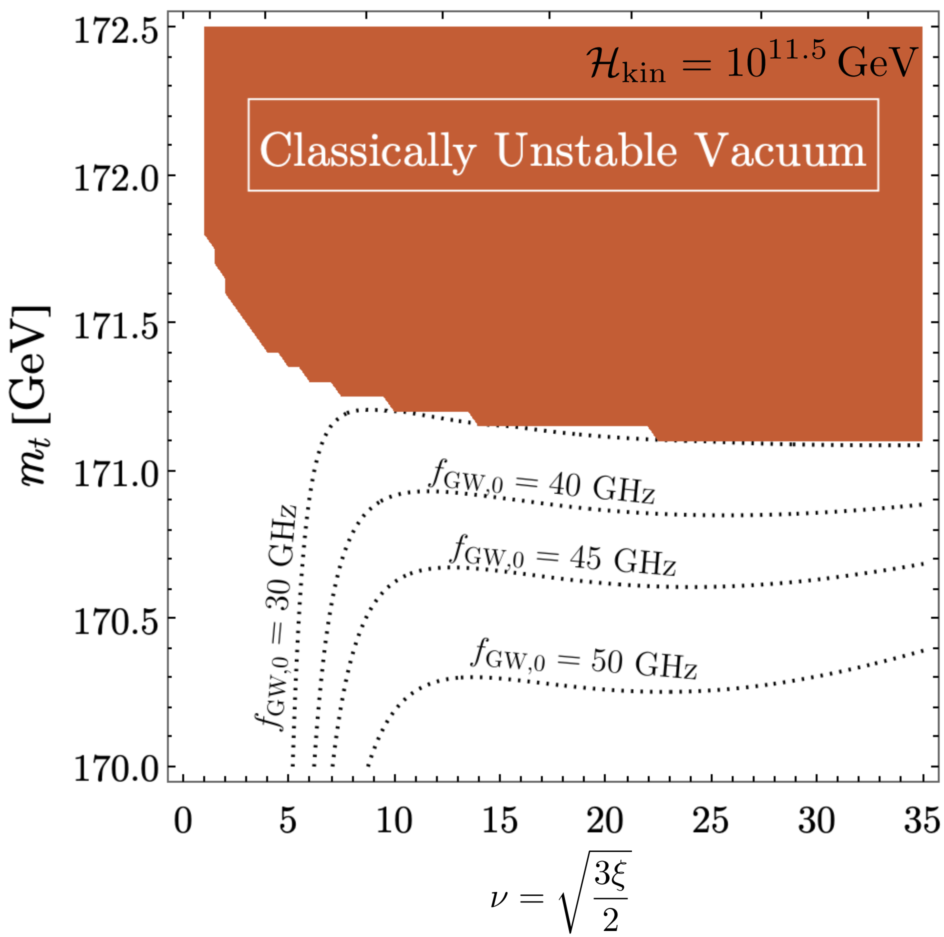


G. Laverda, JR, 2402.06000

GW frequency

$$f_{\mathrm{GW},0}(\nu, m_t) \simeq 1.3 \times 10^9\ \mathrm{Hz}\ \frac{\kappa}{2\pi} \left(\frac{\mathcal{H}_{\mathrm{kin}}\, a_{\mathrm{rad}}}{10^{10}\ \mathrm{GeV}} \right)^{1/2} \left(\frac{\Theta^h_{\mathrm{ht}}}{10^{-8}} \right)^{-1/4}$$





Beyond the Standard Model

$$V_{\text{eff}}(H) = (\xi R + m_h^2) H^\dagger H + \lambda (H^\dagger H)^2 + \frac{1}{\Lambda^2}(H^\dagger H)^3$$