Combined Preheating in Higgs inflation

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Who is the Inflaton? — Higgs field : Natural choice ⟺ No new degrees of freedom

BUT.... — $\lambda\phi^4$ excluded by WMAP ⟺ $\Delta T/T \sim \sqrt{\lambda} \rightarrow \lambda \sim 10^{-13}$ SM

Can we rescue the Higgsflaton? — Non-minimal coupling to R ⟺ Required by renormalizability

Advantages for Preheating? — MANY !!

Higgs Inflation ⟺ No new d.o.f

Who gives mass to the Higgs and fix M_P ?

The Higgs inflation model introduces a non-minimal coupling of the Higgs field to gravity [1]

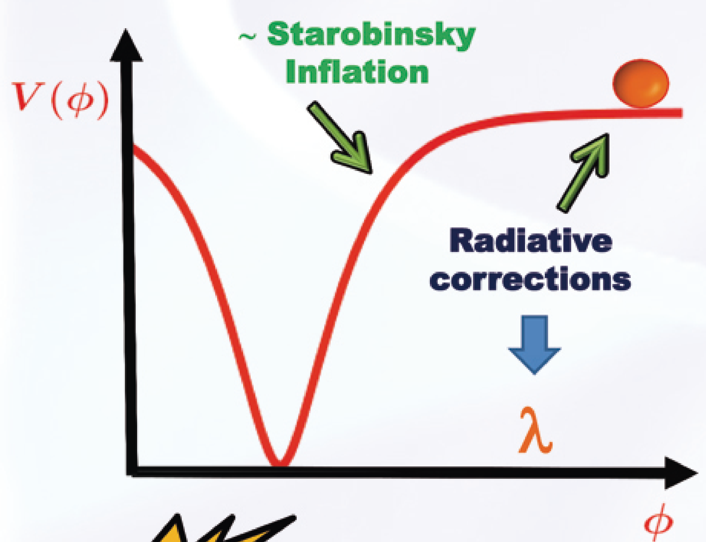
$$S_{HI} = S_{SM} + \int d^4x\sqrt{-g}\left[\frac{M_P^2+\xi_h h^2}{2}R\right]$$

without modifying the Higgs sector/potential

- All particle masses α h
- Ratios of masses do not depend on h

$$U(h) = \frac{\lambda}{4}\left(h^2 - v^2\right)^2$$

A conformal transformation to the Einstein frame can be performed to obtain an action written in an exactly canonical form



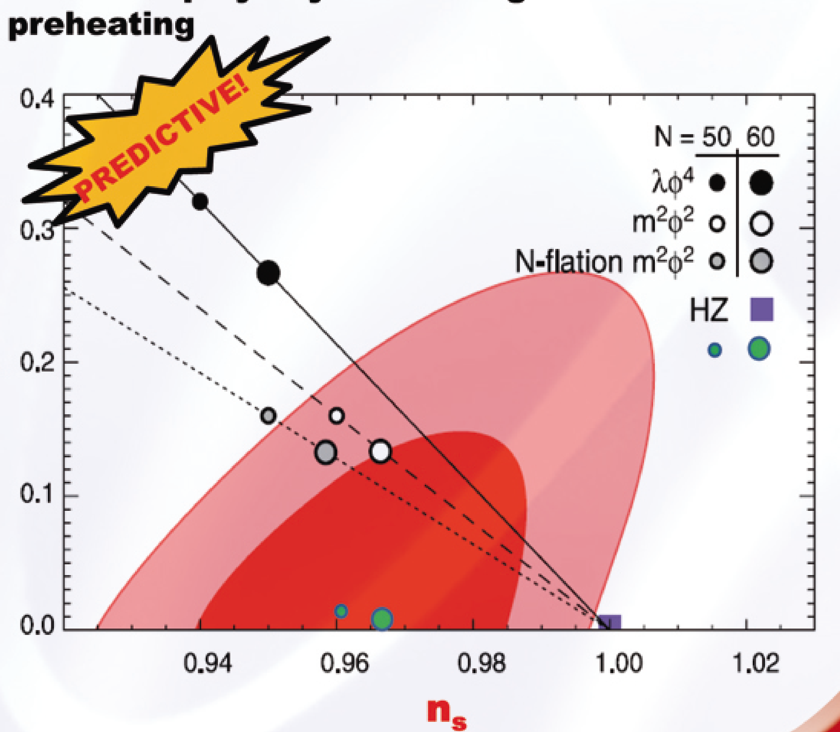
$$S_{HI}^E \supset \int d^4x\sqrt{-\tilde{g}}\left[\frac{M_P^2}{2}\tilde{R} - \frac{1}{2}\tilde{g}^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi - V(\phi)\right]$$

where the new potential resembles that of Starobinsky inflation (same tillts) [1,3]

$$V(\phi) = \frac{\lambda M_P^4}{4\xi_h^2}\left(1 - e^{-\alpha\kappa|\phi|}\right)^2$$

The vev of the Higgs can be neglected since it will not play any role during inflation and/or preheating

PREDICTIVE! ONE FREE PARAMETER — COBE normalization $\xi_h \Leftrightarrow \lambda$



SM must be a valid quantum theory up to Planck scale. Nothing but the Higgs field.

Inflation is possible in the window of Higgs masses (two loops computation)

$$M_H \in [126, 194]\ \text{GeV}$$

Higgs Dilaton ⟺ Scale Invariance

The Higgs- Dilaton inflation model introduces unimodular gravity and scale invariance as a new symmetry [2]

$$S_{H-DI} = S_{SM} + \int d^4x\sqrt{-g}\left[\frac{\xi_h h^2+\xi_\chi\chi^2}{2}R\right]$$

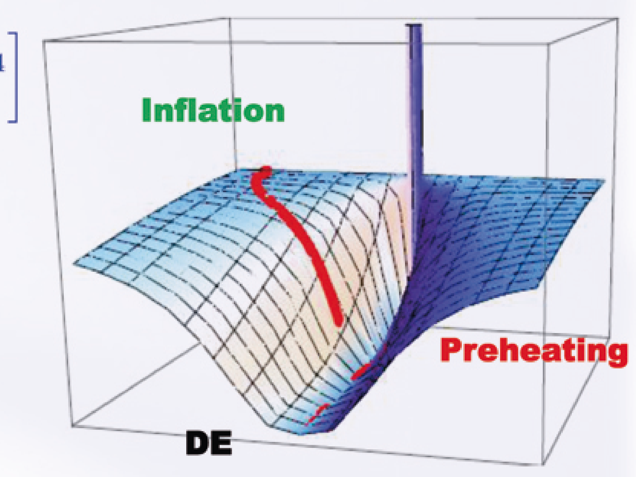
and promotes therefore the vev of the Higgs to a field

Scale invariance is spontaneously broken. All masses : same source

$$U(h,\chi) = \frac{\lambda}{4}\left(h^2 - \zeta\chi^2\right)^2 + \Lambda$$

In Einstein frame the kinetic term can be written in a diagonal form , although it is non-canonical [4] . The two scalar fields are therefore mixed.

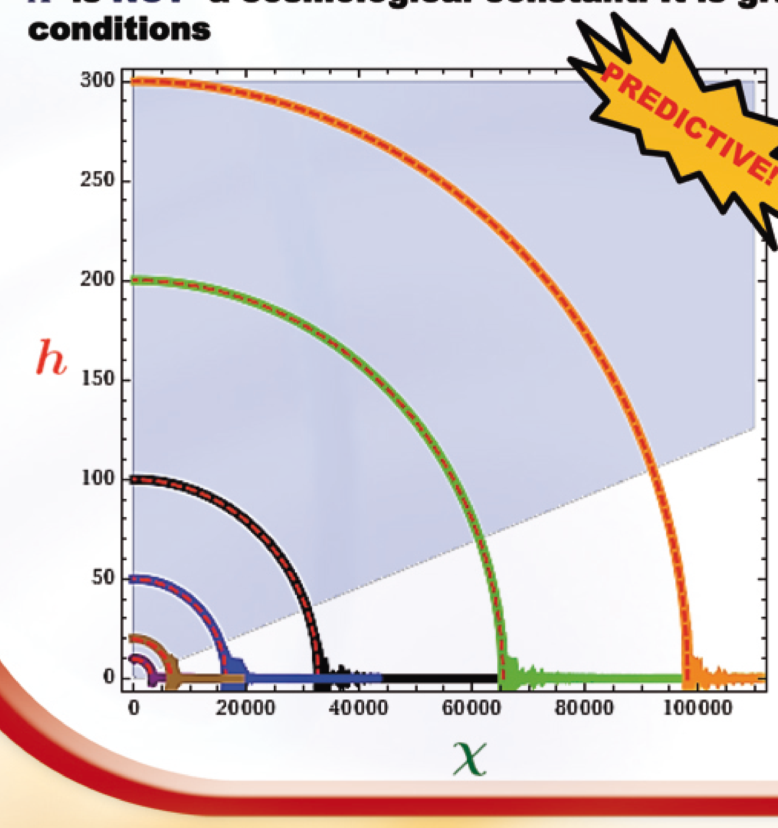
$$S_{H-DI} \supset \int d^4x\sqrt{-\tilde{g}}\left[\frac{M_P^2}{2}\tilde{R} - \tilde{K}_P^{Mix} - V(\psi) + \Lambda/\Omega^4\right]$$



Inflation is driven by a potential similar to that of Higgs inflation [4]

$$V(\psi) = \frac{\lambda M_P^4}{4\xi_h^2}\left(1 - 6\xi_\chi\sinh^2\left(\frac{\psi-\psi_0}{\sqrt{6}M_P}\right)\right)^2$$

Λ is NOT a cosmological constant. It is given by init. conditions

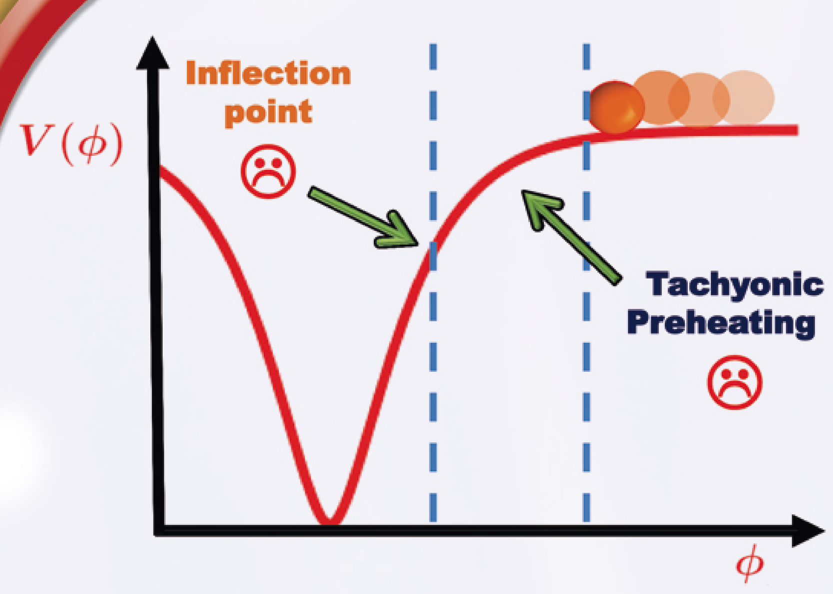


PREDICTIVE! SCALE INVARIANCE ! Inflation ⟺ Dark Energy

The inflationary trajectories are circles in field space [4] dictated by the scale invariance. Non isccurvature perturb.

The Λ term gives rise to a Dark Energy dominated stage in the late Universe, not a cosmological constant

PREDICTIVE! Combined Preheating ⟺ All the couplings are known!



Soon after the end of inflation the Higgs goes through a brief stage of tachyonic preheating, which could provide a huge particle creation. However, this stage is too short for being significant. There is neither important particle creation in the inflection point.

The conditions for perturbative reheating are not satisfied for any of the SM particles. The perturbative decay of the Higgs into W, Z and top quark is not allowed due to phase space reasons, while the decay rate into light fermions is too small as compared with the Hubble rate.

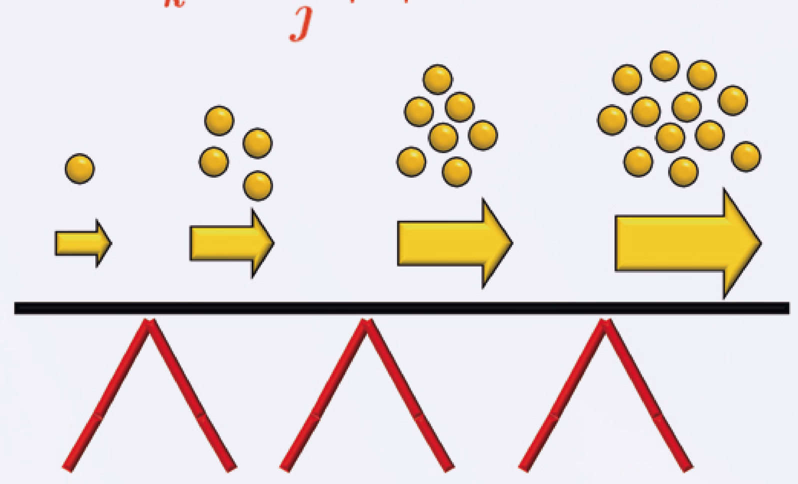
	W, Z, t	Fermions
H > Γ	✓	✗
Phase Space	✗	✓

Finally the Higgs field starts oscillating around the minimum of its potential

$$V(\phi) = \frac{1}{2}M^2\phi^2 + \Delta V(\phi)$$

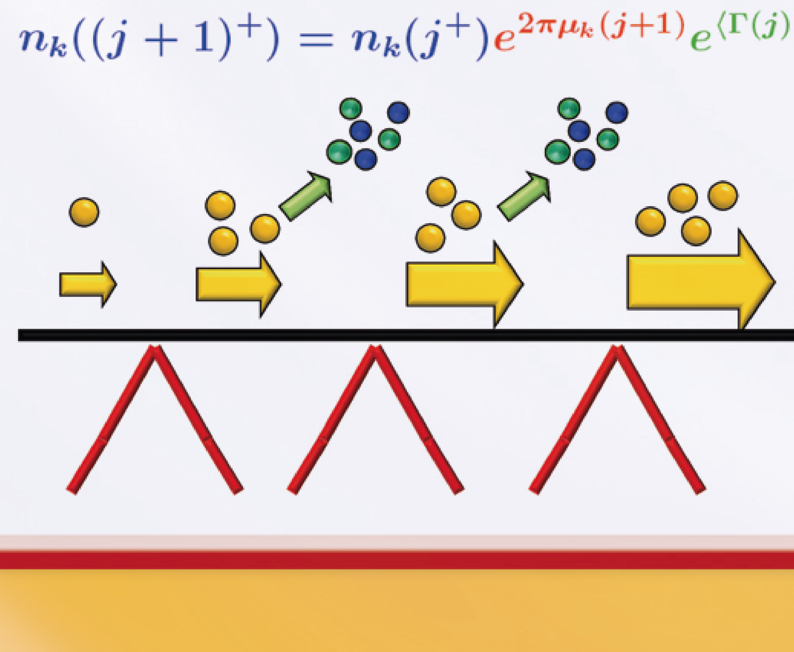
Creation of W and Z bosons occurs due to the violation of the adiabaticity condition every time that the Higgs field crosses zero. The problem can be recasted in the form of a Schrödinger equation with an inverted triangular potential.

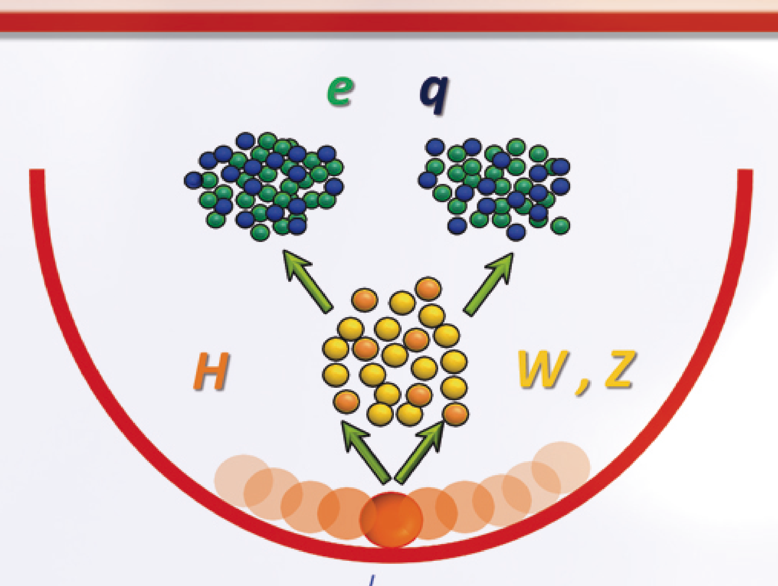
$$-A_k'' - \frac{q_A}{j}|\tau|A_k = K^2 A_k$$



When the amplitude of the Higgs increases towards the maximum of the potential the created W and Z bosons start to decay into SM leptons and quarks, within half a Higgs oscillation, rapidly depleting the occupation numbers of W and Z and preventing the development of parametric resonance.

$$n_k((j+1)^+) = n_k(j^+)\,e^{2\pi\mu_k(j+1)}\,e^{\langle\Gamma(j)\rangle\frac{T}{2}}$$





$$\phi(t) \approx \frac{\phi_{\text{end}}}{j\pi}\sin(\pi j)$$

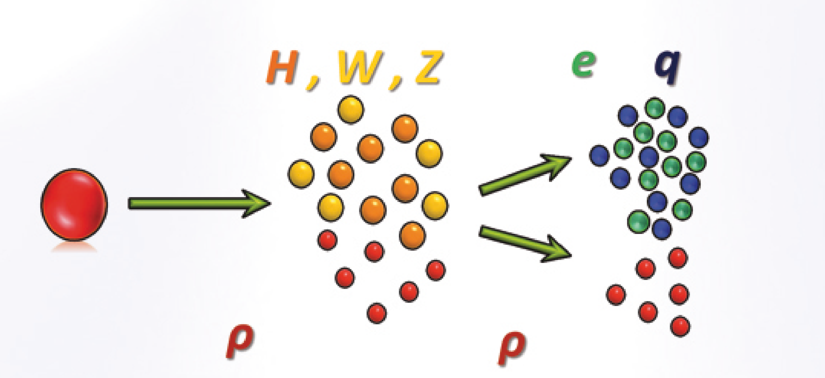
However the fraction of energy of the Higgs field that goes into SM particles is still very small compared to the energy of the oscillations and it is not enough to reheat the Universe, so after a hundred oscillations, the resonance effects eventually dominate over the perturbative decays.

λ	0.2	0. 6	1.0
j	107	113	115
j_{BR}	107	112	114

Around the same time (or slightly earlier) , the backreaction from the gauge bosons into the Higgs condensate starts to be significant and the resonant production of particles stops. Since that stage is very non-linear and non-perturbative it cannot be solved analitically and a careful study via numerical simulations is needed.

$$M^2 \Rightarrow M^2 + f(\phi)\langle\tilde{A}_\mu\tilde{A}^\mu\rangle$$

The described mechanism, known as Combined Preheating [3] applies both to Higgs inflation and Higgs-Dilaton inflation models, although the details can differ due to the different forms of the masses in Einstein frame.



Due to the non-canonical kinetic terms in the Higgs Dilaton model described above there is an effective coupling between the two scalar fields that gives rise to particle creation of both Higgs and Dilaton fields. The created dilatons constitute a new relativistic degree of freedom

$$F''(z) + \left(A_k^2 - \frac{p^2}{2} + 2p\cos 2z + \frac{p^2}{2}\cos 4z\right)F(z) = 0$$

REFERENCES

[1] F. L. Bezrukov and M. Shaposhnikov, Phys. Lett. B 659, 703 (2008).

[2] M. Shaposhnikov and D. Zenhausern, Phys. Lett. B 671, 187 (2009);

[3] J. Garcia-Bellido, D. Figueroa and J. Rubio Phys. Rev. D 79, 063531 (2009)

[4] J. Garcia-Bellido, J. Rubio, M. Shaposhniko D. Zenhäusern (in preparation)