Light Higgs from Pole Attractor

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work in progress, in collaboration with M.Montul

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Approaches to Gauge Hierarchy Problem

The traditional approaches (SUSY, CH, GHU) to the problem either provide a symmetry reason for the Higgs mass to be small or simply lower the cutoff.

A completely different approach is to assume that the Higgs mass is scanned by another field, and takes a full range of values during its cosmological evolution. The current Higgs vev is defined by a back-reaction of the Higgs, which stops the evolution of the scanning field. Graham-Kaplan-Rajendran [1504.07551], Dvali-Vilenkin[0304043]

Lesson from Cosmological Relaxation by GKR: new solutions to the Gauge Hierarchy problem require highly non-standard physics (e.g. monodromy)

Higgs-Sensitive Pole for the Scanning Field

(toy model)

The Higgs mass is scanned by a field ρ

$$V_h = (-\Lambda^2 + \kappa\Lambda\rho)h^2 + \lambda h^4$$

Λ - cutoff

κ - typical ρ coupling

which is driven by its potential (exact form unimportant)

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The non-canonical kinetic term of ρ

$$\frac{\Lambda^{2n}}{h^{2n}}(\partial_\mu\rho)^2$$

starts diverging, effectively flattening to zero the ρ potential, thus terminating the scanning.

Higgs-Sensitive Pole for the Scanning Field

To track the ρ evolution let us integrate out the Higgs field

$$h^2 \sim (-\kappa\Lambda\rho + \Lambda^2)$$

Which results in the kinetic term

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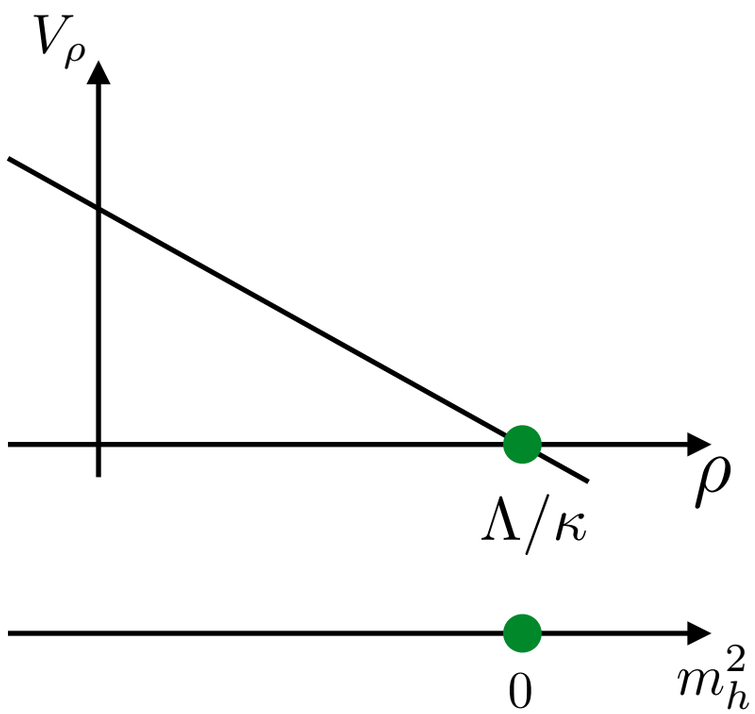
Such kinetic terms were already considered previously in pole inflation scenarios. It can now be normalised canonically using

n=1	$\rho - \Lambda/\kappa = -\phi^2$
n=2	$\rho - \Lambda/\kappa = -\exp(-\phi)$
n>2	$\rho - \Lambda/\kappa = \phi^{\frac{1}{1-n}}$

for n=2,3,… the $\rho = \Lambda/\kappa$ point corresponds to $\phi \to \infty$ and hence never reached or overshot (ideally).

Higgs-Sensitive Pole for the Scanning Field

Potential of the canonically normalised scanning field:



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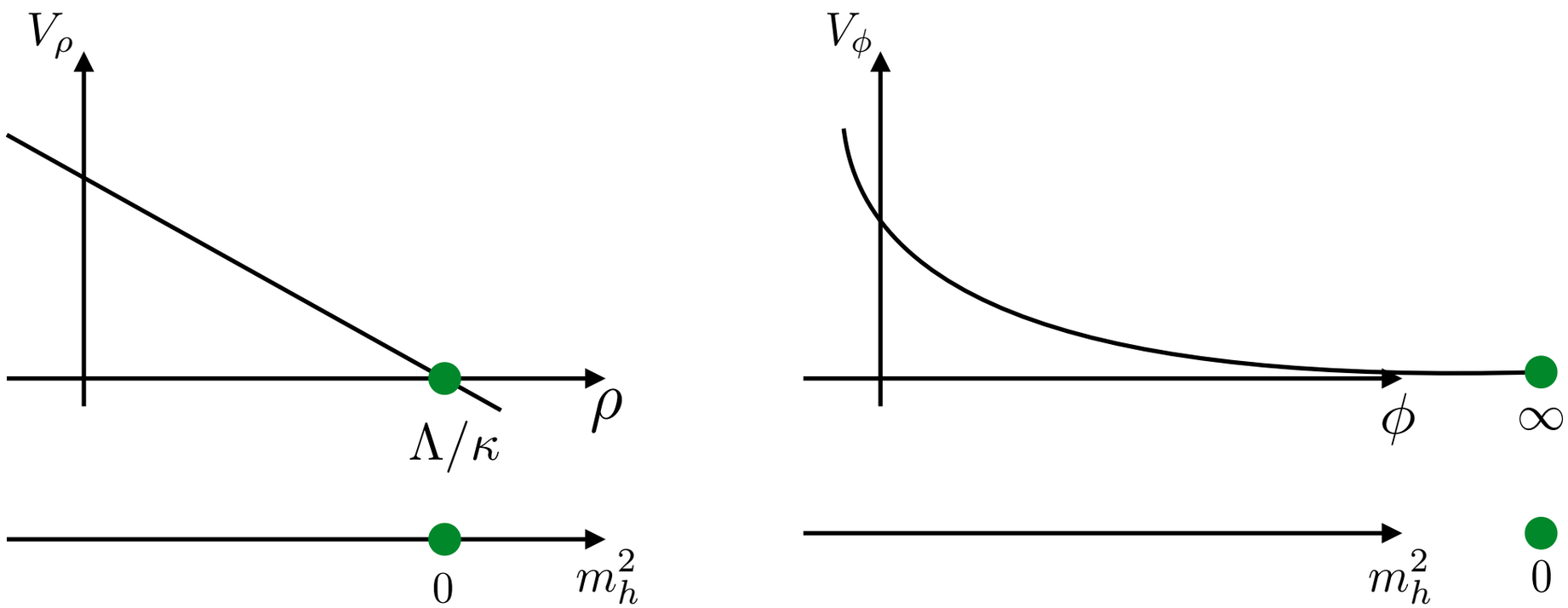

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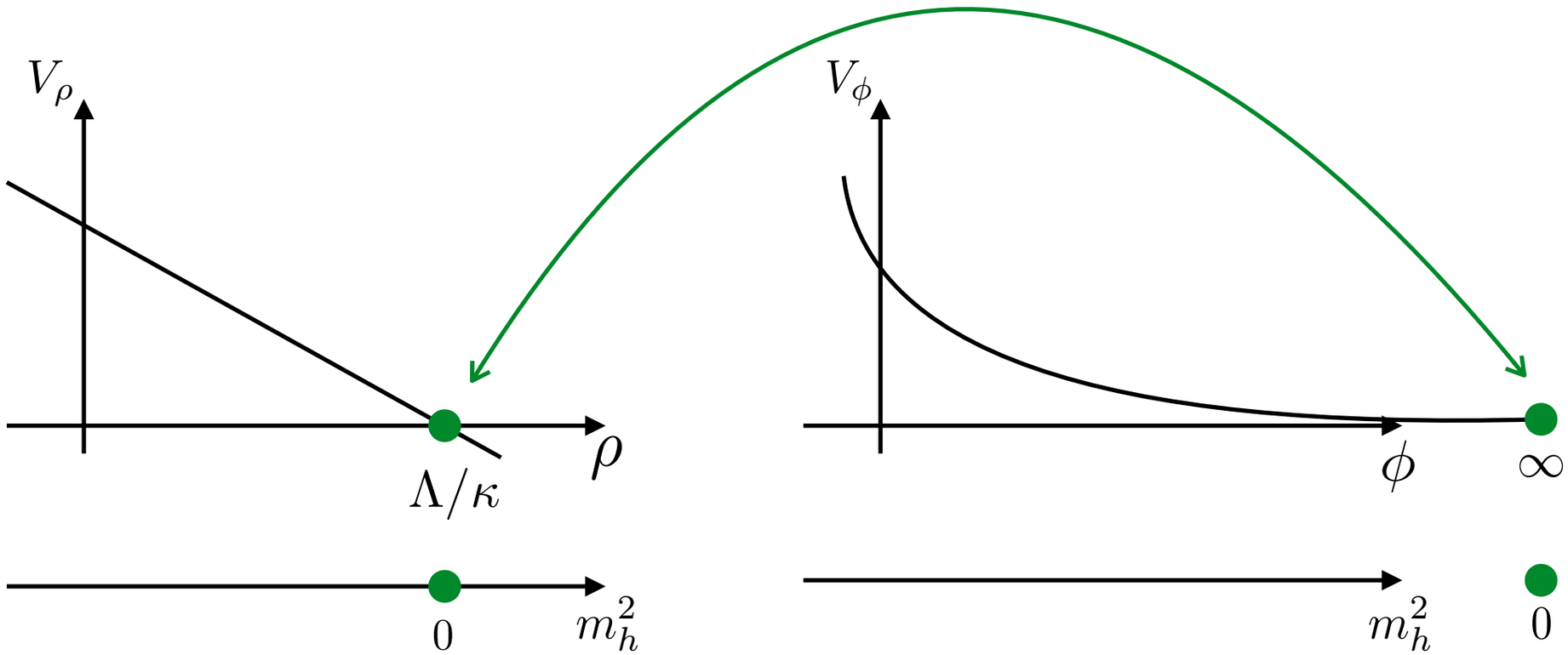

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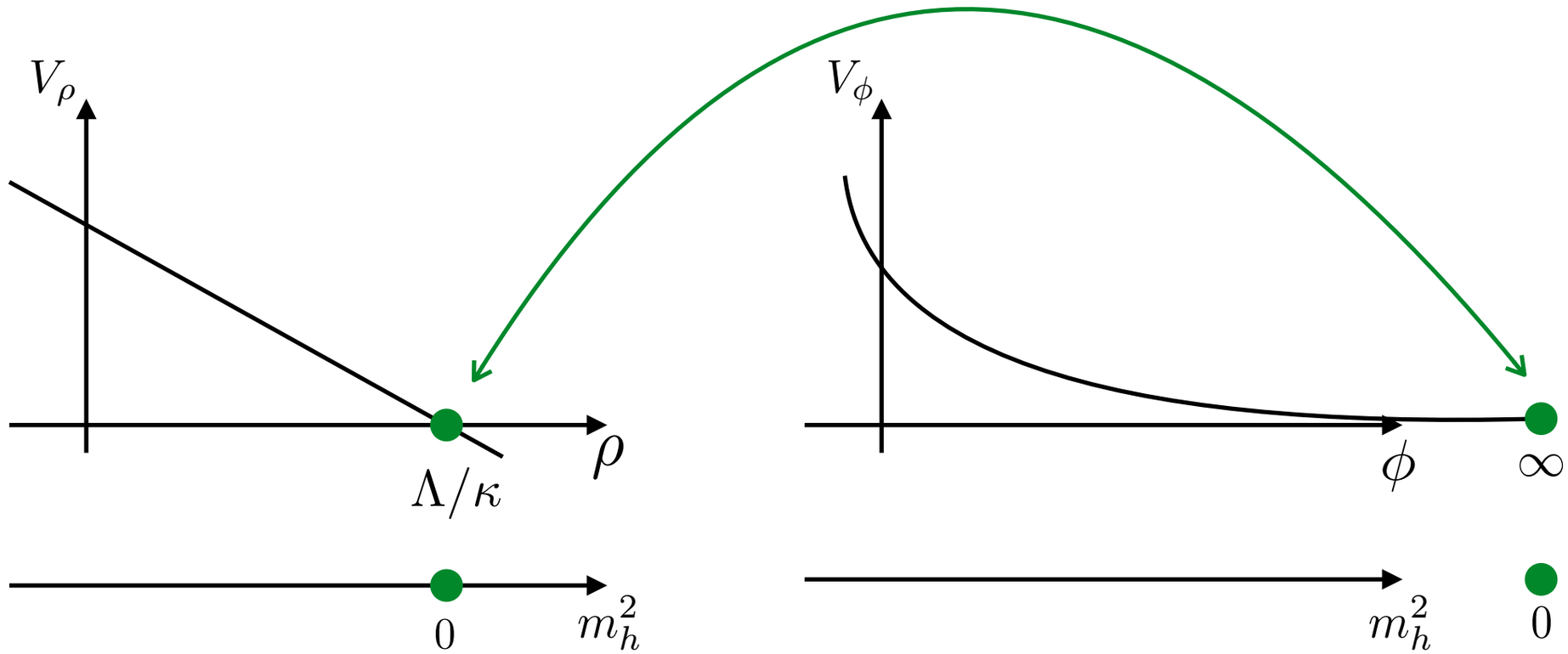
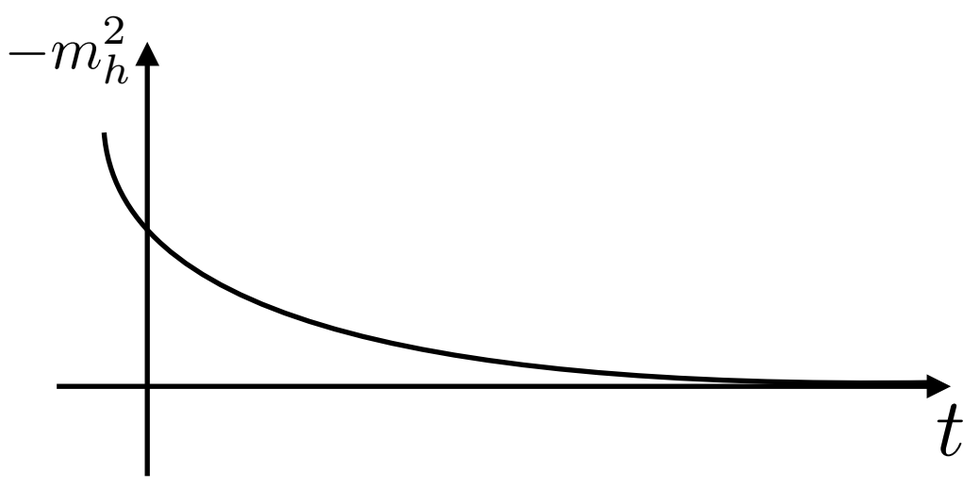


Higgs mass evolution with time:



Cosmological Evolution

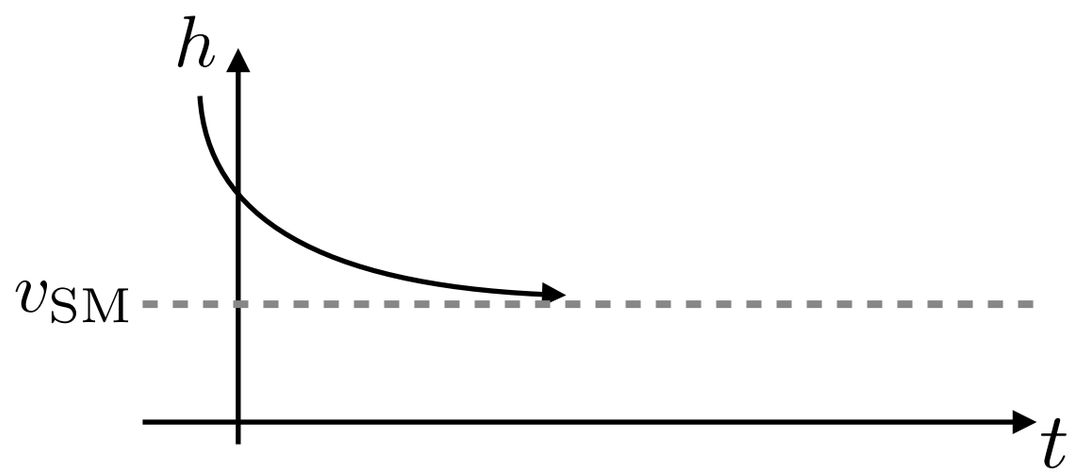
The Higgs vev should reach (get close to) its current value before the BBN times, hence the stabilisation of h and ρ around attractor should happen during or sufficiently quickly after inflation.

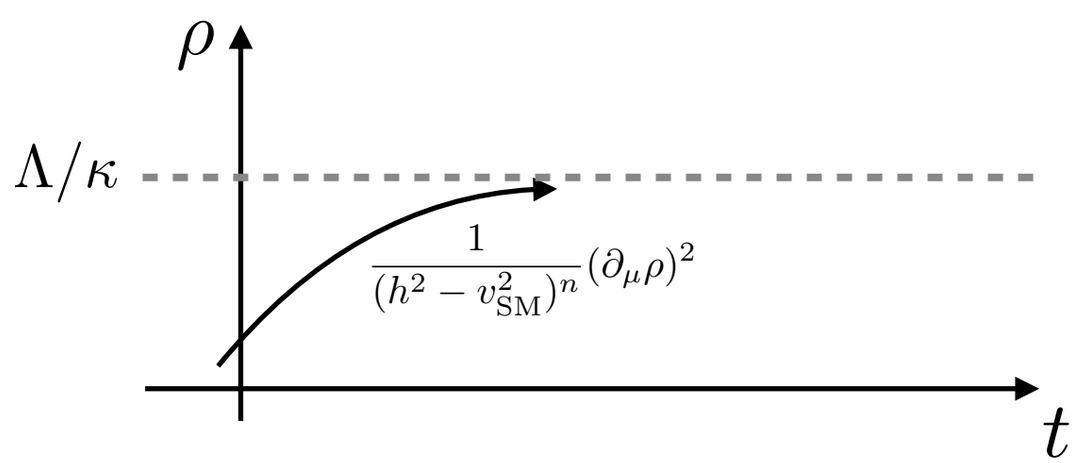
If the scanning completes during inflation, the fluctuations of the Higgs field induced by metric expansion $\delta h \sim H_I^2/m_h$ could cause an overshooting of the attractor point.

Another threat is the temperature growth during reheating. If the scanning is complete before reheating, the effective Higgs vev will get shifted, moving away from attractor point and allowing ρ to scan further without stop.

Cosmological Evolution

(attractor at $v_{\rm SM} \neq 0$, will be discussed later)





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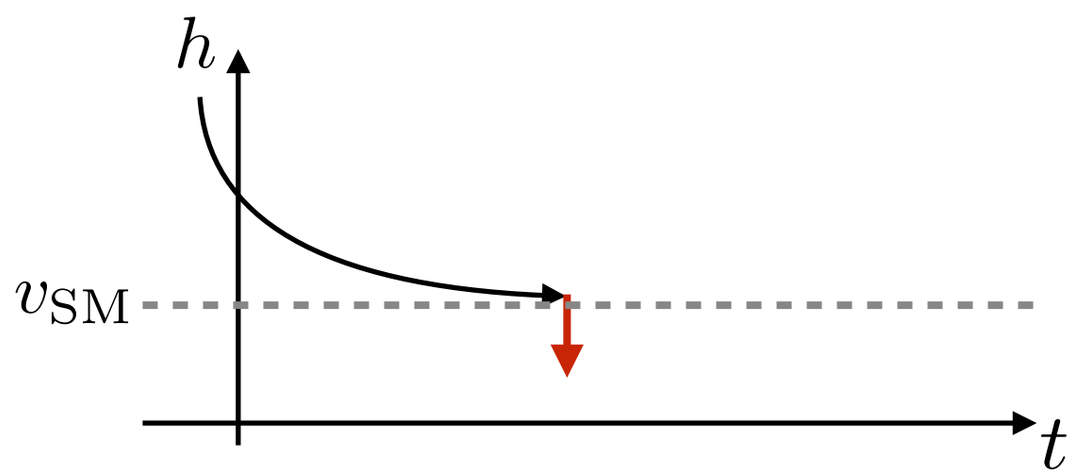

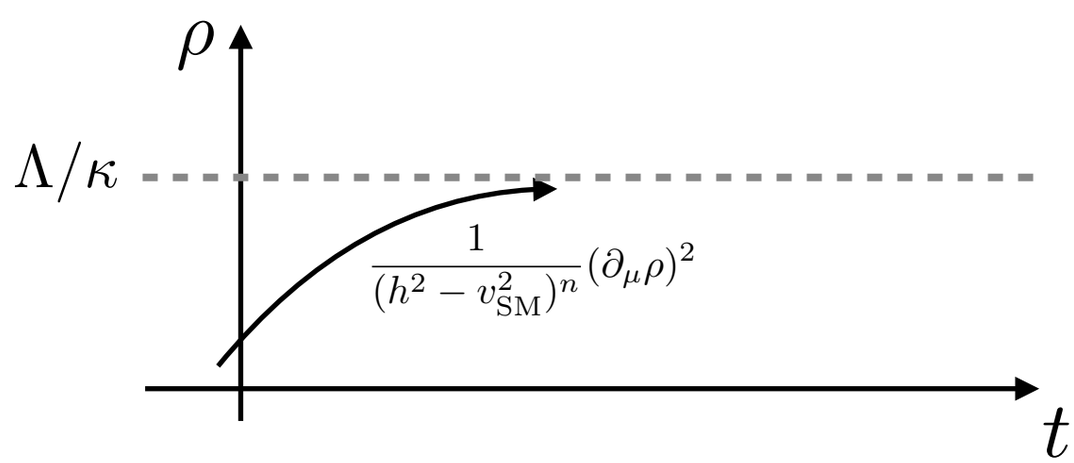

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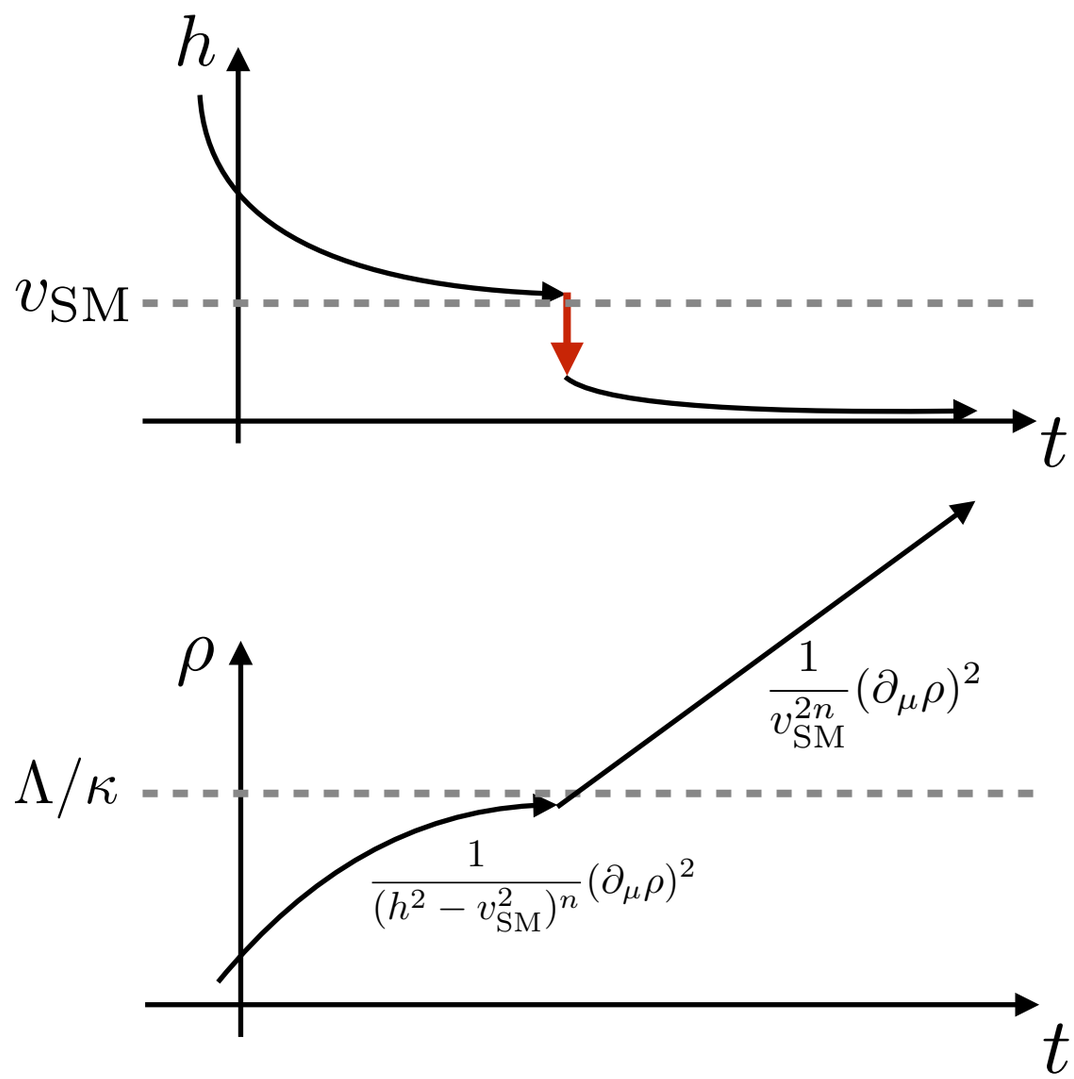


attractor overshot, Higgs mass becomes large and positive

Cosmological Evolution

Assuming that the EW phase transition is of second order (h changes continuously with a temperature) the following scenario becomes favorable.

1) Start with a large Higgs vev, but the scanning is not complete during inflation, provided by

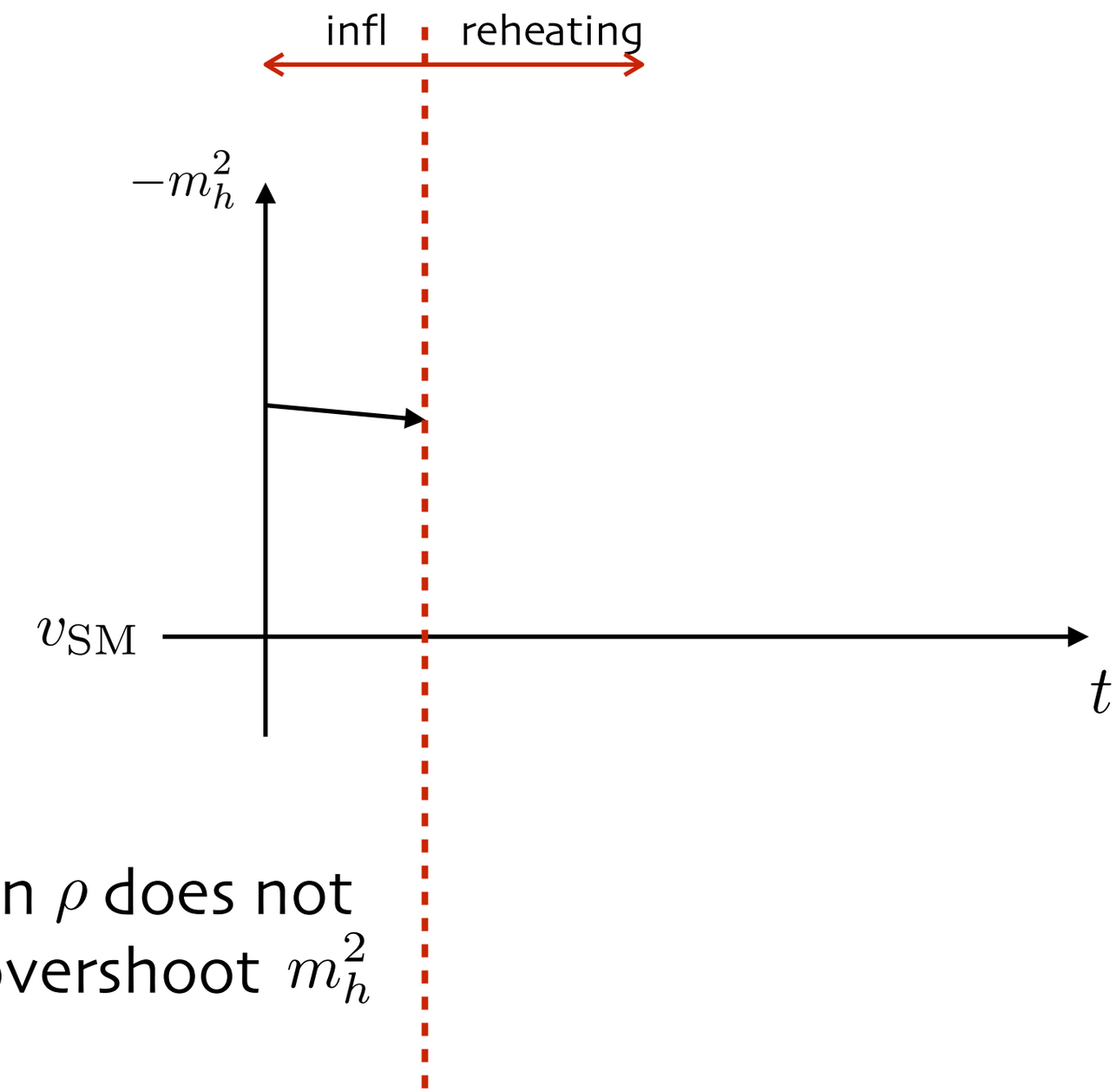
$$\kappa^2 \frac{\Lambda^2}{m_{h,fin}^2} N_e \ll 1$$

2) After inflation completes, reheated plasma contributes to the Higgs mass and makes it smaller.

$$m_h^2 \sim -|m_h^{(0)2}| + T^2$$

But given that the initial value of h is large, it does not cross the attractor point.

Cosmological Evolution



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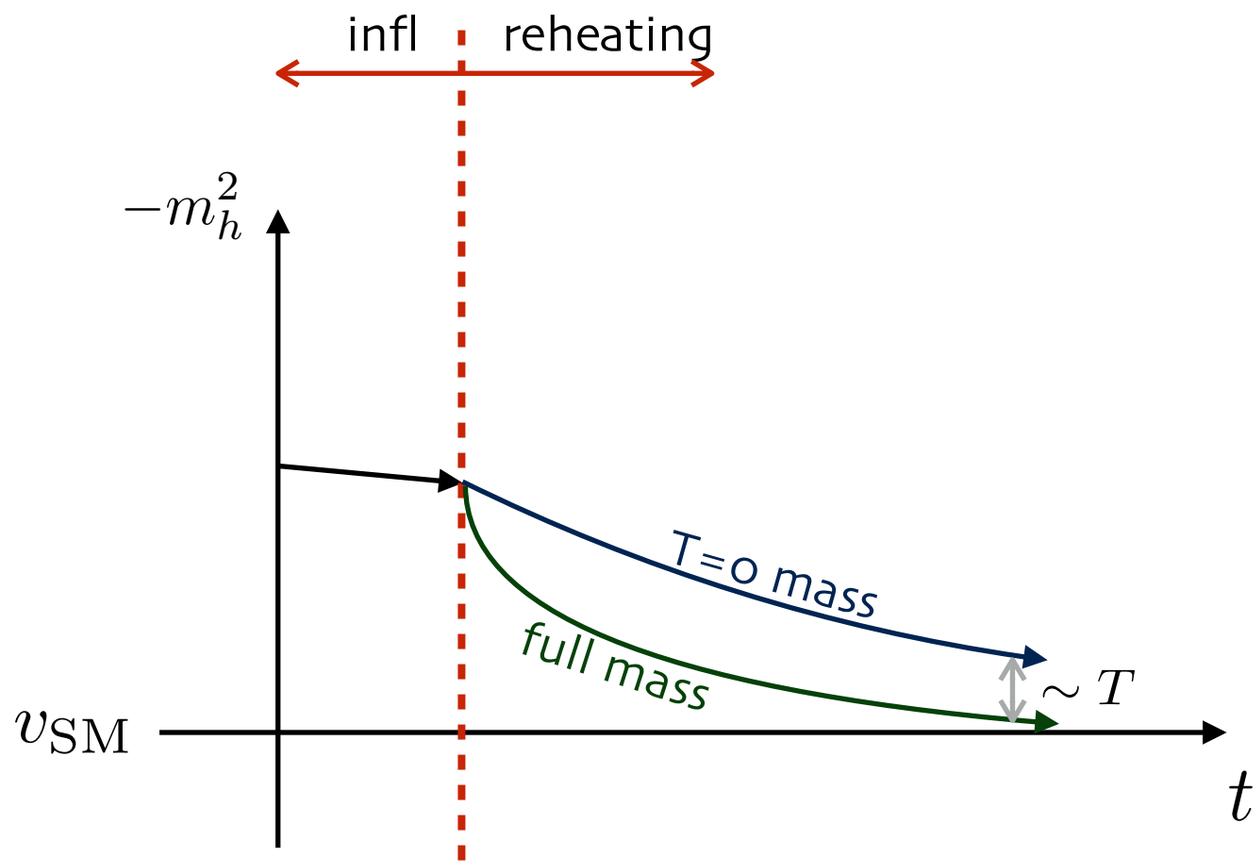

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during reheating $h \gg v_{\rm SM}$, hence for $T_R < h$ (which can still be large) the higgs vev is not overshot

Partial UV Completion: Extra Scalar

Obtaining a ~1/h pole in the kinetic term directly from some UV completion may be impossible due to the number of features that the SM Higgs has.

To simplify this task one may use an intermediate UV completion: the ρ kinetic term pole is set by an extra SM-neutral field χ

$$\frac{1}{\chi^l}(\partial_\mu \rho)^2$$

whose vev is for instance induced by a Higgs-dependent tadpole

$$V = \mu\, h^2 \chi + \Lambda^2 \chi^2 \qquad \Rightarrow \qquad \langle \chi \rangle \sim \frac{\mu h^2}{\Lambda^2}$$

then the attractor $\langle \chi \rangle = 0$ is reached for $h \sim 0$

The χ field itself can have either canonical kinetic term $(\partial_\mu \chi)^2$ or $\frac{1}{\chi^l}(\partial_\mu \chi)^2$

Partial UV Completion: 2HDM

Such type of UV completion has to contain a mechanism ensuring the absence of large h-insensitive quantum corrections to the tadpole

$$\mu h^2 \chi \to \mu \Lambda^2 \chi$$

We use a two Higgs doublet model inspired by relaxion model of Espinosa et al [1506.09217]

The χ tadpole is now $\alpha h_1 h_2 \chi$, hence protected from power corrections.

SU(2)R symmetry ensures that both doublets are not too heavy, otherwise would be equivalent to one-doublet model

$$(\tilde{h}_1, h_2) \to g_L (\tilde{h}_1, h_2) g_R^\dagger$$

Partial UV Completion: 2HDM

Both masses scanned symmetrically by ρ

$$V_\rho = \kappa\Lambda\rho(h_1^2 + h_2^2 - \Lambda^2) + \lambda(h_1^2 + h_2^2)^2 + \Delta_h h_2^2$$

With the largest SU(2)R breaking contribution generated at two loop with quarks and hypercharge g.b.

$$\Delta_h \gtrsim y^2 g_1^2 \Lambda^2/(4\pi)^4$$

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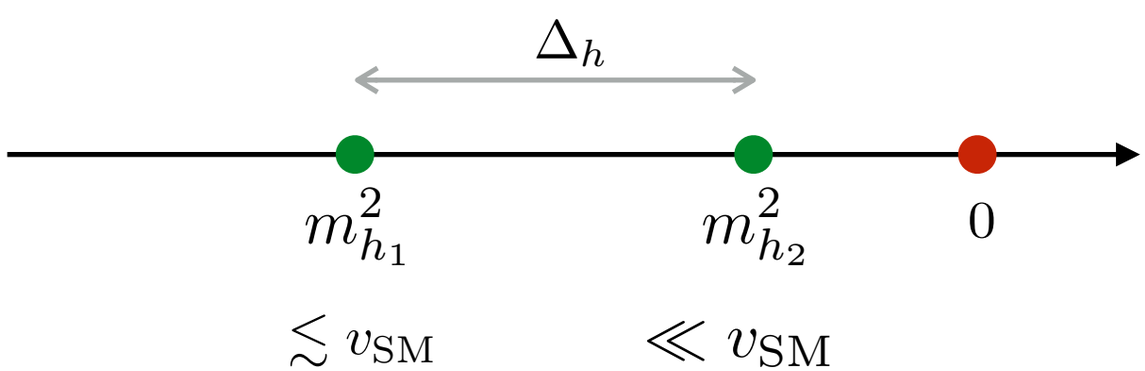

One Higgs much lighter than $v_{\rm SM}$

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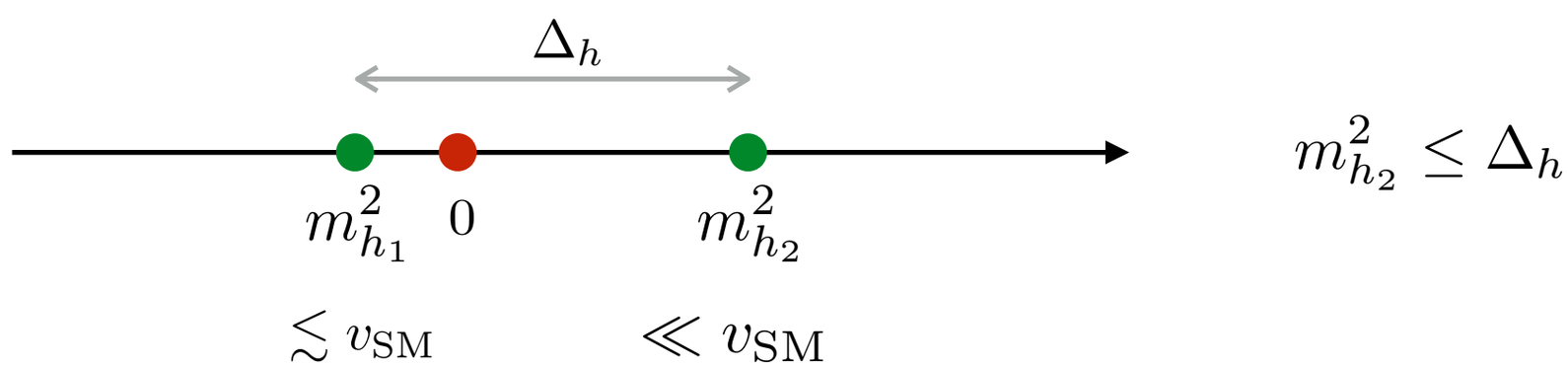

SM-like Higgs is the lightest. The second positive-mass Higgs gets a vev from the exp. breaking by the first one.

Partial UV Completion: 2HDM

After integrating h_2 out we obtain, accounting for quantum corrections

$$\langle \chi \rangle \sim \frac{h_1^2}{m_{h_2}^2} - \frac{\log \Lambda^2/m_{h_2}^2}{(4\pi)^2}$$

During h1,h2 evolution $\langle \chi \rangle$ decreases to O. If we want the attractor point $\langle \chi \rangle = 0$ to appear at $h_1 = v_{\rm SM}$ and $m_{h_2}^2 \simeq \Delta$ we need to set

$$\Lambda \sim 10^{5-6}\ \text{GeV}$$

Which corresponds to $m_{h_2} \sim 10\,\text{TeV}$

Summary

Searches for traditional NP solving the hierarchy problem do not give results, slowly forcing them into more tuned regions.

We present a new model aiming at addressing the HP and belonging to the class of scenarios with a dynamically scanned Higgs mass.

The minimal implementation contains new scalars in a multi-TeV range and a light but very weakly interacting scanning field.

The UV completions for the main ingredient of the model — non-canonical kinetic term mixing two fields — need further investigation.

$$\frac{\Lambda^{2n}}{h^{2n}}(\partial_\mu \rho)^2 \longrightarrow (\partial_\mu \rho)^2$$

$$(-\Lambda^2 + \kappa\Lambda\rho)h^2 \longrightarrow m_h^2 h^2 + \kappa\Lambda\rho h^2 \left(\frac{h}{\Lambda}\right)^n$$