A complete model of cosmology and particle physics scales

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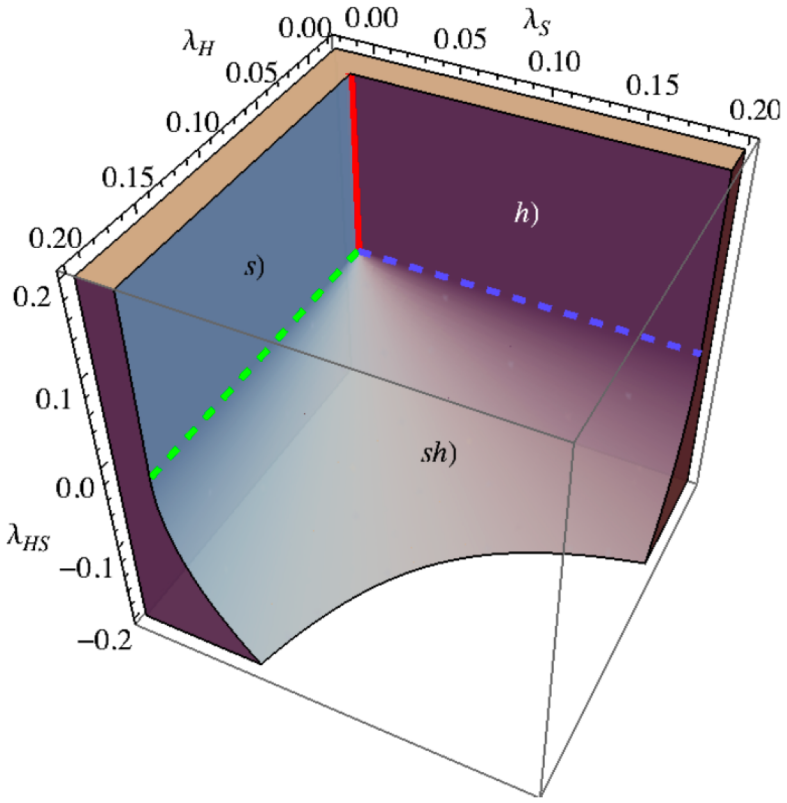
Work in progress

Outline

- Multi-phase criticality and Coleman-Weinberg mechanism
- Freeze-out in DM induced multi-phase dynamical symmetry breaking
- Freeze-in in DM induced multi-phase dynamical symmetry breaking
- A complete model of cosmological scales
- Conclusions

Classically scale invariant Higgs-Dilaton model



$$V = \lambda_H |H|^4 + \lambda_{HS} |H|^2 \frac{s^2}{2} + \lambda_S \frac{s^4}{4}$$

- Phase $s)$ $s \neq 0$ and $h = 0$

$$\lambda_S = 0$$

- Phase $h)$ $h \neq 0$ and $s = 0$

- Phase $sh)$ $s, h \neq 0$

$$2\sqrt{\lambda_H \lambda_S} + \lambda_{HS} = 0$$

- Multi-phase criticality: masses and mixings vanish

$$\lambda_S(\bar{\mu}) = \lambda_{HS}(\bar{\mu}) = 0,$$

CW mechanism and multi-phase criticality

- Dynamical symmetry breaking around the MP criticality: GW not good

$$V^{(1)}|_{\overline{\rm MS}} = \frac{1}{4(4\pi)^2}\,{\rm Tr}\left[M_S^4\left(\ln\frac{M_S^2}{\bar\mu^2}-\frac{3}{2}\right)+\right.$$
$$\left.-2M_F^4\left(\ln\frac{M_F^2}{\bar\mu^2}-\frac{3}{2}\right)+3M_V^4\left(\ln\frac{M_V^2}{\bar\mu^2}-\frac{5}{6}\right)\right] \qquad (10)$$

$$s \approx e^{-1/4}s_S, \qquad h \approx \frac{e^{-1/4}s_S}{4\pi}\sqrt{\frac{-\beta_{\lambda_{HS}}\ln R}{2\lambda_H}},$$

$$R = e^{-1/2}s_S^2/s_{HS}^2$$

$\boldsymbol{\beta}$-function suppressed $\quad m_s^2 \approx \frac{2s^2\beta_{\lambda_S}}{(4\pi)^2}, \qquad m_h^2 \approx \frac{-s^2\beta_{\lambda_{HS}}\ln R}{(4\pi)^2} = 2\lambda_H h^2$ $\quad$ $\boldsymbol{\beta}$-function suppressed

$$\theta \approx \sqrt{-\frac{\beta_{\lambda_{HS}}^3\ln R}{2\lambda_H}}\,\frac{1+\ln R}{4\pi(2\beta_{\lambda_S}+\beta_{\lambda_{HS}}\ln R)},$$

$\boldsymbol{\beta}$-function suppressed

For small couplings the CW must be treated with better precision than the Gildener-Weinberg approximation

DM induced multi-critical dynamical symmetry breaking

- The scalar model: the Higgs, a dilaton and scalar DM

$$V = \lambda_H |H|^4 + \frac{\lambda_S}{4} S^4 + \frac{\lambda_{S'}}{4} S'^4 + \frac{\lambda_{HS}}{2} |H|^2 S^2 + \frac{\lambda_{HS'}}{2} |H|^2 S'^2 + \frac{\lambda_{SS'}}{4} S^2 S'^2.$$

$$m_h^2 \simeq -\frac{\beta_{\lambda_{HS}}}{(4\pi)^2} w^2 \ln R,$$

$$m_s^2 \simeq 2\frac{\beta_{\lambda_S}}{(4\pi)^2} w^2,$$

$$m_{s'}^2 \simeq \frac{1}{2} \lambda_{SS'} w^2.$$

$$w \simeq \frac{\sqrt{2} m_{s'}^2}{4\pi m_s}.$$

One scale w

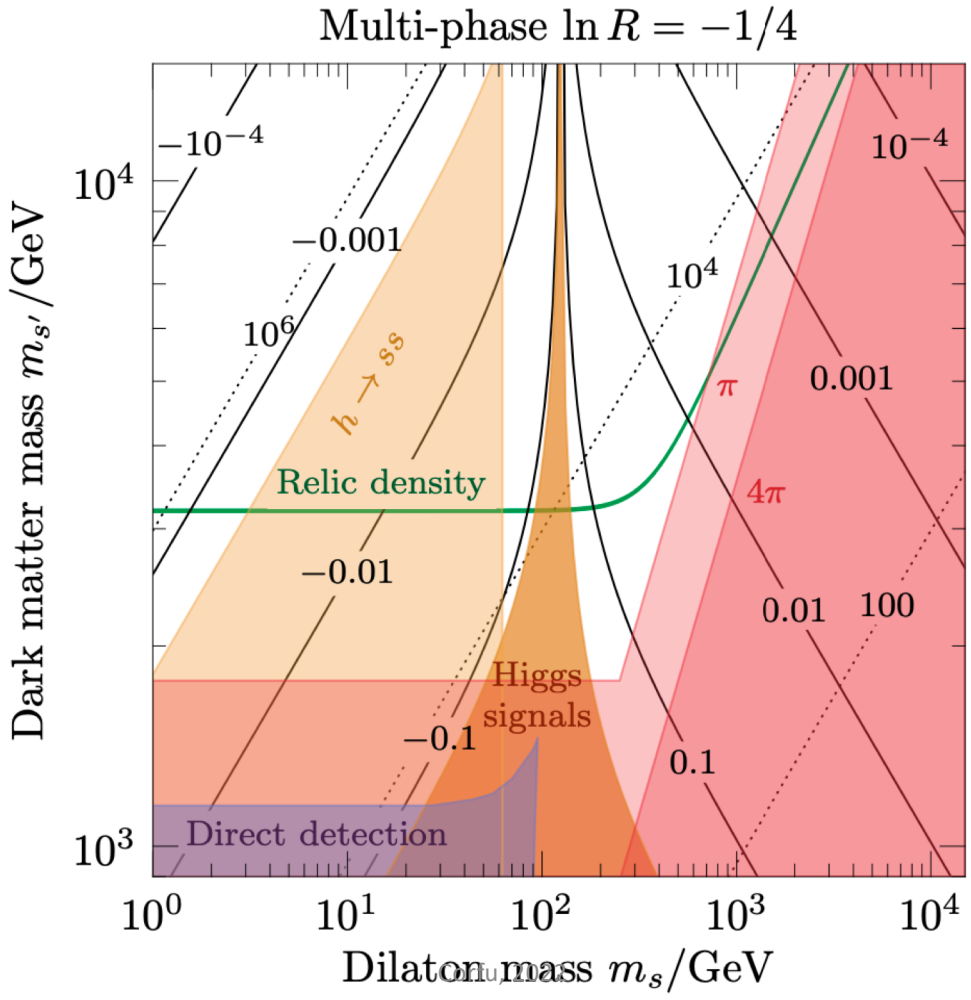
$$\lambda_{SS'} \approx \frac{(4\pi)^2 m_s^2}{m_{s'}^2},$$

$$\lambda_{HS'} \approx -\frac{(4\pi)^2 m_h^2}{m_{s'}^2 \ln R}.$$

$$\theta \simeq \frac{2\sqrt{2}\pi m_s m_h^2 v (1 + \ln R)}{(m_h^2 - m_s^2) m_{s'}^2 \ln R}.$$

Scalar DM must be heavy, the dilaton can be heavier or lighter than the Higgs boson

DM freeze out in this model



DM freeze-in in the multi-critical framework

- All scalar couplings, except the Higgs quartic, must be super small.
  The dilaton is also an inflaton

- Criticality naturally embedded: $\lambda_S(\bar{\mu}) = 0, \qquad \lambda_{HS}(\bar{\mu}) \approx 0$

- Problem: no reheating. Solution: introduce RH neutrinos N.

$$-\mathcal{L}_Y = y_H \bar{\ell} \tilde{H} N_R + \frac{y_S}{2} S \bar{N}_R^c N_R + \text{h.c.},$$

- A complete model of cosmology is obtained.

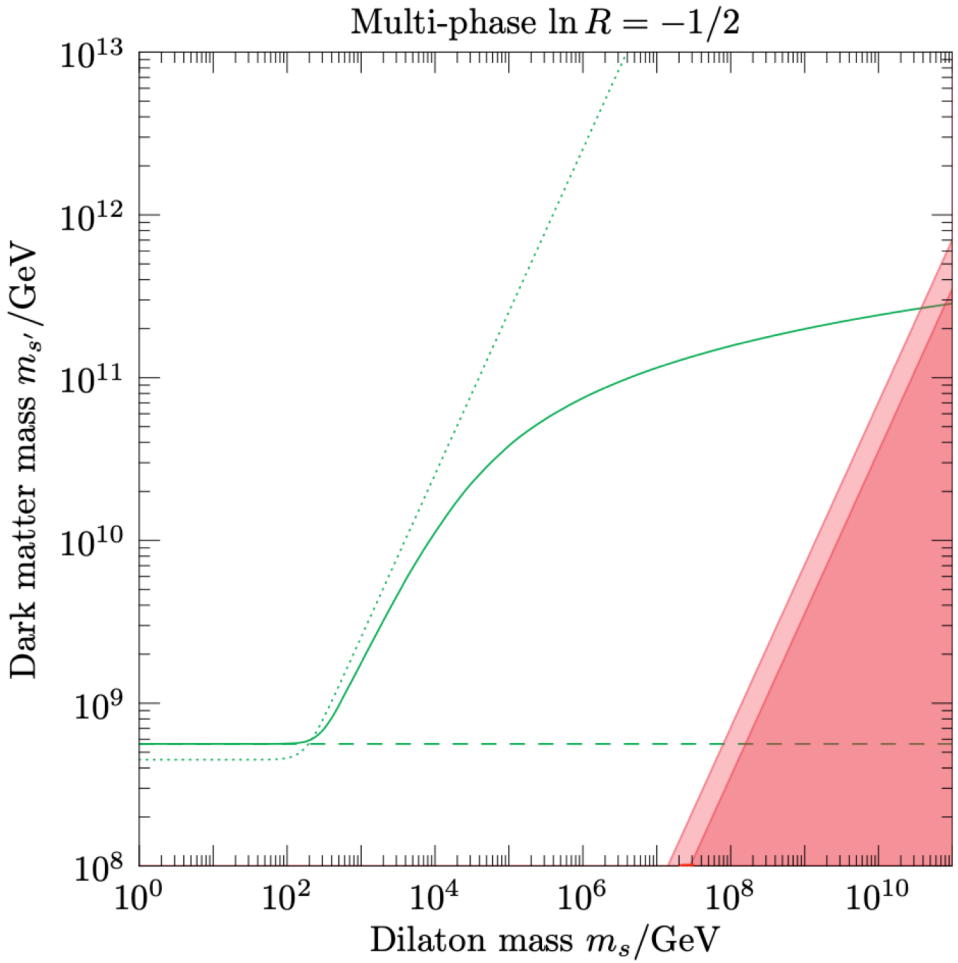
Neutrino masses, leptogenesis, inflation

- Small neutrino masses are explained via seesaw type I
- Leptogenesis occurs due to decays of N in a usual way
- Inflaton is the dilaton which must be non-minimally coupled to gravity ξ

$$\xi \simeq 49000\sqrt{\lambda}\,, \qquad n_s = 1 - \frac{2}{N}, \quad r = 12/N^2 \sim 10^{-3}$$

- Complete cosmology obtained, no ingredient can be removed

DM induced CW and freeze-in results



Conclusions: this is a Theory of Everything

- The SM + dilaton + scalar singlet DM + N + dynamical symmetry breaking explains all the known physical phenomena
- The scalar DM is very heavy, is produced in freeze-in and triggers CW
- Huge but technically natural hierarchy between the EW and DM scales
- Inflaton is the dilaton, RH neutrinos N needed for reheating, neutrino masses, leptogenesis, cannot remove any of the fields
- This scenario predicts one more light scalar, the dilaton, which may be lighter or heavier than the SM Higgs boson. Its mixing with Higgs is suppressed