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Cosmological constraints on the Higgs portal

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Initial conditions set by inflation

- During inflation, the scalar sector of the model is specified by the potential

$$V(h,s) = \frac{\lambda_h}{4}h^4 + \frac{\lambda_s}{4}s^4 + \frac{\lambda_{sh}}{2}h^2s^2$$

- No non-minimal coupling to gravity (No higgs inflation[1], assume stability of the higgs potential[2])
- Typical magnitudes of the scalar condensates generated during inflation are

$$h_* = \mathcal{O}(0.1)\frac{H}{\lambda_h^{1/4}}\,, \qquad s_* = \mathcal{O}(0.1)\frac{H}{\lambda_s^{1/4}}$$

[1] Bezrukov & Shaposhnikov (1403.6078)

[2] Fairbairn & Hogan (1403.6786), Enqvist et al. (1404.3699)

Condensates acquire a large thermal mass

- Assume inflaton decaying into SM particles and instantly reheating the Universe $\Rightarrow T^4 \simeq M_P^2 H_*^2$
- This causes all fields i coupled to thermal bath to acquire a large effective thermal mass,

$$m_i^2(T) = m_i^2(0) + c_i T^2$$

- For example, the Higgs condensate mass satisfies

$$\frac{m_h^2(T)}{m_h^2(0)} \simeq \frac{c_h T^2}{3\lambda_h \langle h^2 \rangle} \simeq \frac{M_P}{H_*}$$

No effective decay channels open

- The scalar background equation of motion is given by

$$\ddot{h} + 3H(t)\dot{h} + c_h T^2 h = 0$$

- Reveals that the envelope scales as $h(t) \propto T \propto a^{-1}$
  $\Rightarrow$ resonances very narrow $\Rightarrow$ no non-perturbative decay
- Thermal bath changes the dispersion relations and thus the condition for condensates' perturbative decay. No effective channels are found to be open.

Going to two loops

- At two-loop and higher level there are no energy thresholds and the decay of a scalar condensate can take place.
- The magnitude of the two-loop processes can be estimated by calculating the "rising-sun" diagrams, which give[3]

$$\Gamma_h = \frac{3}{256\pi}\frac{g^4}{m_h(T)}T^2$$

- Why is this important? In order to have a strong EWPT one needs the two fields to relax on $\langle s\rangle = w_c$, $\langle h\rangle = 0$.

[3] Elmfors et al. (9307210)

What about perturbations?

- Inflaton couples to SM $\Rightarrow$ Higgs condensate has no time to grow its energy density w.r.t. inflaton decay products $\Rightarrow$ no effect on large-scale perturbations[4]
- Also unlikely for the singlet
- But: Maybe the singlet can act as a DM particle...
- Coming soon to the arXiv near you: "Standard Model with a real singlet scalar and Inflation"

[4] As in curvaton-type models. See e.g. Lyth & Liddle (0110002)