Electroweak-scale inflation, inflaton-Higgs mixing and the scalar spectral index

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Outline:

- **Motivation** and general issues low-scale inflation
- **Model**, constraints and predictions
- **Conclusions**

Motivation and general issues

Motivation: minimalist approach to cosmology:

- **Inflation** with minimal extension **Standard Model** of particle physics: add one scalar field to SM
- **Electroweak baryogenesis**: needs only SM + low-scale inflation

(Baryogenesis conditions satisfied in SM *[Rubakov, Shaposhnikov]*, but effects too small in standard transition. Possible solution: tachyonic electroweak preheating after low-scale inflation *[Krauss, Trodden, Garcia-Bellido, Grigoriev, Kusenko, Shaposhnikov, . . .]* $\Rightarrow$ strongly non-equilibrium and larger CP violation *[J.Smit hep-ph/0407161]*)

Constraints from WMAP + SM physics + Baryogenesis

Some possible conflicts:

- Large inflaton-Higgs coupling (fast transition $\rightarrow$ non-equilibrium) $\leftrightarrow$ Small coupling (small quantum corrections $\rightarrow$ flat inflaton pot.)

  $\Rightarrow$ (+SM constraints) $p = 5$ highest power inflaton potential

- Low-scale inflation $\leftrightarrow$ Spectral index $\tilde{n} = -0.03 \pm 0.03$

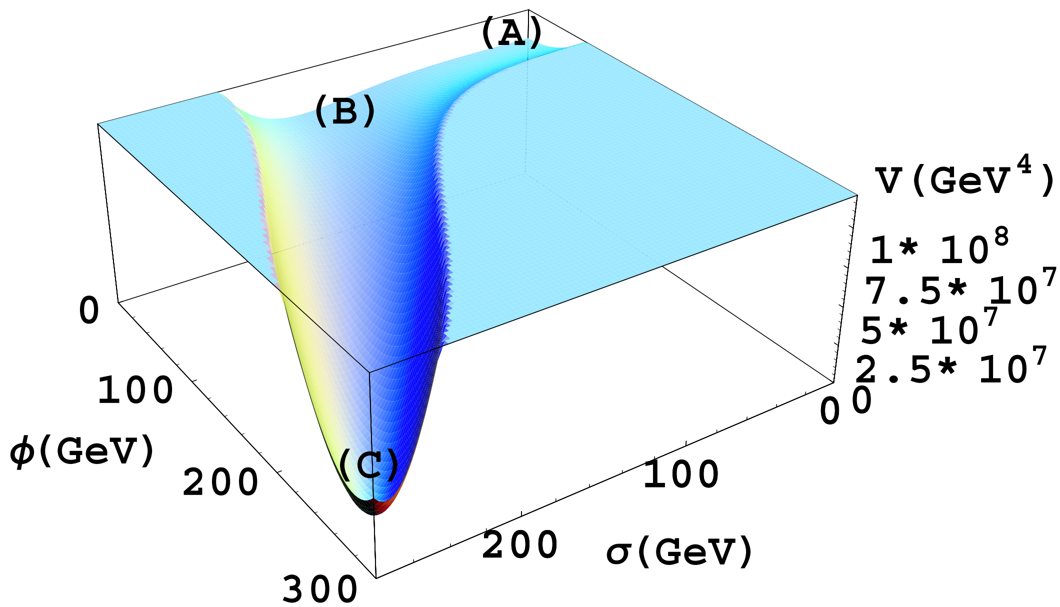
  $\tilde{n} \approx -\frac{2}{N_k}\frac{p-1}{p-2}$. Standard infl.: $N_k \sim 60$; EW-scale: $N_k = 22$

Model

Inflaton σ and SM Higgs ϕ with effective potential:
(based on earlier work by *[Copeland, Lyth, Rajantie, Trodden]*)

$$V(\sigma,\phi) = V_0 - \frac{1}{2}\alpha_2\sigma^2 + \frac{1}{4}\alpha_4\sigma^4 - \frac{1}{5}\alpha_5\sigma^5 + \frac{1}{6}\alpha_6\sigma^6 - \frac{1}{2}\lambda_{\sigma\phi}\sigma^2\phi^2 + \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda_\phi\phi^4$$

Electroweak-scale inflation: $V_0 = (100\ \text{GeV})^4$



(A) Slow-roll inflation ($\phi = 0$, first line potential)

(B) EW phase transition ($\sigma \gtrsim \mu/\sqrt{\lambda_{\sigma\phi}} \to \phi$ tachyonic)

(C) Absolute minimum $(\sigma,\phi) = (v_\sigma, v_\phi)$

Constraints and predictions

(A) **WMAP**: amplitude $|\delta_{\mathbf{k}}|^2$ and spectral index $\tilde{n}$

$$|\delta_{\mathbf{k}}|^2 = \frac{\alpha_4}{225\pi^2}\left(\frac{R}{x}\right)^3 \left(R\tilde{\sigma}_H - 3\tilde{\sigma}_H^3 + \tilde{\sigma}_H^4\right)^{-2}, \qquad \left(x \equiv \frac{M_P^2\,\alpha_2}{8\pi V_0}\right)$$

$$\tilde{n} = -\frac{2x}{R}\left(R - 9\tilde{\sigma}_H^2 + 4\tilde{\sigma}_H^3\right). \qquad (\tilde{\sigma}_H = \tilde{\sigma}_H(R,x), \quad R \equiv \frac{27\alpha_2\alpha_5^2}{\alpha_4^3})$$

$\Rightarrow \tilde{n} = \tilde{n}(R,x) \Rightarrow$ given α_2: $\tilde{n} \to \alpha_5$, $|\delta_{\mathbf{k}}|^2 \to \alpha_4$

(C) **Standard Model**: accelerator results v_ϕ, μ^2, m_ϕ^2

$$\frac{\partial V}{\partial \sigma}(v_\sigma, v_\phi) = 0, \qquad \frac{\partial^2 V}{\partial \phi^2}(v_\sigma, v_\phi) = m_\phi^2$$
$$\frac{\partial V}{\partial \phi}(v_\sigma, v_\phi) = 0, \qquad V(v_\sigma, v_\phi) = 0 \qquad \Rightarrow \alpha_6, \lambda_{\sigma\phi}, \lambda_\phi, v_\sigma$$

(B) **Baryogenesis**: fast enough EW transition

$$\left.\frac{1}{\mu^3}\frac{\mathrm{d}(\mu^2 - \lambda_{\sigma\phi}\sigma^2)}{\mathrm{d}t}\right|_{\sigma=\mu/\sqrt{\lambda_{\sigma\phi}}} \gtrsim 0.1 \qquad \Rightarrow \qquad \lambda_{\sigma\phi} > 0.01$$

Quantum corrections under control: $\lambda_{\sigma\phi} < 1$

For $V = V_0 - \frac{1}{p}\alpha_p\sigma^p + \frac{1}{q}\alpha_q\sigma^q - \frac{1}{2}\lambda_{\sigma\phi}\sigma^2\phi^2 + \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda_\phi\phi^4$:

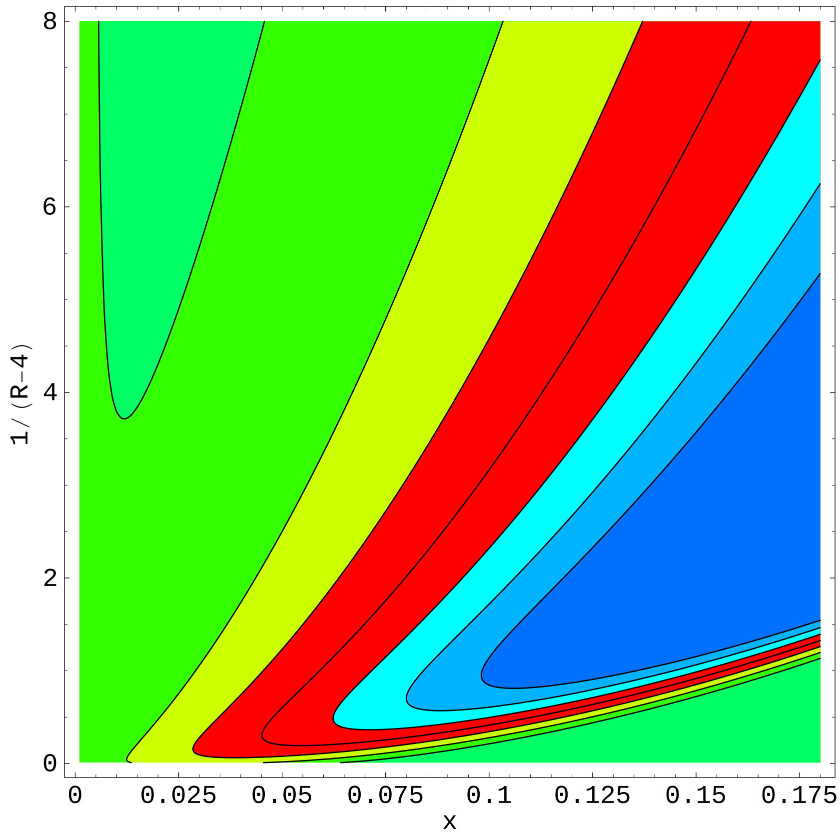
(p,q)	(4,6)	(5,6)	(6,7)	(6,8)
$\lambda_{\sigma\phi}$	$1.4 \cdot 10^{-6}$	0.36	$2.0 \cdot 10^3$	$3.1 \cdot 10^3$

$\Rightarrow p = 5$

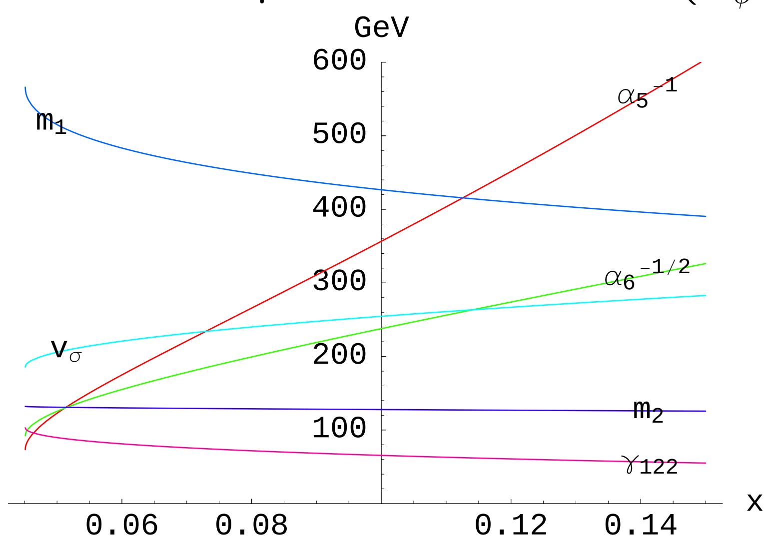
Prediction: Two scalar particles with mass $\mathcal{O}(100\ \text{GeV})$, couplings to SM equal to SM Higgs (up to mixing angle)

$$\left.\begin{pmatrix} V_{,\sigma\sigma} & V_{,\sigma\phi} \\ V_{,\phi\sigma} & V_{,\phi\phi} \end{pmatrix}\right|_{(v_\sigma,v_\phi)} \xrightarrow[\text{modes}]{\text{eigen-}} \phi_1 = \sigma\cos\xi - \phi\sin\xi, \ \phi_2 = \sigma\sin\xi + \phi\cos\xi$$

Contourplot for $\tilde{n}$ as function of x and $(R-4)^{-1}$:



Change dimensionful parameters with x ($m_\phi = 200$ GeV):



Finetuning?

Yes:	**but**:
$\sqrt{\alpha_2} \sim 10^{-15}$ GeV	$\sim \sqrt{V_0}/M_P \to$ Price for EW-scale
$\alpha_4 \sim 10^{-12}$	Same as "normal" inflation
$0 < \sigma_0 \lesssim 10^{-10}$ GeV	Quantum tunnelling from $\sigma < 0$?
	All others have "natural" values

Good reward: working minimalist model EW inflation!

Loop corrections

- Do they disrupt inflation?
- Break-down scale (non-renormalizable) model?

$$V^{(1)} = \varepsilon(m_1^2) + \varepsilon(m_2^2) + \text{counter-terms}$$

(m_1^2, m_2^2 eigenvalues σ-ϕ mass matrix)

$$\varepsilon(m^2) = \frac{1}{2}\int_{|\mathbf{p}|<\Lambda} \frac{\mathrm{d}^3\mathbf{p}}{(2\pi)^3}\sqrt{m^2 + |\mathbf{p}|^2}$$

Renormalization conditions:

1. Potential up to σ^5 unchanged during inflation;
2. VEVs and masses in absolute minimum unchanged.

$\Rightarrow$ Only **small changes** in coupling parameters; flatness inflaton potential **not disrupted** by corrections σ^6 term.

Break-down $<$ TeV; can model be imbedded in MSSM?

Summary and conclusions

- Presented explicit electroweak-scale inflation model, motivated by minimalist viewpoint:
  Inflation + **Baryogenesis** as minimal extension **SM**.

- **Constraints** from **WMAP** + **SM** + **Baryogenesis** = non-trivial, but possible to satisfy.

- General consequences of constraints:
  - σ^5 present as highest power inflaton potential;
  - WMAP spectral index difficult to satisfy:
    need also σ^2, σ^4 terms.

- Our model predicts two Higgs-like particles
  $\Rightarrow$ can be **falsified**.

- Loop corrections do not disrupt inflation.

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