

Reheating from Curvature: Higgs Dynamics after Inflation

Javier Rubio

Universidad Complutense de Madrid & IPARCOS

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



Particle Physics and Cosmology (PPC2026)



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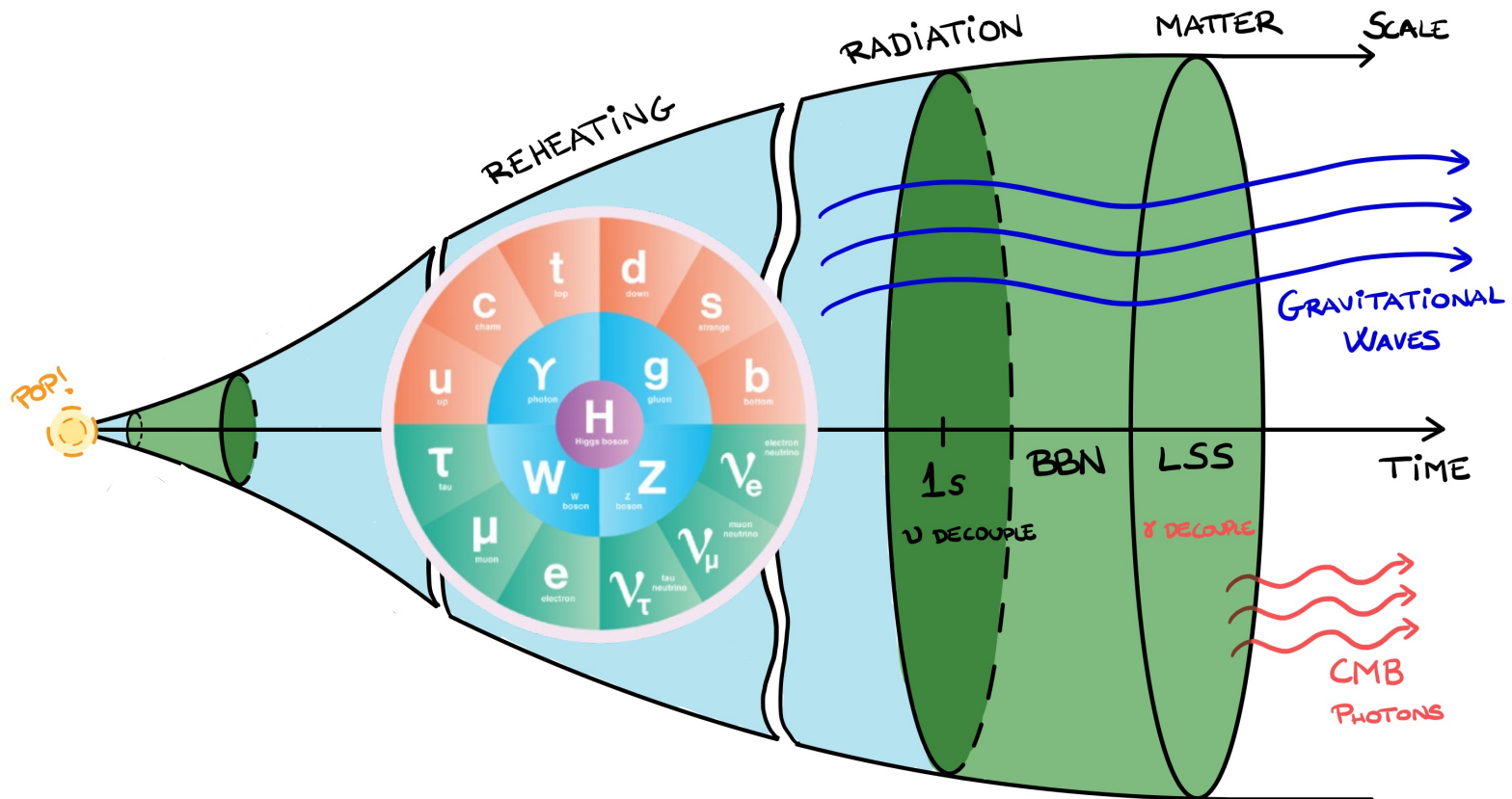


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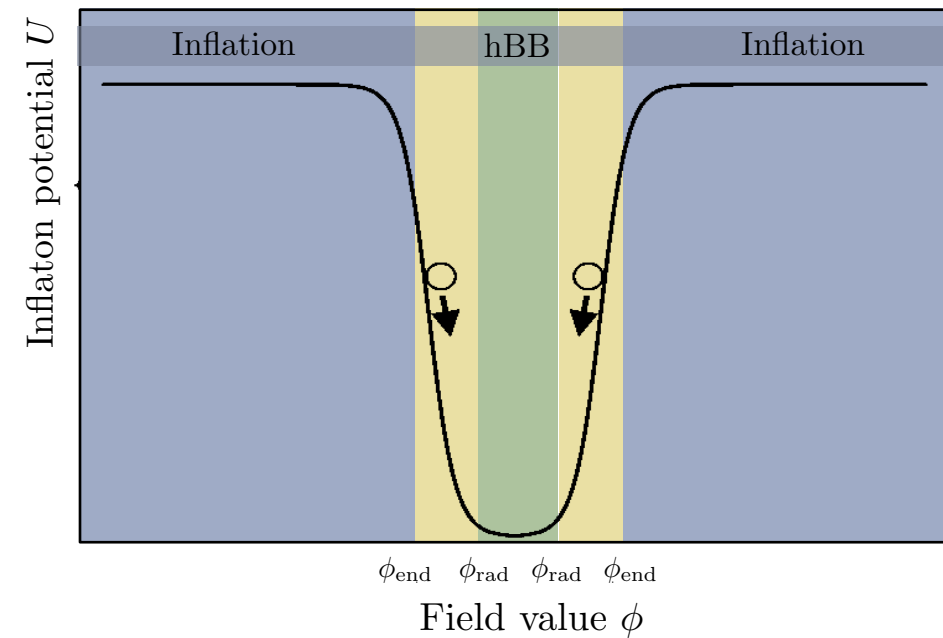
Fundación
BBVA

From inflation to the hot Big Bang

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

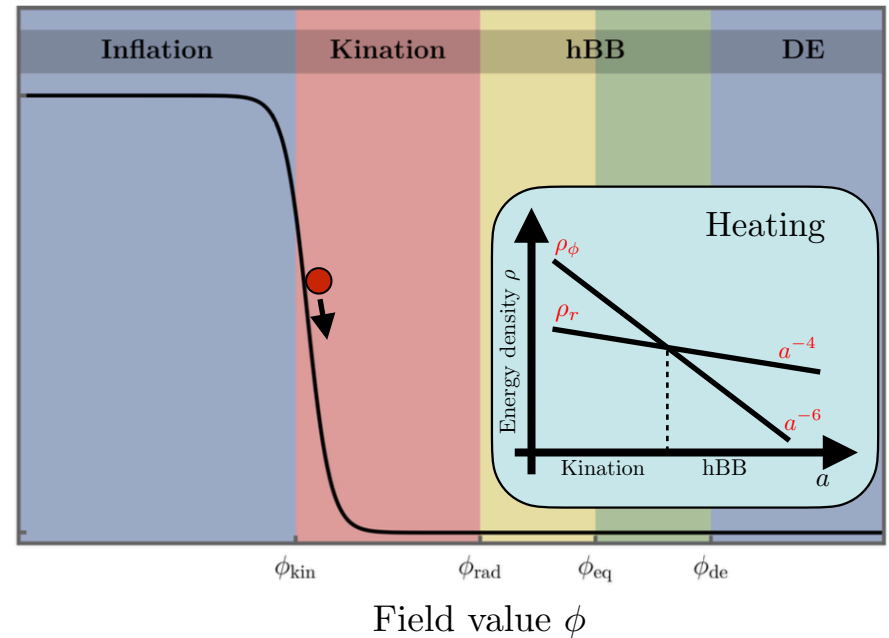


Oscillatory vs. Non-oscillatory



- 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

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

Interesting outputs

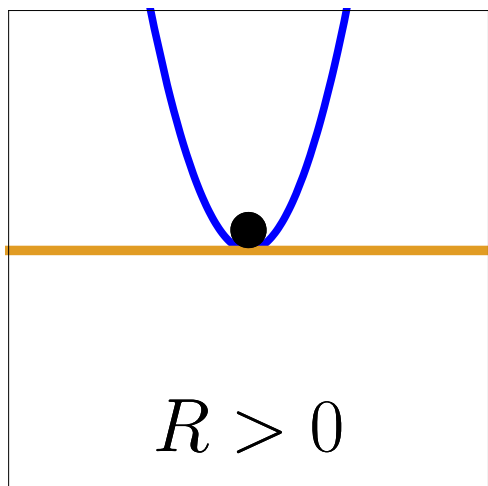
- The Higgs field is safely stabilized during inflation (no isocurvature pert.)
- Appealing connection between SM parameters and (post-)inflationary era
- The Higgs field itself can be responsible for heating the Universe

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, $\xi h^2 \ll M_P^2$

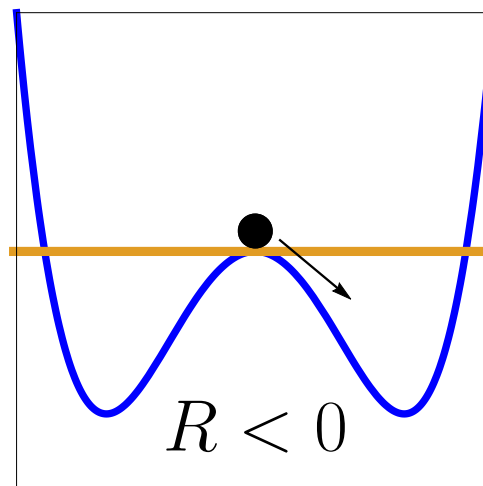
Inflation $w_\phi = -1$



No isocurvature
perturbations



Kination $w_\phi = 1$



Tachyonic
production

Tachyonic particle production

$$Y \equiv \frac{a}{a_{\text{kin}}} \frac{h}{h_*}$$

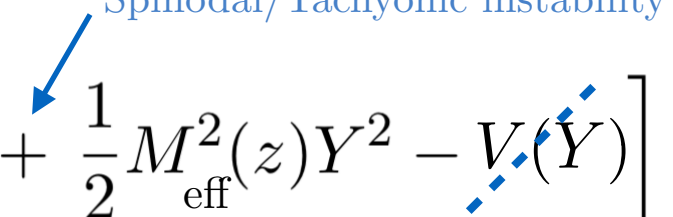
$$\vec{y} \equiv a_{\text{kin}} h_* \vec{x}$$

$$z \equiv a_{\text{kin}} h_* \tau$$

$$h_* \equiv \sqrt{6\xi} H_{\text{kin}}$$

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

Spinodal/Tachyonic instability


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

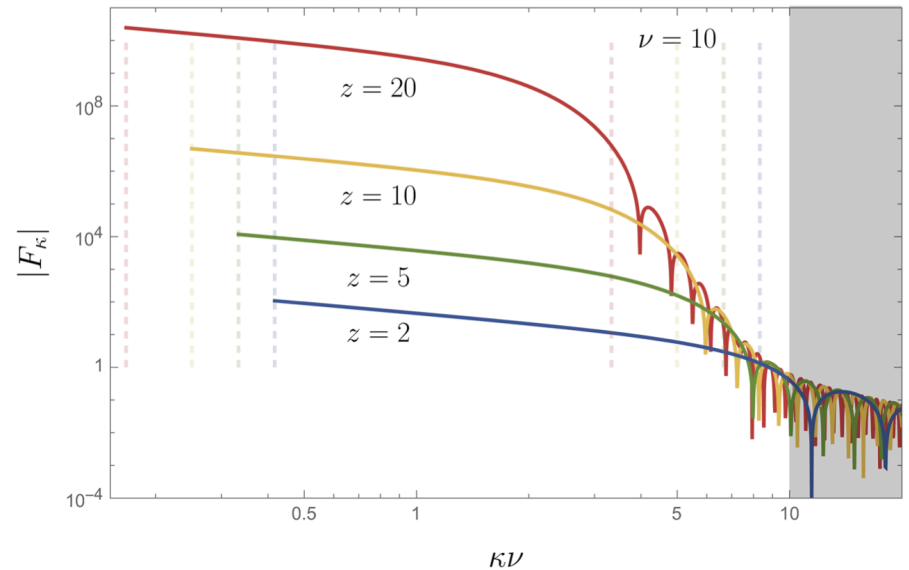
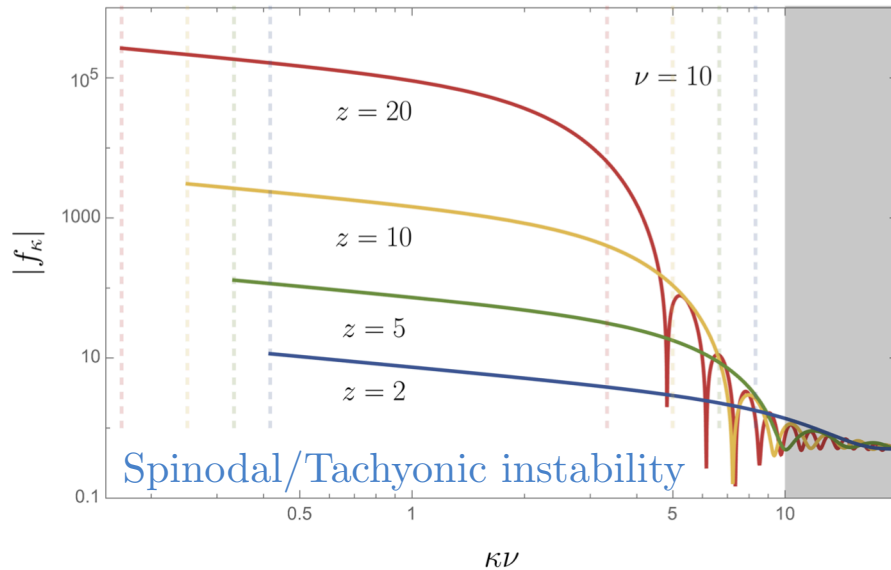
- The field is *not* classical but rather quantum.
- A homogeneous component description is *completely inaccurate*.

Classicalization

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

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

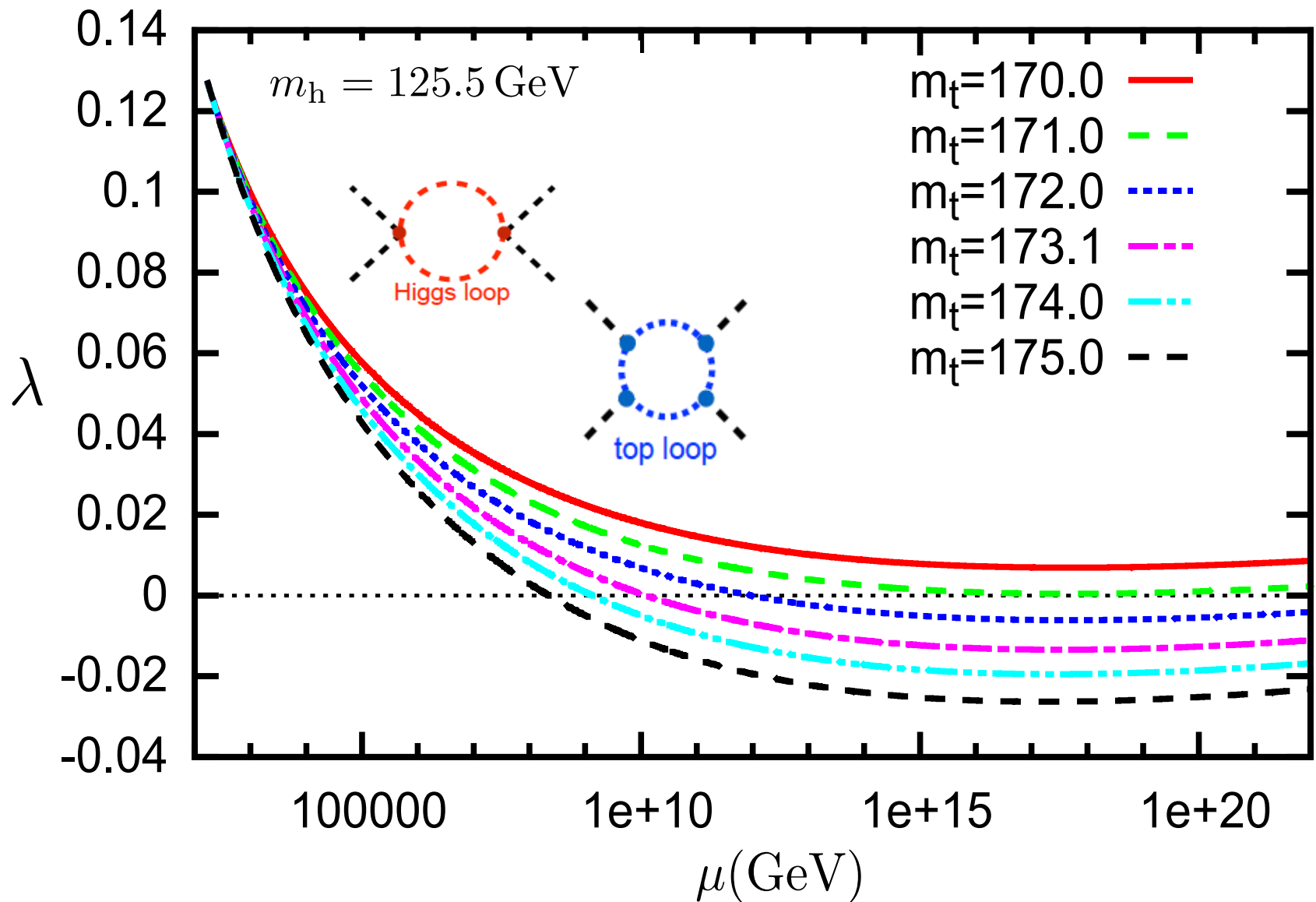
$$F_{\kappa}(z) = \text{Re}(f_{\kappa}^* f'_{\kappa})$$



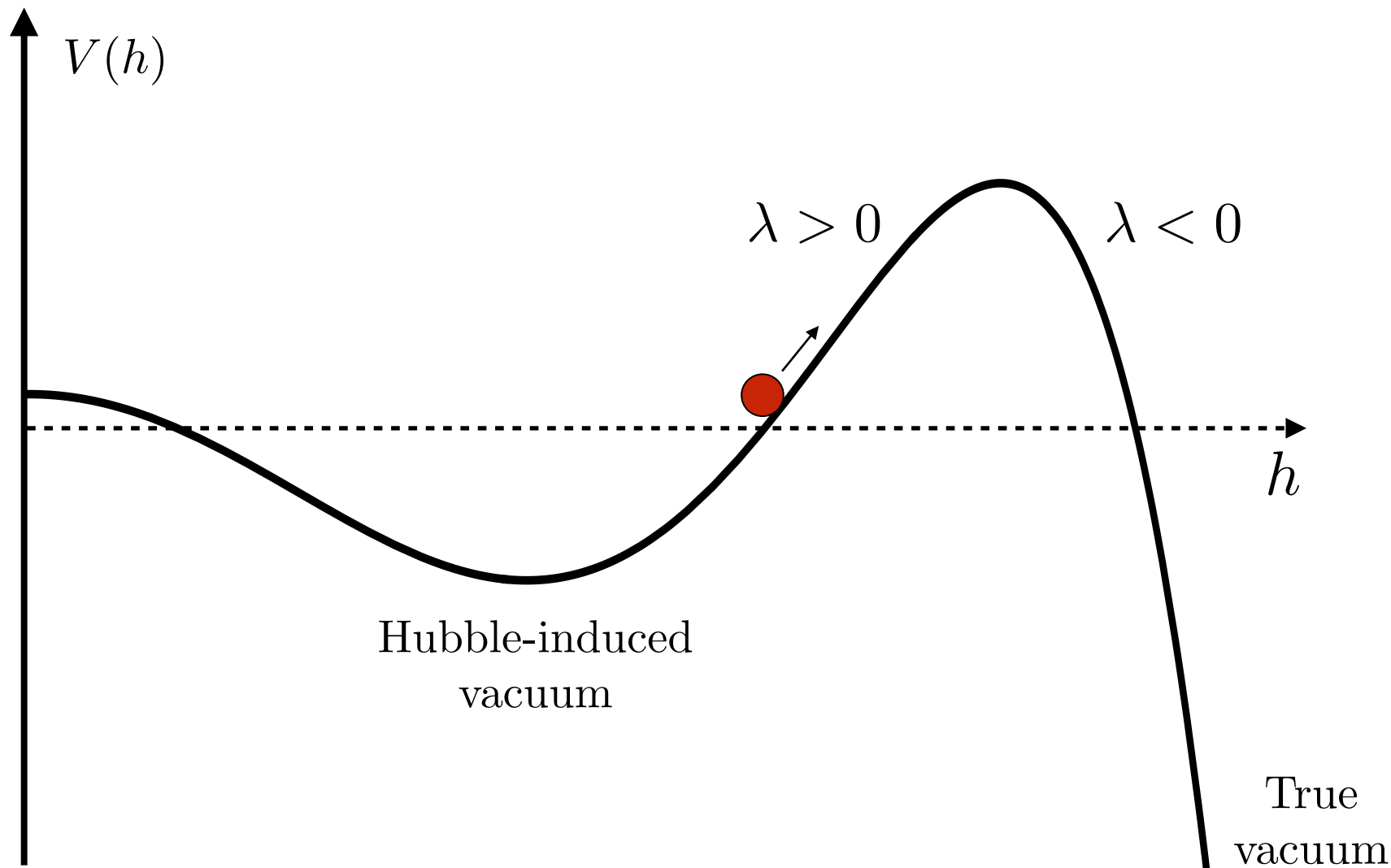
$$\Delta Y_{\kappa}^2 \Delta \Pi_{\kappa}^2 = |F_{\kappa}(z)|^2 + \frac{1}{4} \geq \frac{1}{4} \left| \langle [Y_{\kappa}(z), \Pi_{\kappa}^{\dagger}(z)] \rangle \right|^2$$

- Following dynamics needs non-analytical techniques.
- High occupation numbers $\rightarrow$ Classical Lattice Simulations

Standard Model running



Higgs effective potential



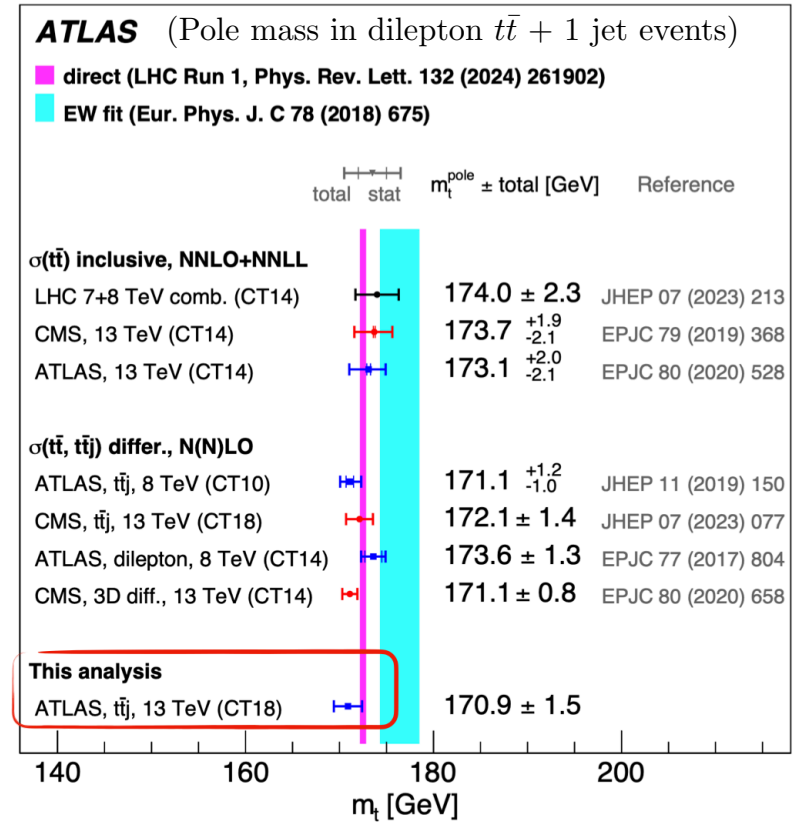
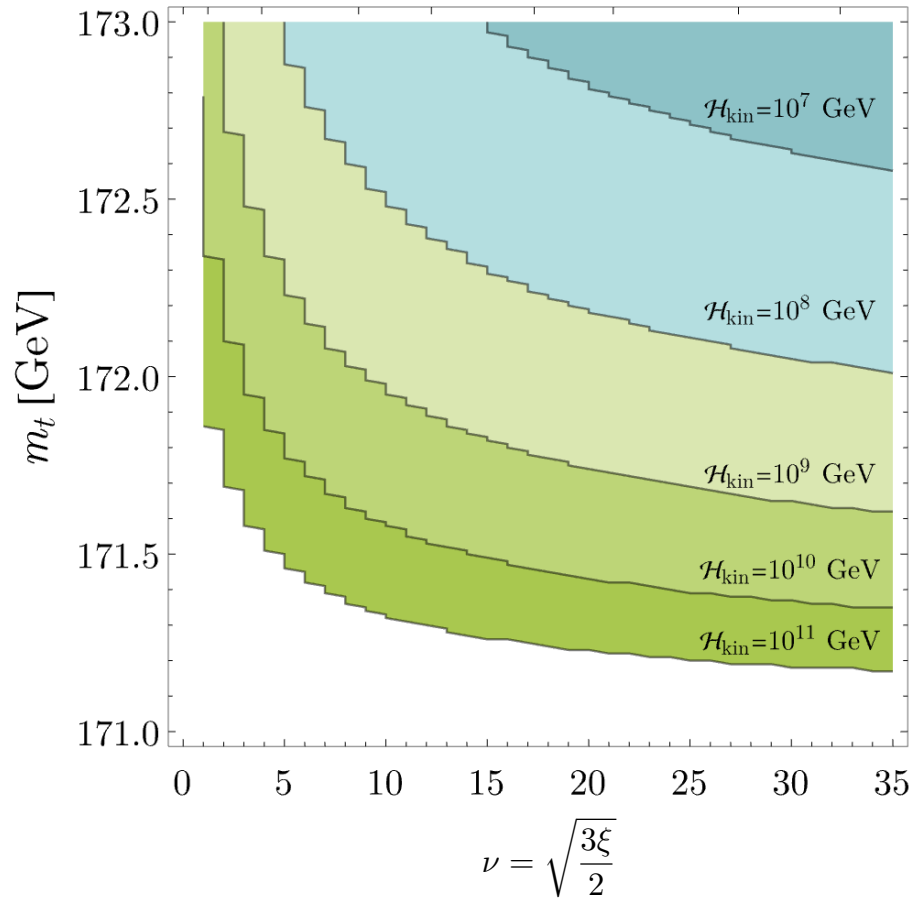
Scanning of parameter space

- 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 $\mathcal{H}_{\text{kin}} \sim 10^6 - 10^{15}$ GeV
- O(1000) 3+1-dimensional classical lattice simulations.
- Checking for existence and crossing of the barrier

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

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

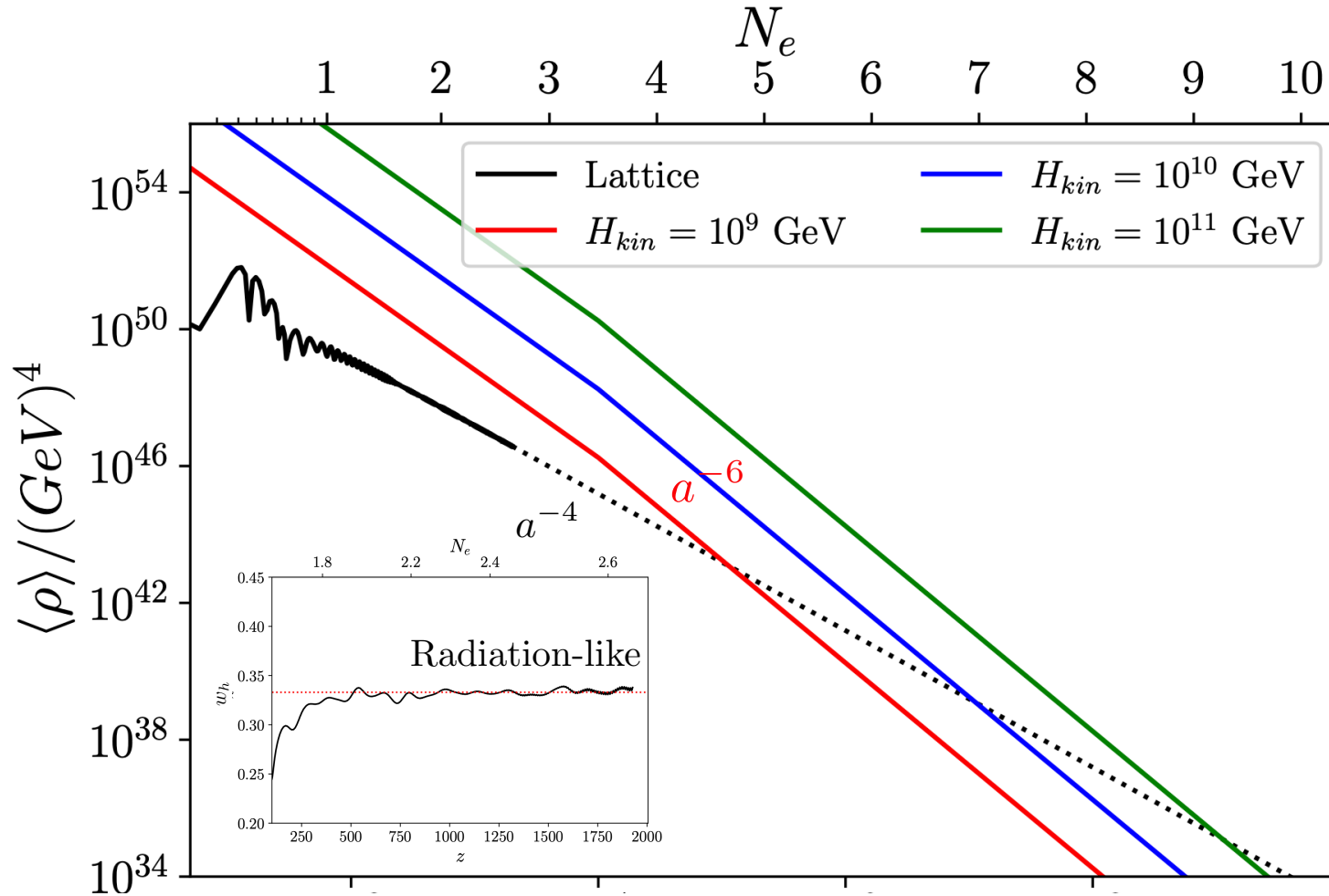
Stability constraints on the top mass



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

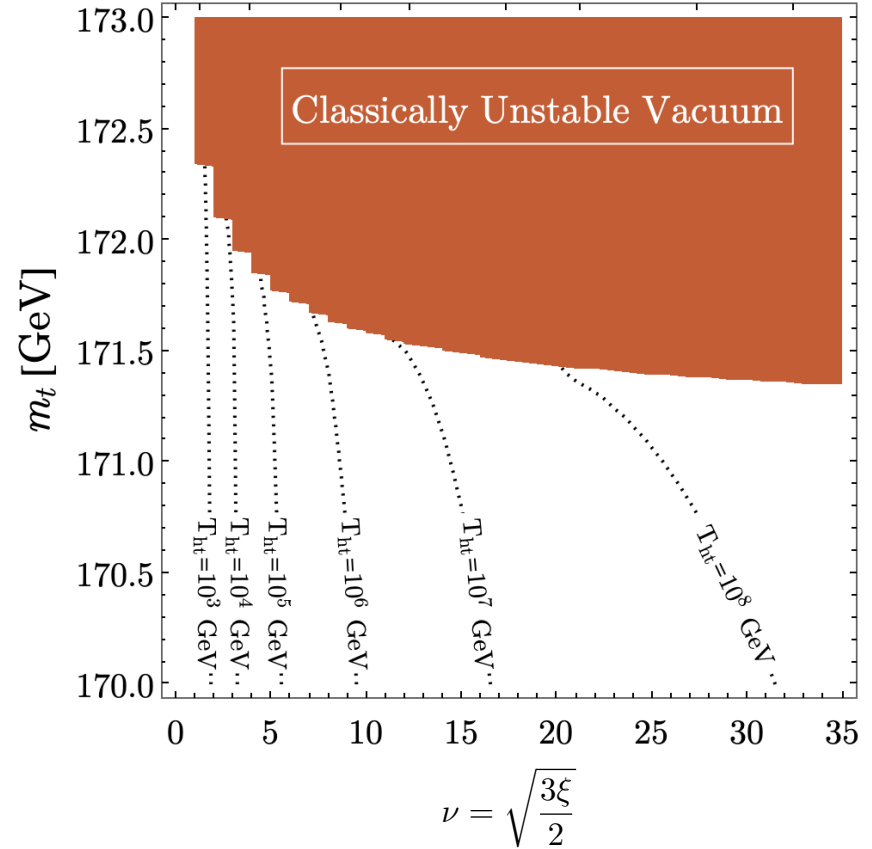
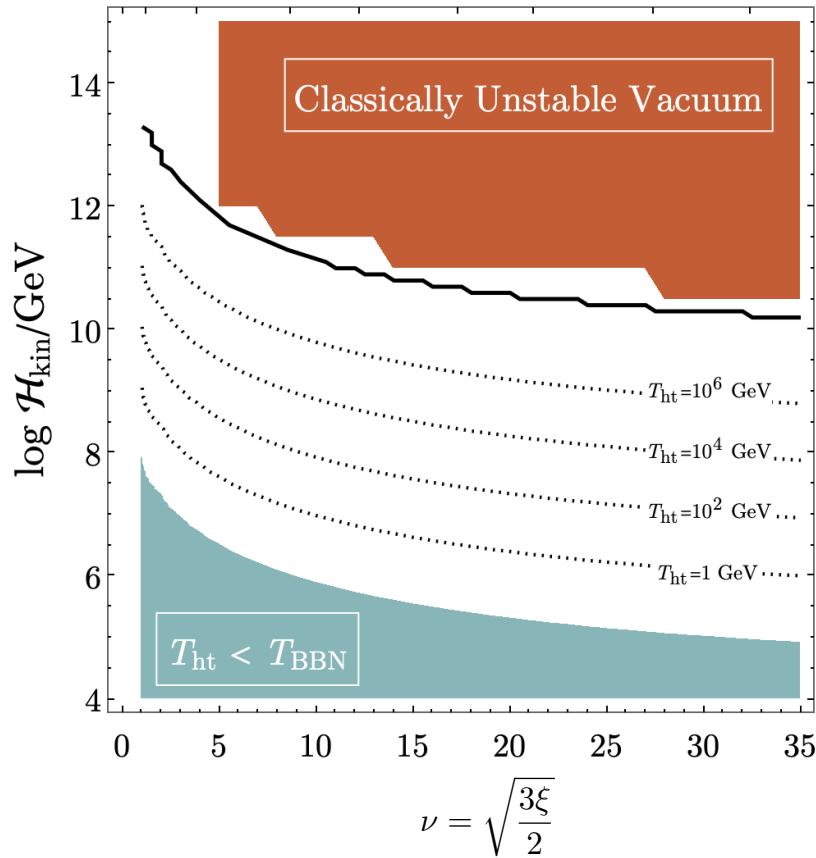
Heating the Universe before BBN

Explosive tachyonic Higgs production allows to heat the Universe.



Heating the Universe before BBN

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

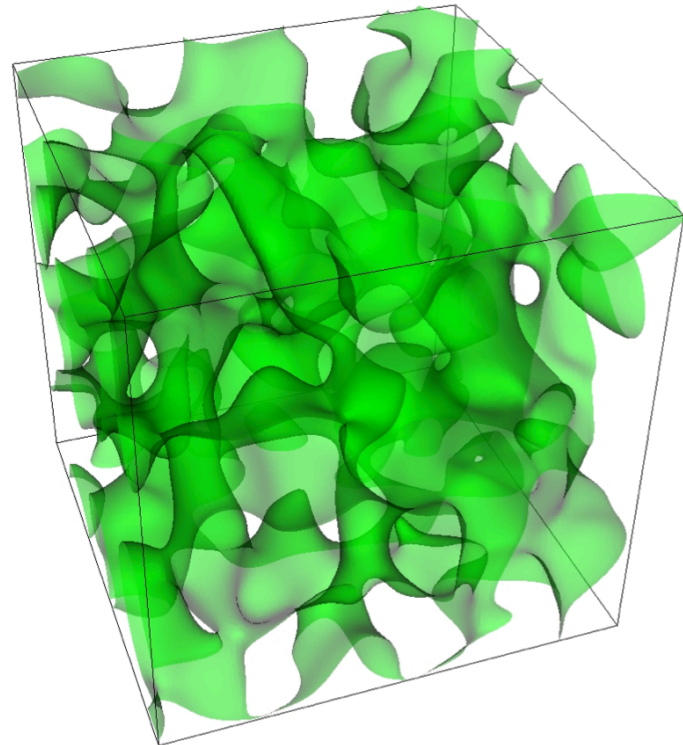
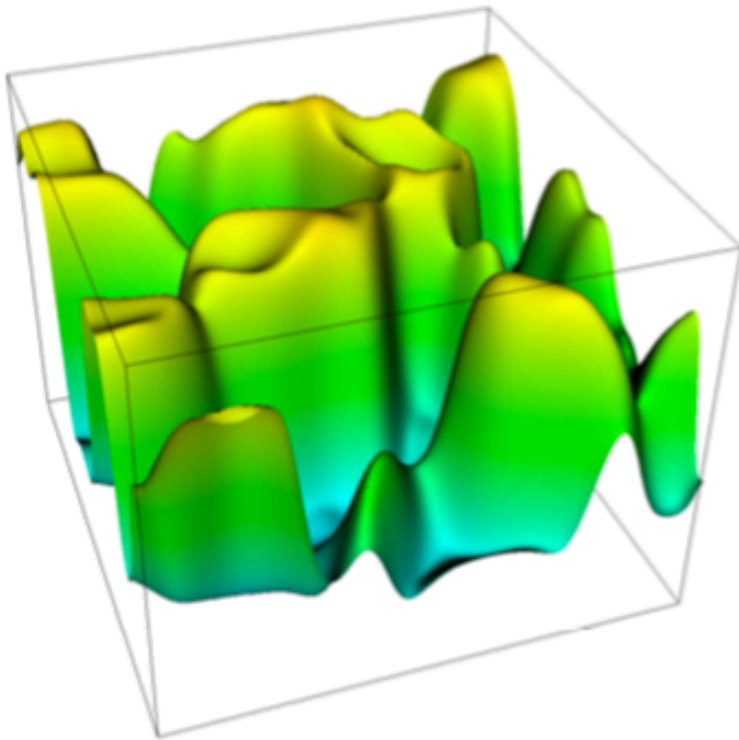


$$T_{\text{ht}} \simeq 2.7 \times 10^8 \text{ GeV} \left(1 + \frac{z_{\text{rad}}}{\nu}\right)^{-3/4} \left(\frac{\rho_{\text{rad}}^{\chi}/\rho_{\text{rad}}^{\phi}}{10^{-8}}\right)^{3/4} \left(\frac{H_{\text{kin}}}{10^{11} \text{ GeV}}\right)^{1/2}$$

Gradients are large!

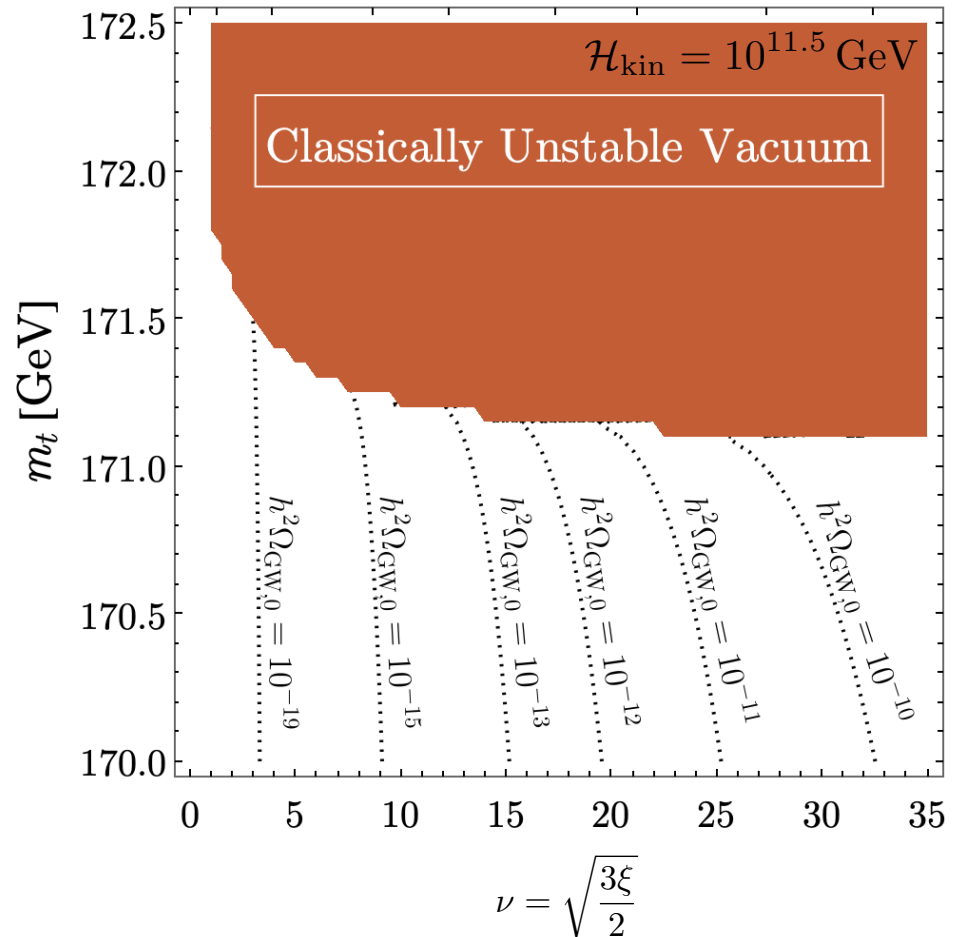
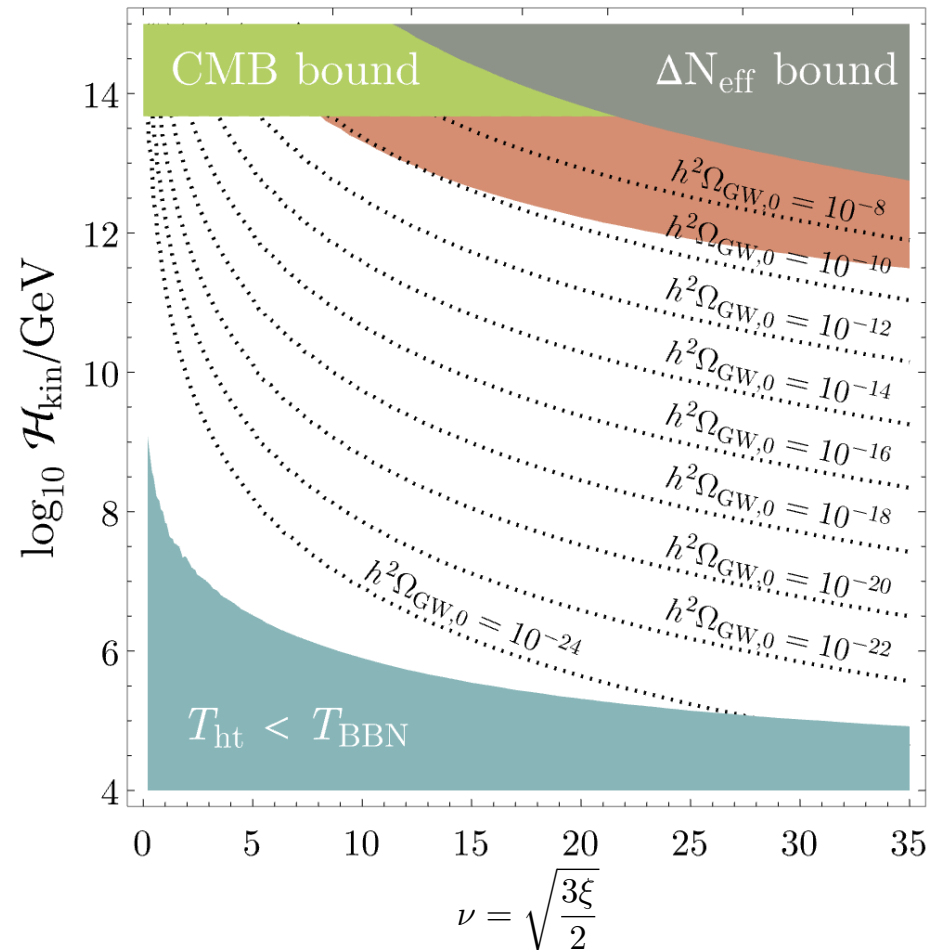
$$(h_{ij}^{TT})'' + 2H(h_{ij}^{TT})' - \frac{\nabla^2 h_{ij}^{TT}}{a^2} \simeq \frac{2a^2}{M_P^2} \Pi_{ij}^{TT}$$

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



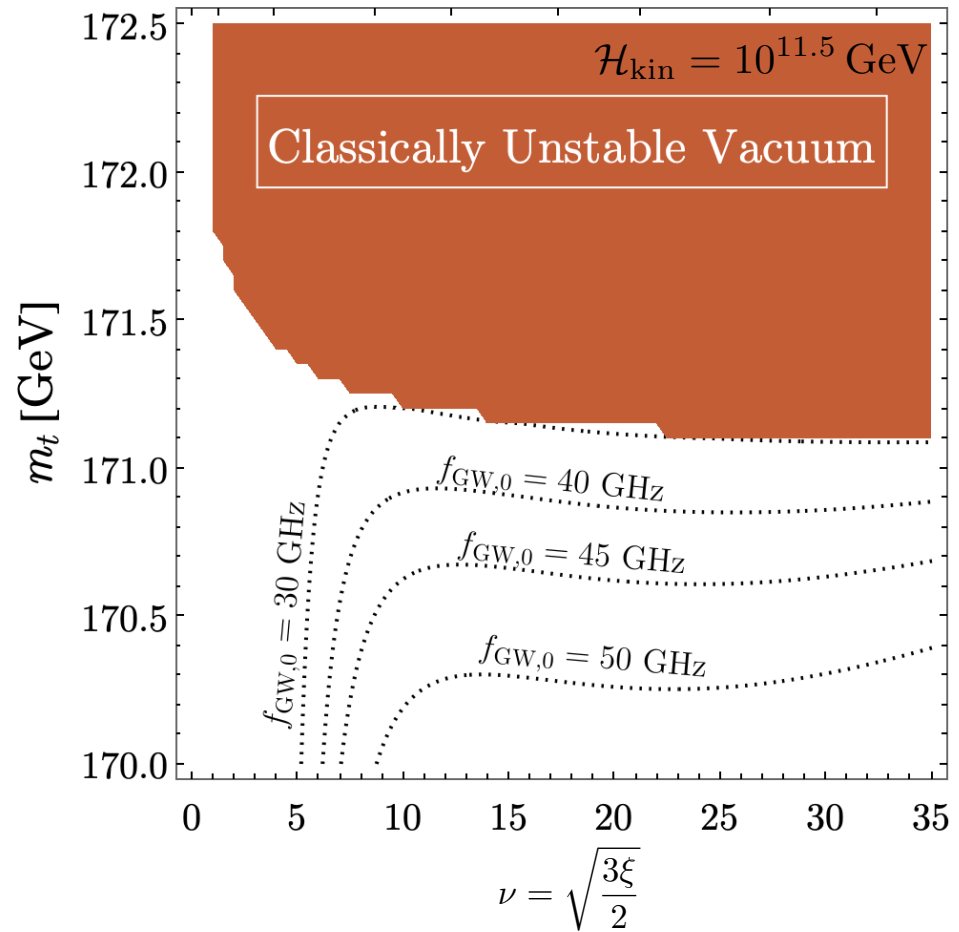
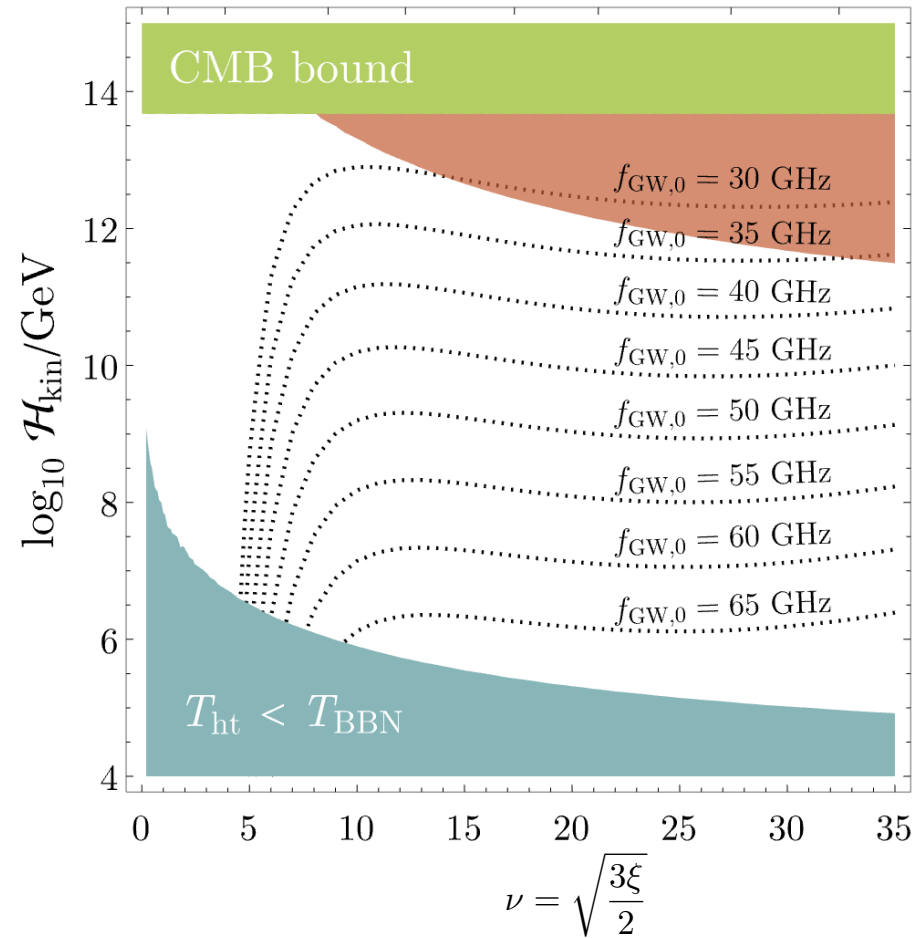
GW energy density

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

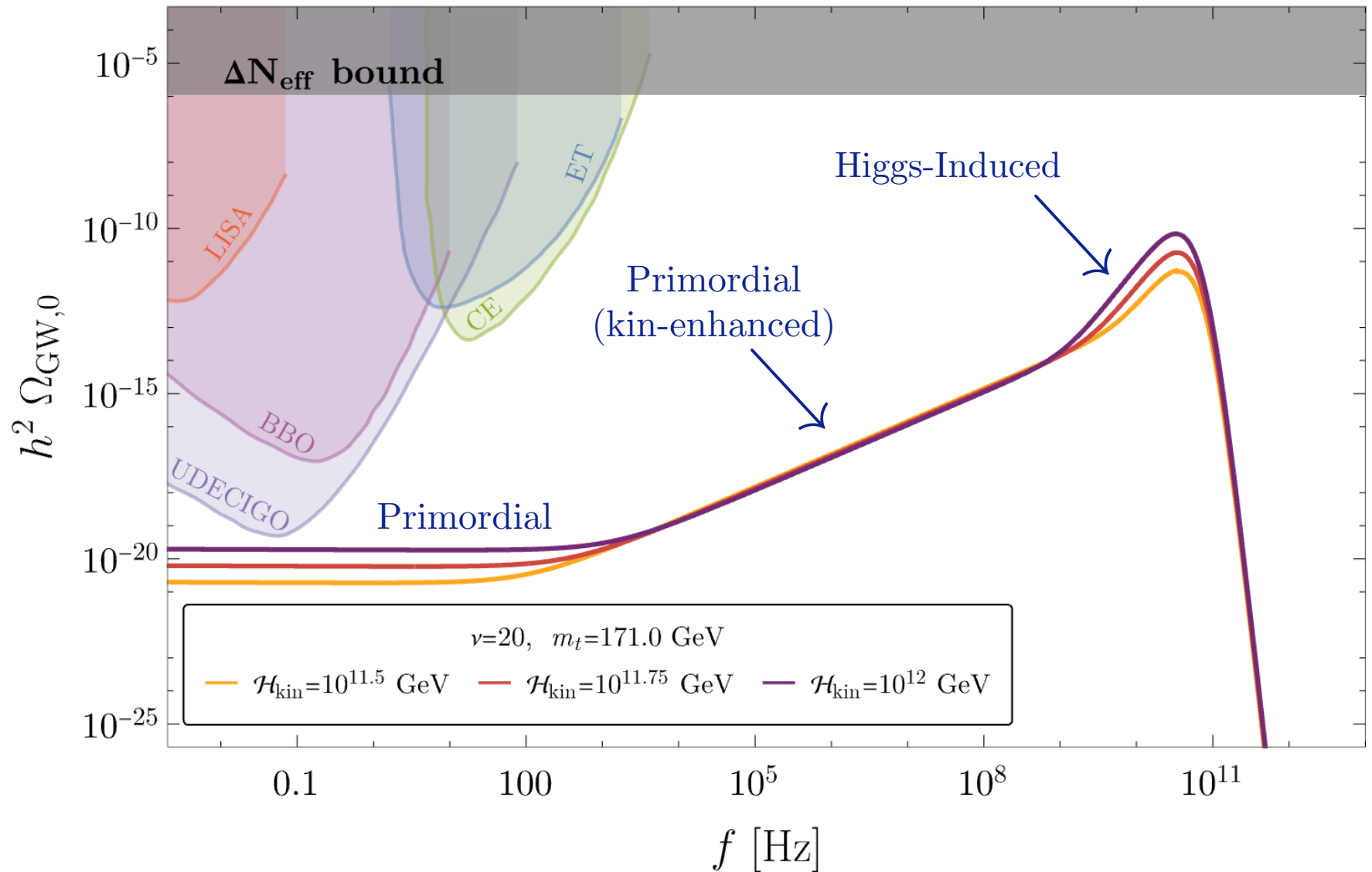


GW frequency

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



GW spectra

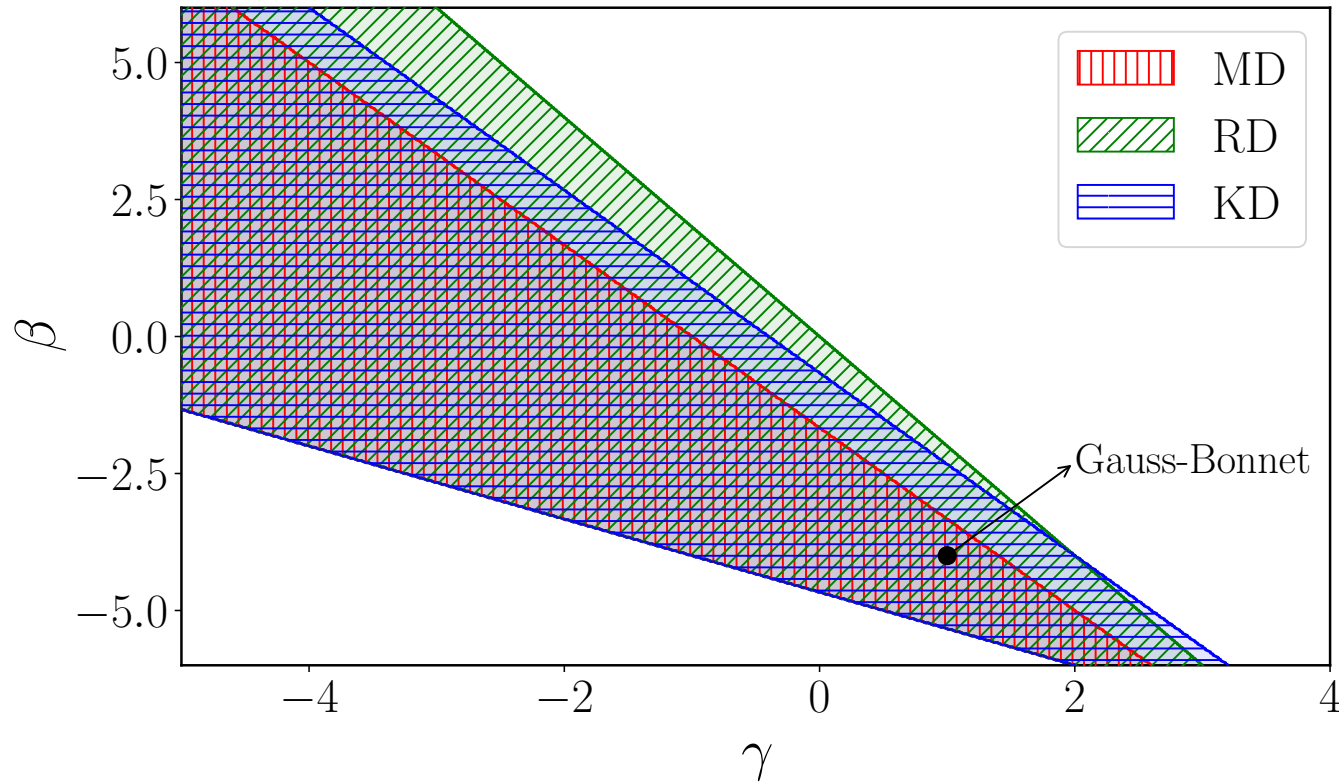


A dedicated program

1. Quintessential Affleck–Dine baryogenesis with non-minimal couplings,
D. Bettoni, J. Rubio, Phys. Lett. B 784 (2018) 122–129.
2. Gravitational waves from global cosmic strings in quintessential inflation,
D. Bettoni, G. Domènech, J. Rubio, JCAP 02 (2019) 034.
3. Hubble-induced phase transitions: Walls are not forever,
D. Bettoni, J. Rubio, JCAP 01 (2020) 002.
4. Hubble-induced phase transitions on the lattice with applications to Ricci reheating,
D. Bettoni, J. Rubio, JCAP 01 (2022) 002.
5. Ricci reheating reloaded,
G. Laverda, JCAP 03 (2024) 033.
6. From Hubble to Bubble,
M. Kierkla, G. Laverda, M. Lewicki, A. Mantziris, M. Piani, JHEP 11 (2023) 077.
7. The rise and fall of the Standard-Model Higgs: electroweak vacuum stability during kination,
G. Laverda, J. Rubio, JHEP 05 (2024) 339.
8. Tachyonic gravitational dark matter production after inflation,
G. Laverda, T. Mendes, J. Rubio, arxiv: 2601.07670

Beyond kination: Gravitational EFT

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



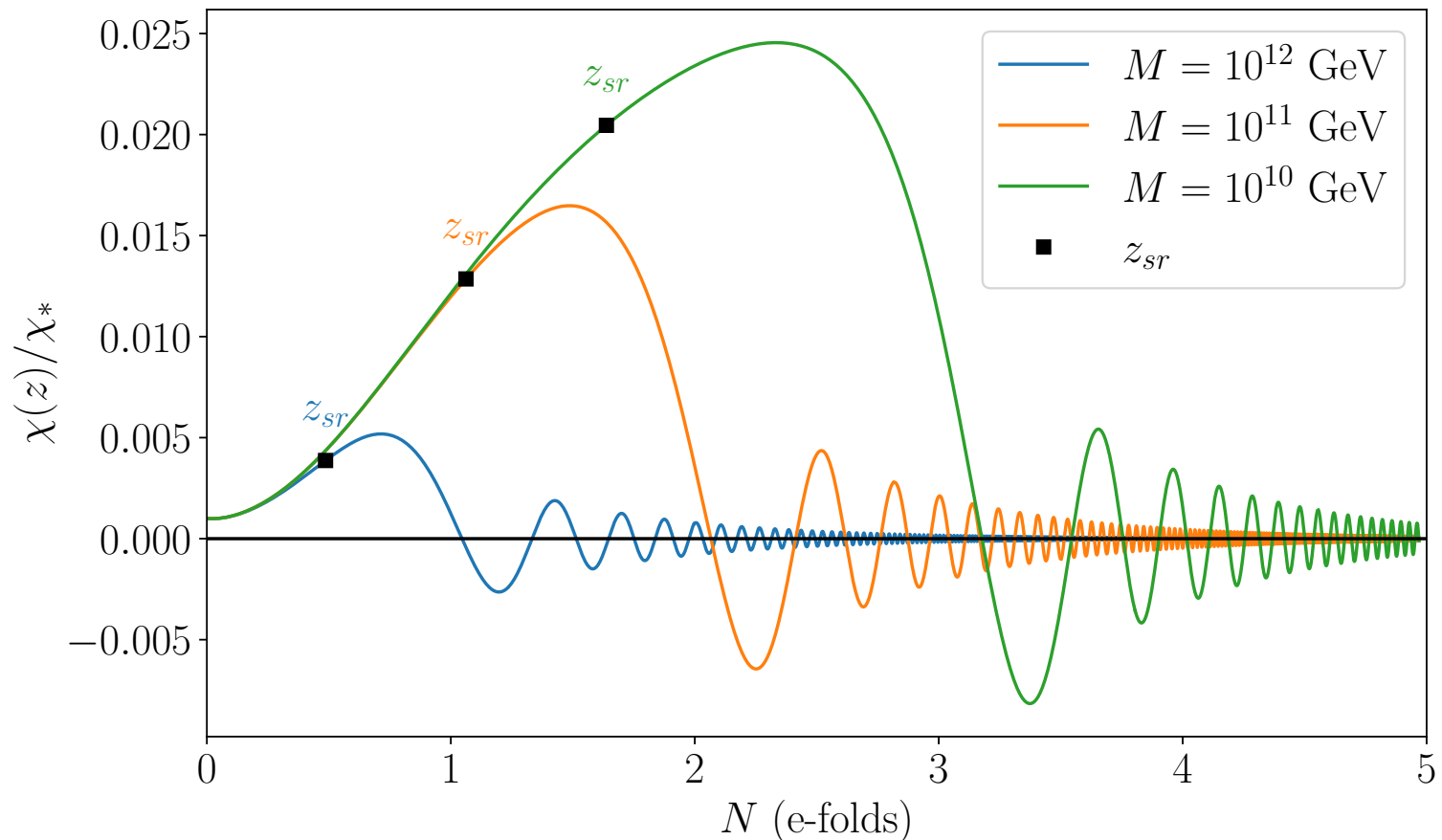
$$M_{\text{eff}}^2 = M^2 + 3\xi(1 - 3w)H^2 + C(\alpha, \beta, \gamma, \omega) \frac{H^4}{\Lambda^2}$$

Higher-order operators may become relevant during radiation domination

The Gauss Bonnet case

$$\mathcal{G} = R^2 - 4R_{\mu\nu}R^{\mu\nu} + R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} = -12(1 + 3w)H^4$$

- $m_{\text{eff}}^2 > 0$ (inflation) $\rightarrow m_{\text{eff}}^2 < 0$ (RD)



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





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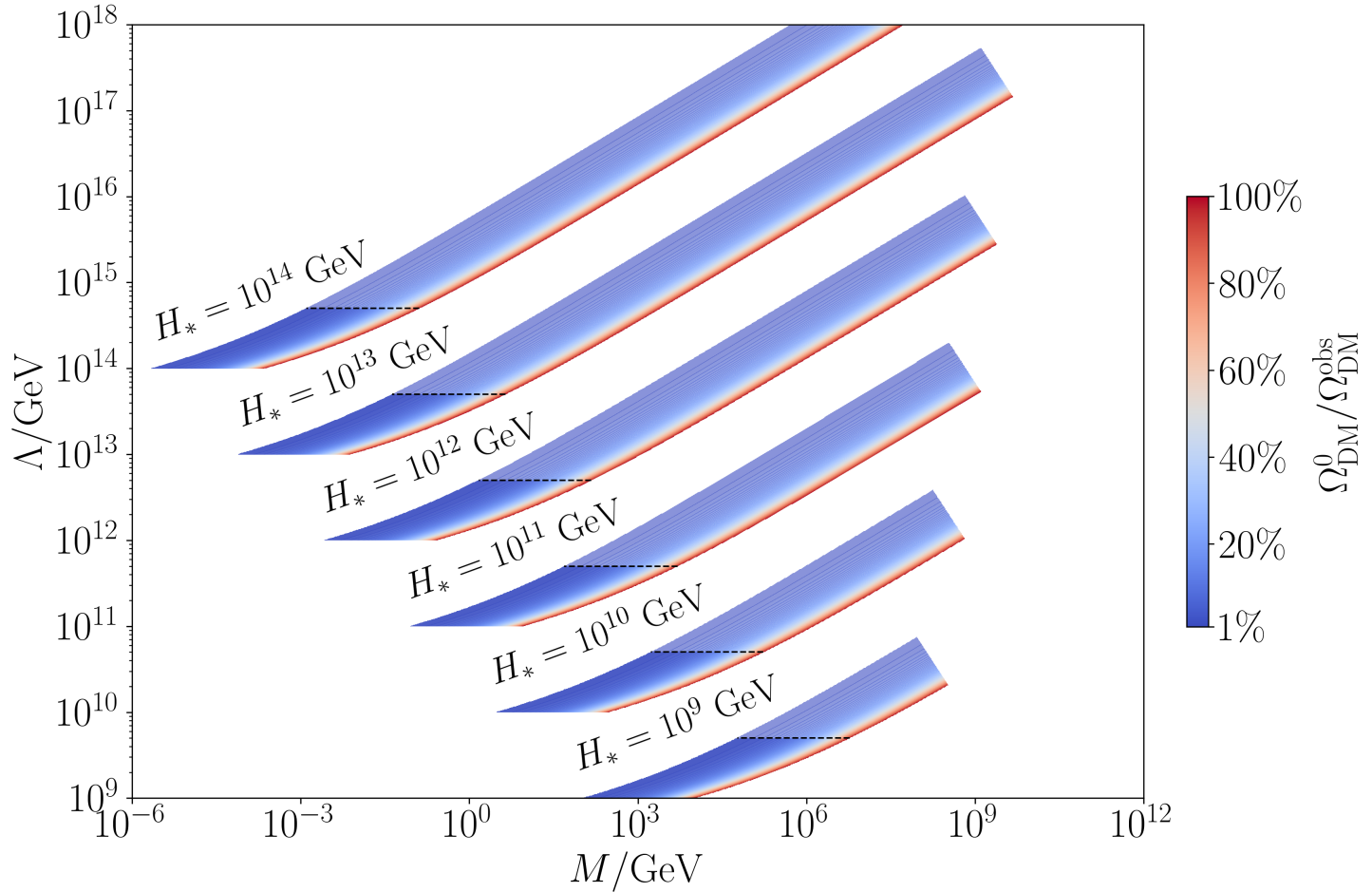
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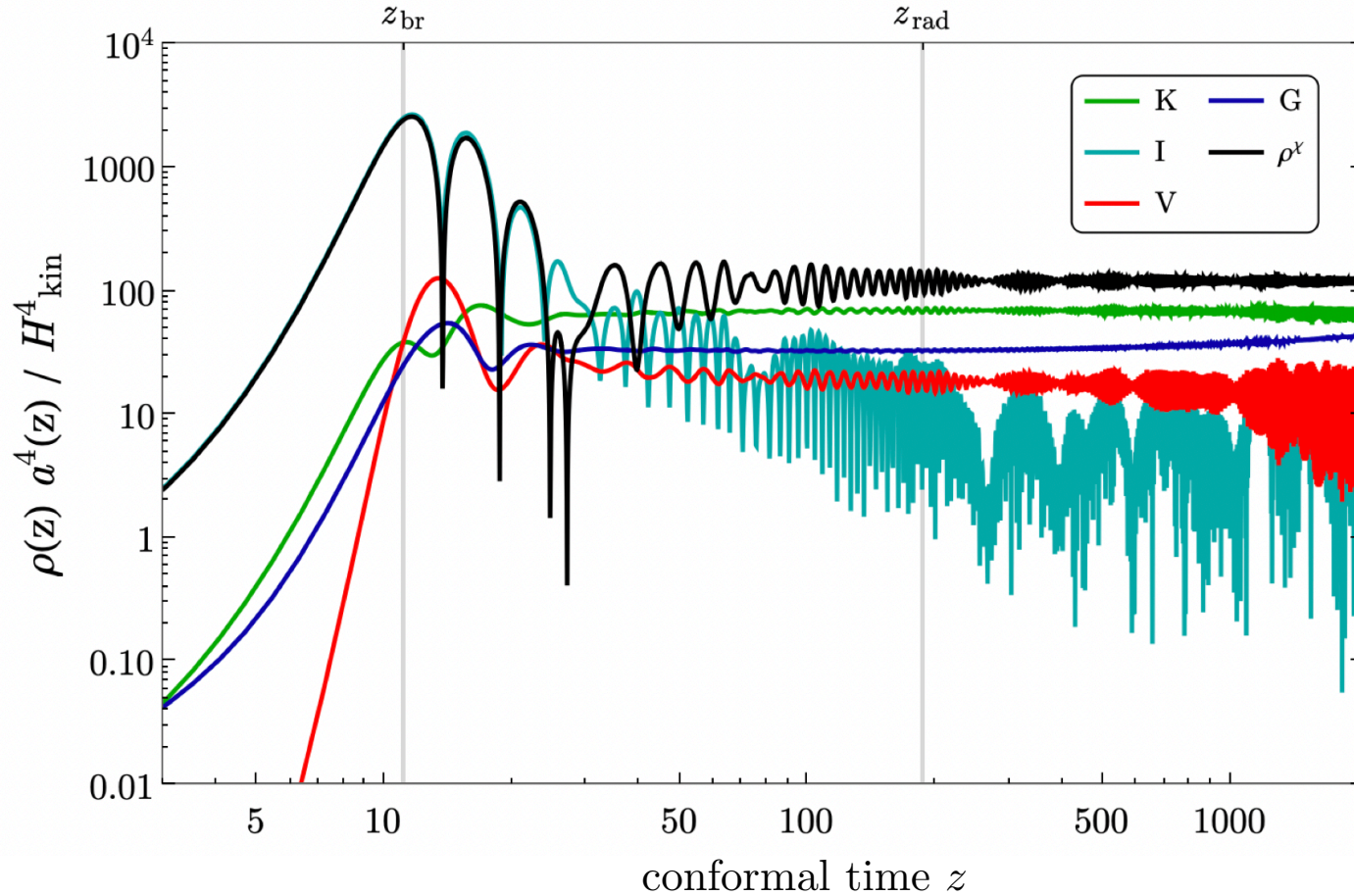
Backup slides

Hitting the right DM abundance



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

Energy distribution

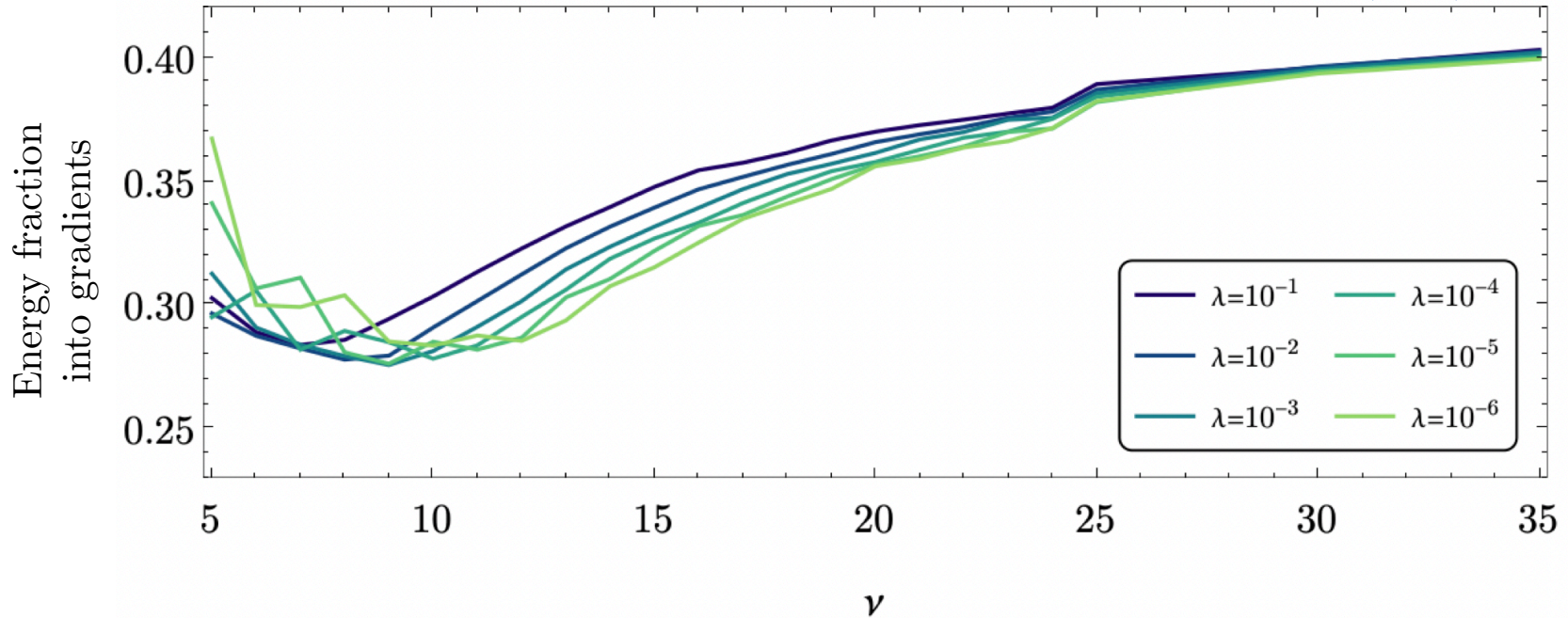


Lattice-based fitting formulas: $O(100)$ 3+1 classical lattice simulations

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

Gradients are crucial

G. Laverda, JR, JCAP 03 (2024) 033



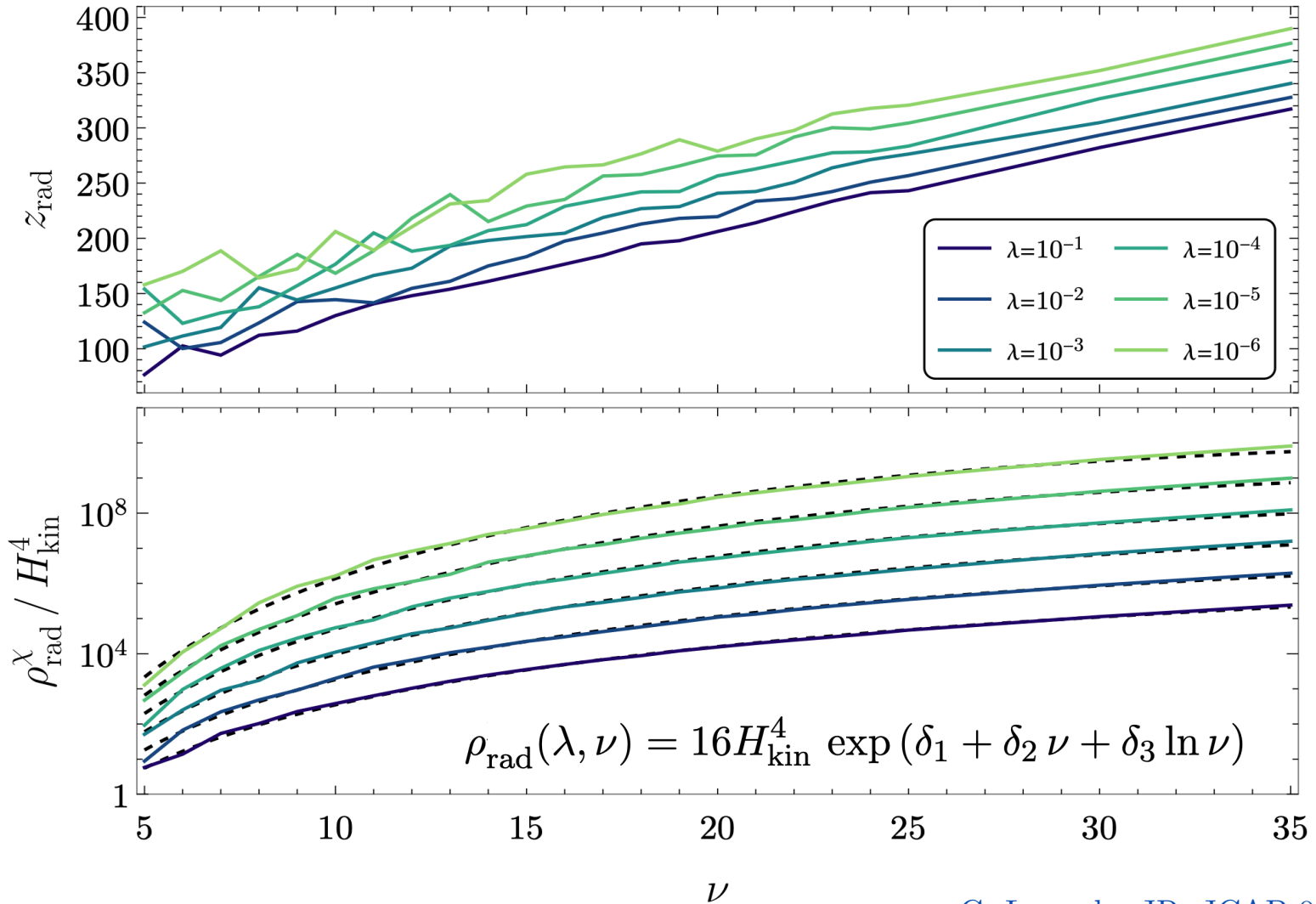
Radiation-like products for arbitrary potential

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

D.Bettoni, A. Lopez-Eiguren, JR, JCAP 01 (2022) 01, 002

Onset of radiation domination

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



Beyond the Standard Model

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

