Higgs inflation as a mirage

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based upon arXiv:1501.02231

after a digression…

Scalars have a bad reputation in particle physics

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Unless they are:

bureaucrats of the supersymmetric party

or

aristocrats of the Goldstone family

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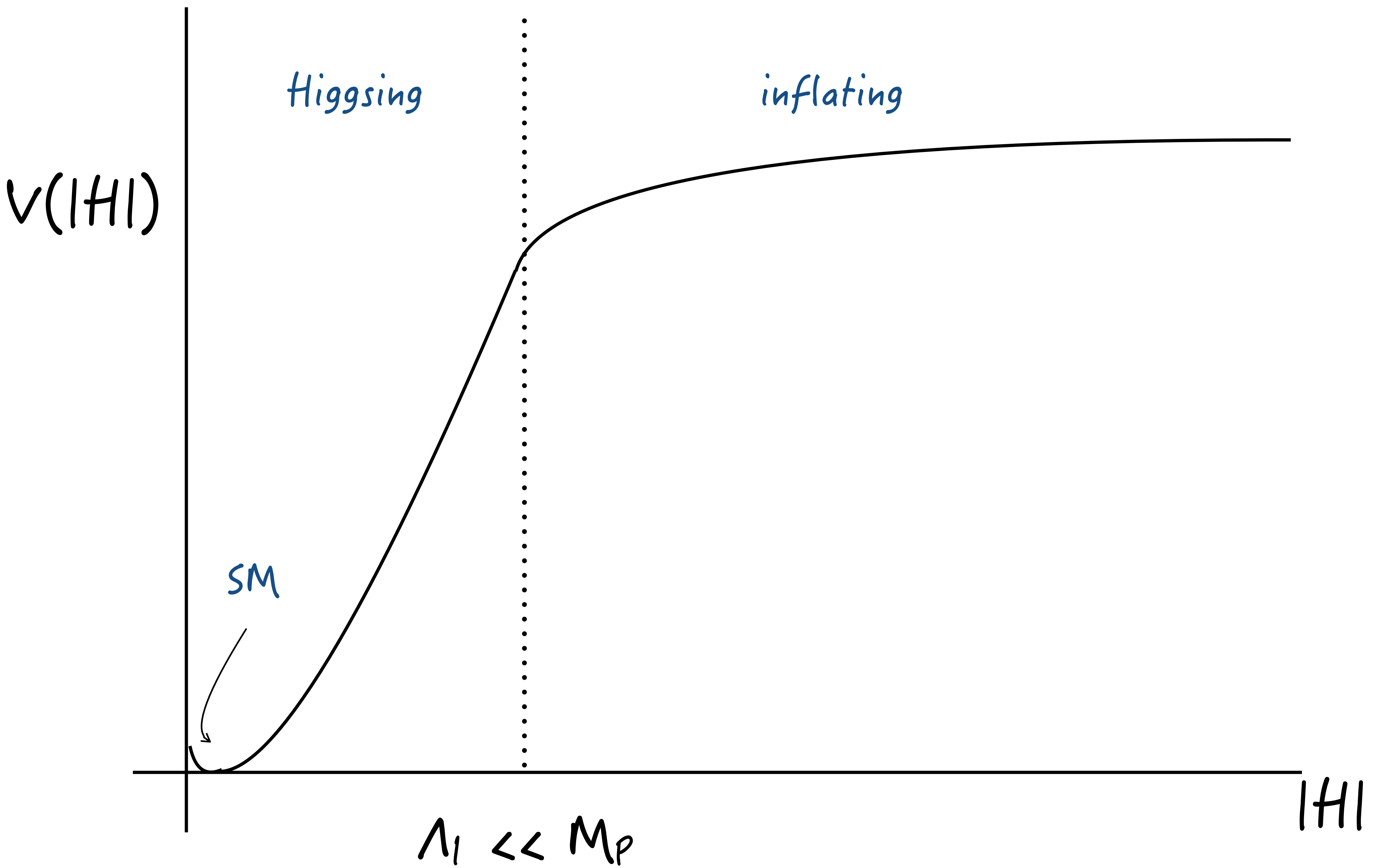
In that case the Occam jihad would rather send H into forced labour

Not only H has to Higgs the SM,
it has to inflate the Universe!

Higgs inflation mantra: H IS ONE AND ONLY D.O.F.



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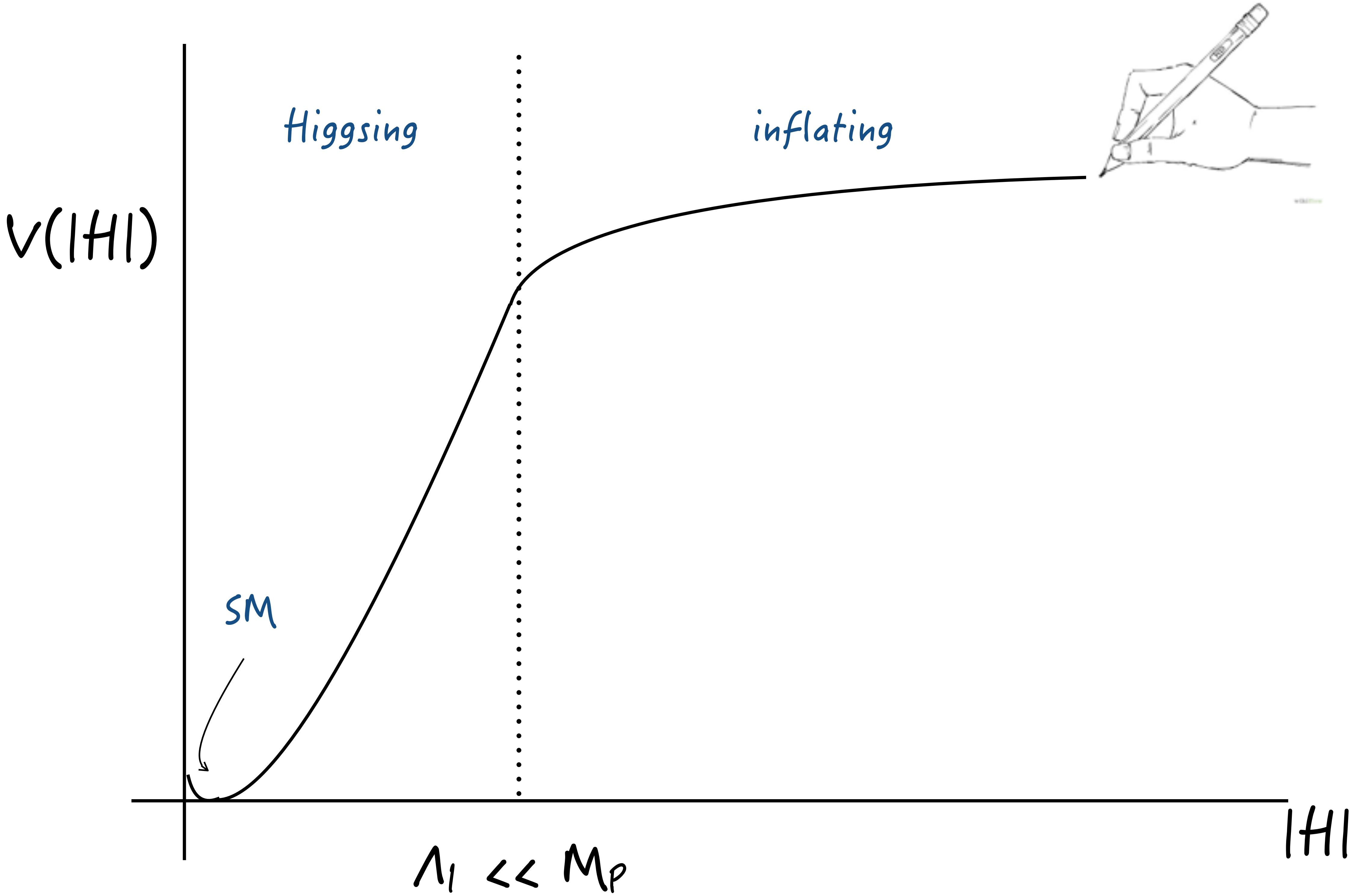


Remarkably, it can be done with ONE extra parameter

$$\mathcal{L}_{SM} + \frac{M_P^2}{2} R + \xi |H|^2 R$$

Bezrukov & Shaposhnikov (2007)

a Higgs mass term proportional to Ricci curvature

but also

a Higgs-dependent Newton constant

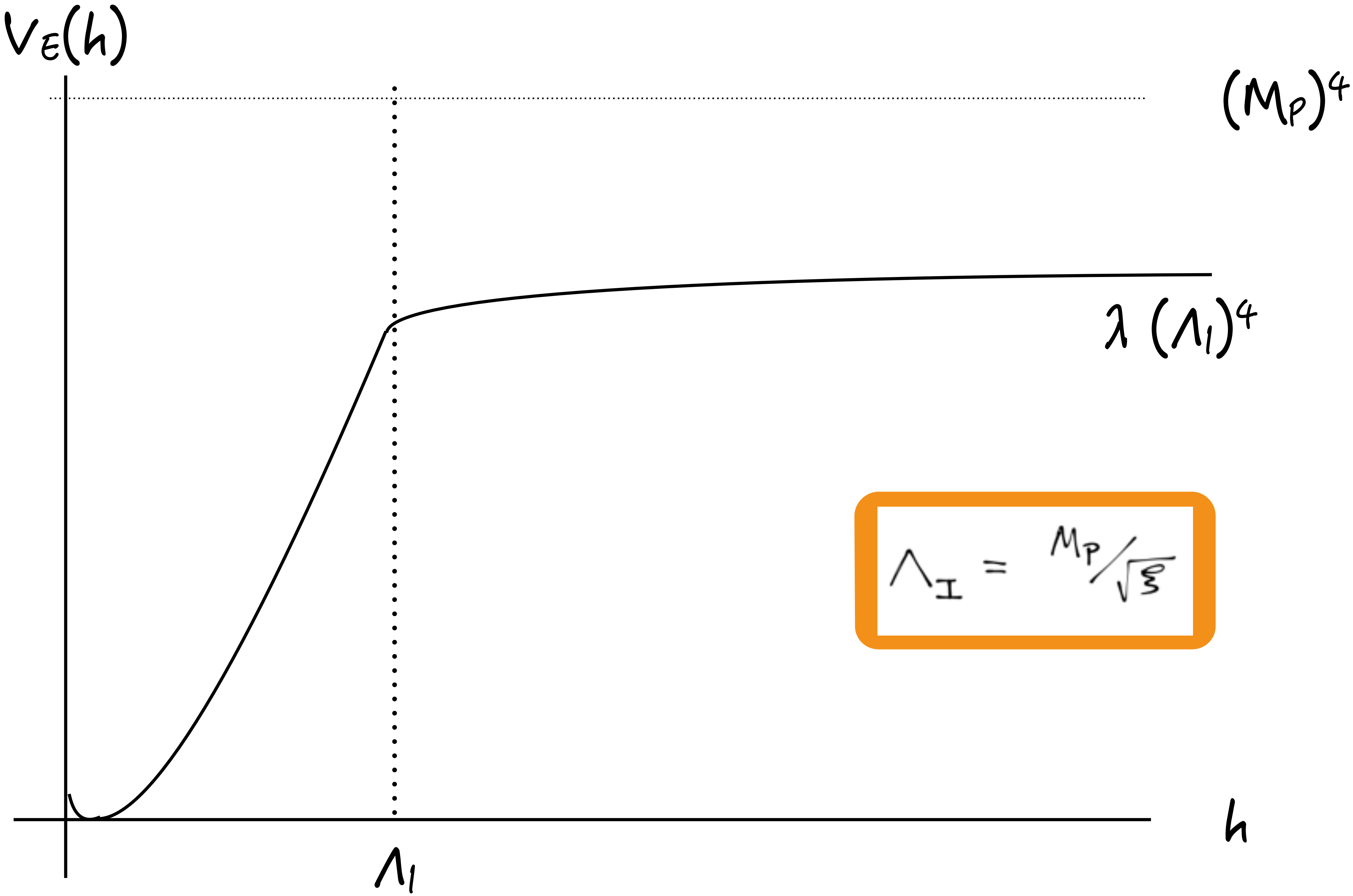
Restoring standard G_N with a conformal rescaling

$$(\text{length})^2 \longrightarrow \frac{(\text{length})^2}{(1+2\xi\,|H|^2/M_P{}^2)}$$

The SM model potential gets rescaled as well at large fields

$$V_{SM}(h) \approx \frac{\lambda}{4}(h^2-v^2)^2 \quad \Rightarrow \quad V_E(h) = \frac{V_{SM}(h)}{(1+\xi\,h^2/M_P^2)^2}$$

$$|H|^2 = h^2/2$$


$V_E(h)$
$(M_P)^4$
$\lambda\,(\Lambda_I)^4$
$\Lambda_I = M_P/\sqrt{\xi}$
Λ_I
h

A fit to $\delta\rho/\rho \sim 10^{-5}$ fixes

$\xi \sim 10^4$

The plateau slow-rolls like Starobinsky's

It leads to a "perfect" value for $n_s \sim 0.964$

and a small tensor/scalar ratio $r \sim 0.0033$

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A DREAM MODEL?

BUT ...

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There are further problems of detail, such as the tension of n_s with the measured value of $M_{top} \,/\, M_{Higgs}$

cf. A. Salvio (2013) for a recent update

Computing quantum corrections is an "art" in itself

cf. Burgess, Patil & Trott (2014) for a recent discussion with references

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$$V_E(h) \longrightarrow \frac{V_{SM}(h)}{(1+\xi f(h))^2}$$

The asymptotic plateau requires a FUNCTIONAL TUNING

$V_{SM}(h) \sim f(h)^2$ asymptotically

WHY?

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SHIFT SYMMETRY

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This is looking more like a mere case of

There are further structural peculiarities of the model, associated to the fact that $\xi \gg 1$

The main one is the existence of a lower dynamical scale Λ namely for $\xi \gg 1$ we have the hierarchy

Burgess, Lee & Trott (2009)
JFB & Espinosa (2009)

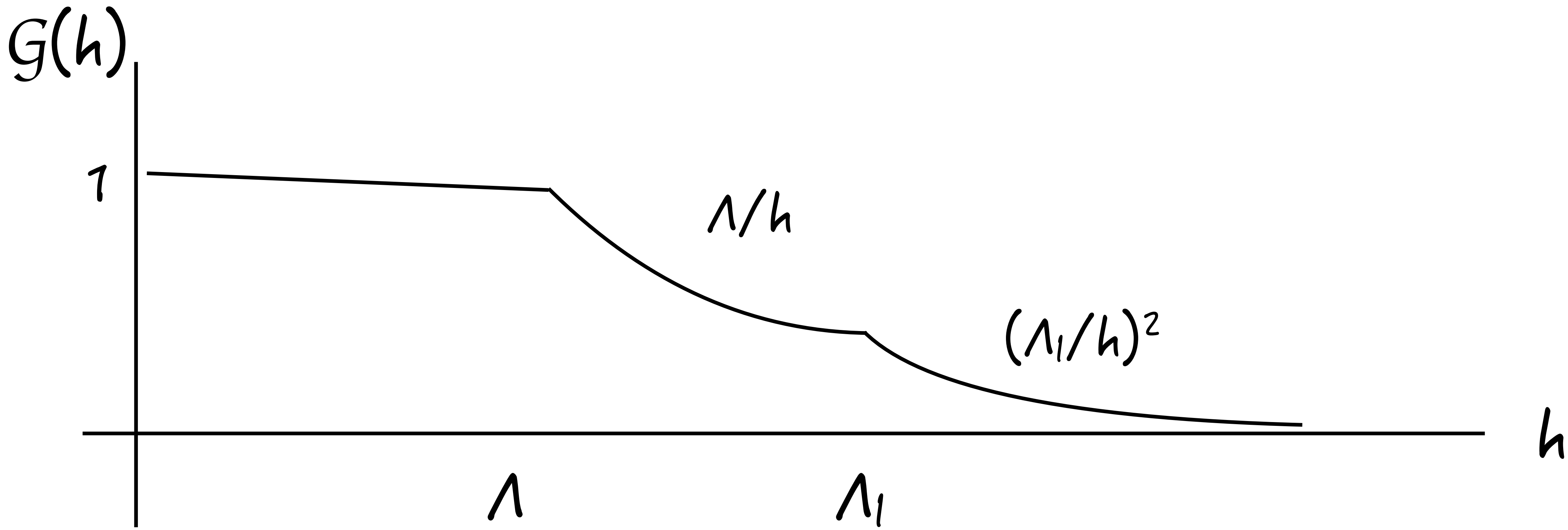
$$\boxed{\Lambda = M_P/\xi} \ll \boxed{\Lambda_I = M_P/\sqrt{\xi}} \ll \boxed{M_P}$$

inflation scale

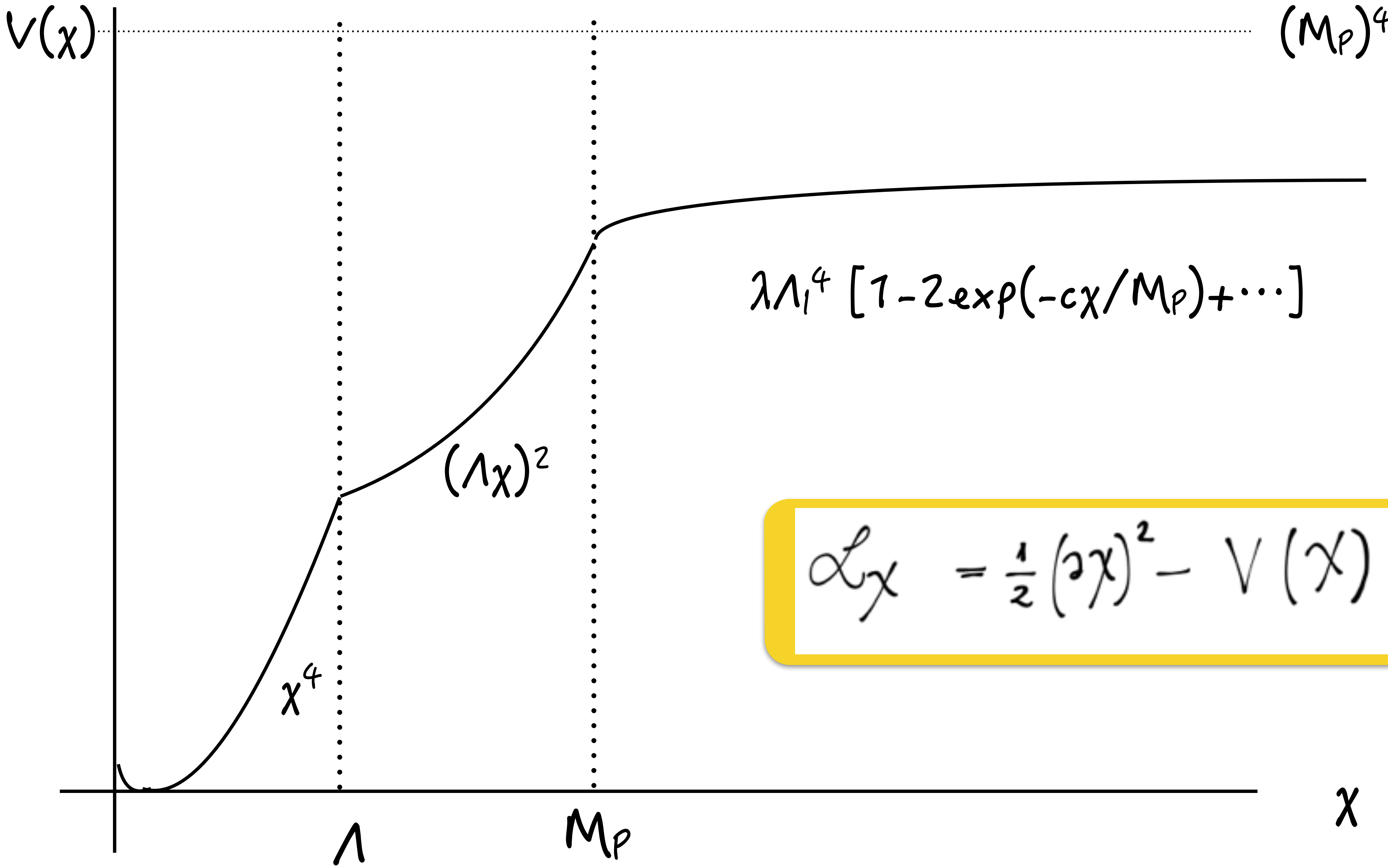
The map to Einstein frame gives us not only $V_E(h)$ but also a modified field metric

$$\mathcal{L}_h = \frac{1}{2}\mathcal{G}(h)\,(\partial h)^2 - V_E(h)$$

It turns out that the function $G(h)$ is nontrivial for $h > \Lambda$



The "true face" of Higgs inflation



$$\mathcal{L}_\chi = \frac{1}{2}(\partial\chi)^2 - V(\chi)$$

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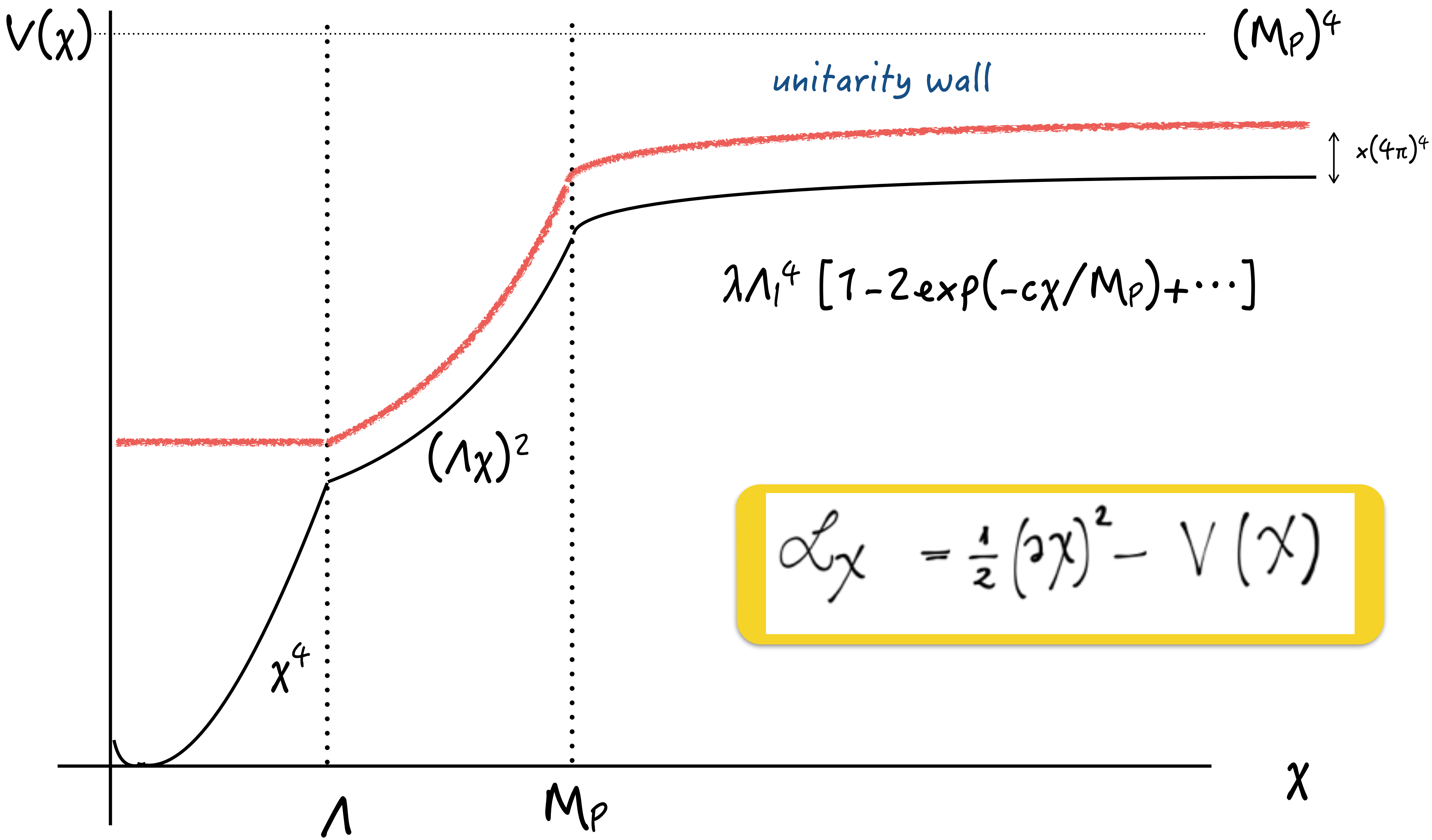

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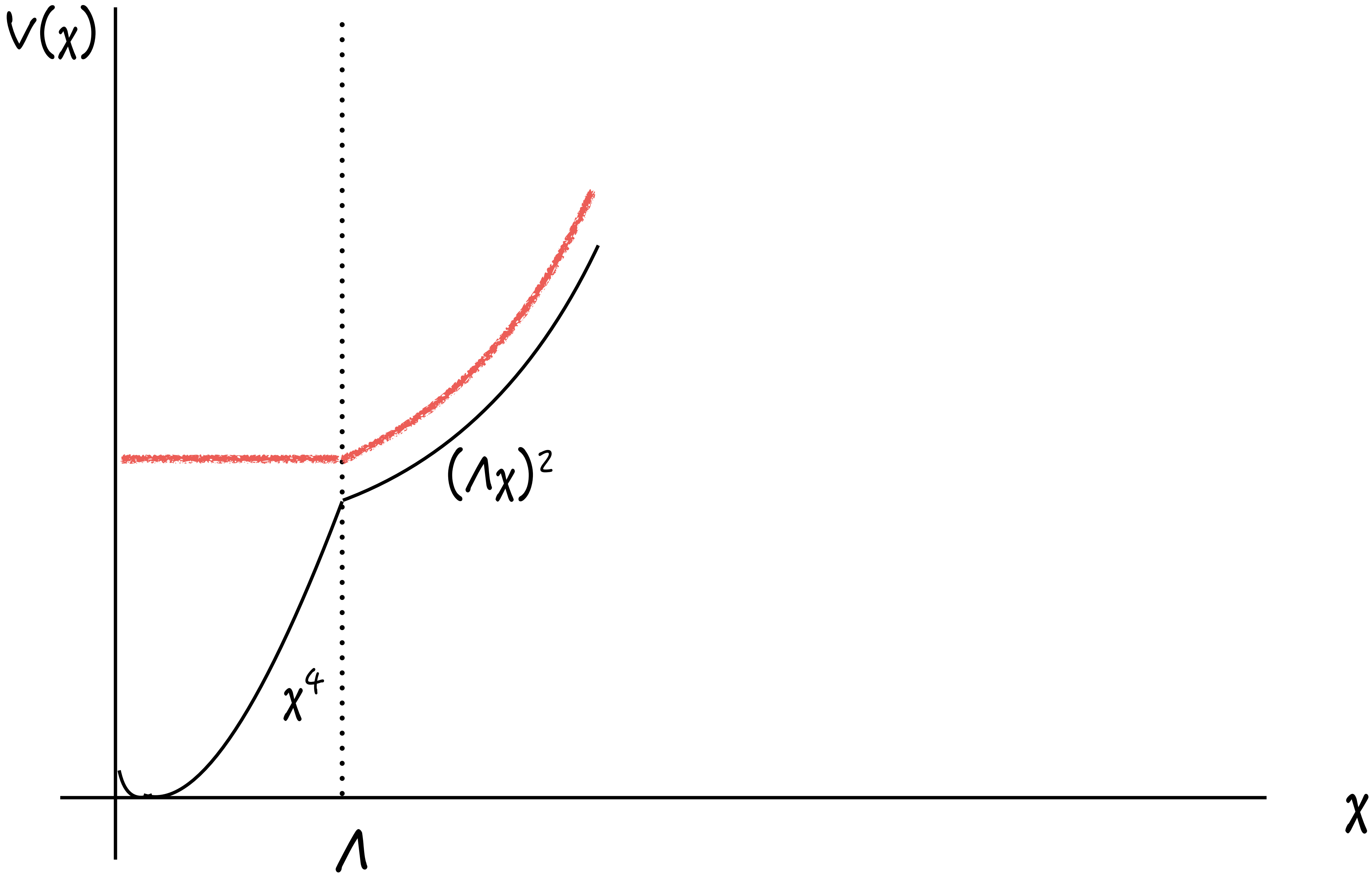
focus on the "kink" at the scale Λ



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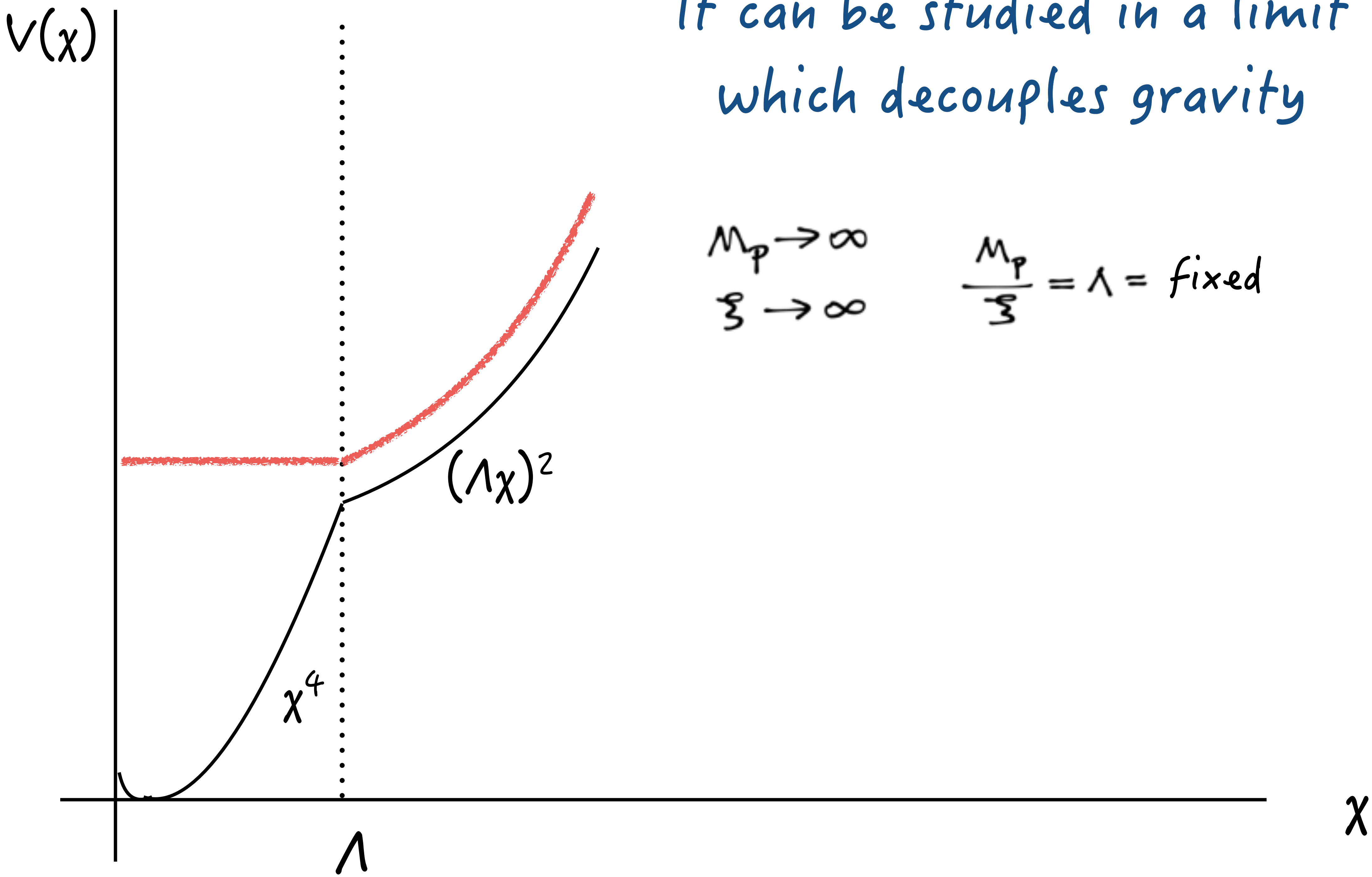

It can be studied in a limit which decouples gravity

$$M_p \to \infty \qquad \frac{M_p}{\xi} = \Lambda = \text{fixed}$$
$$\xi \to \infty$$

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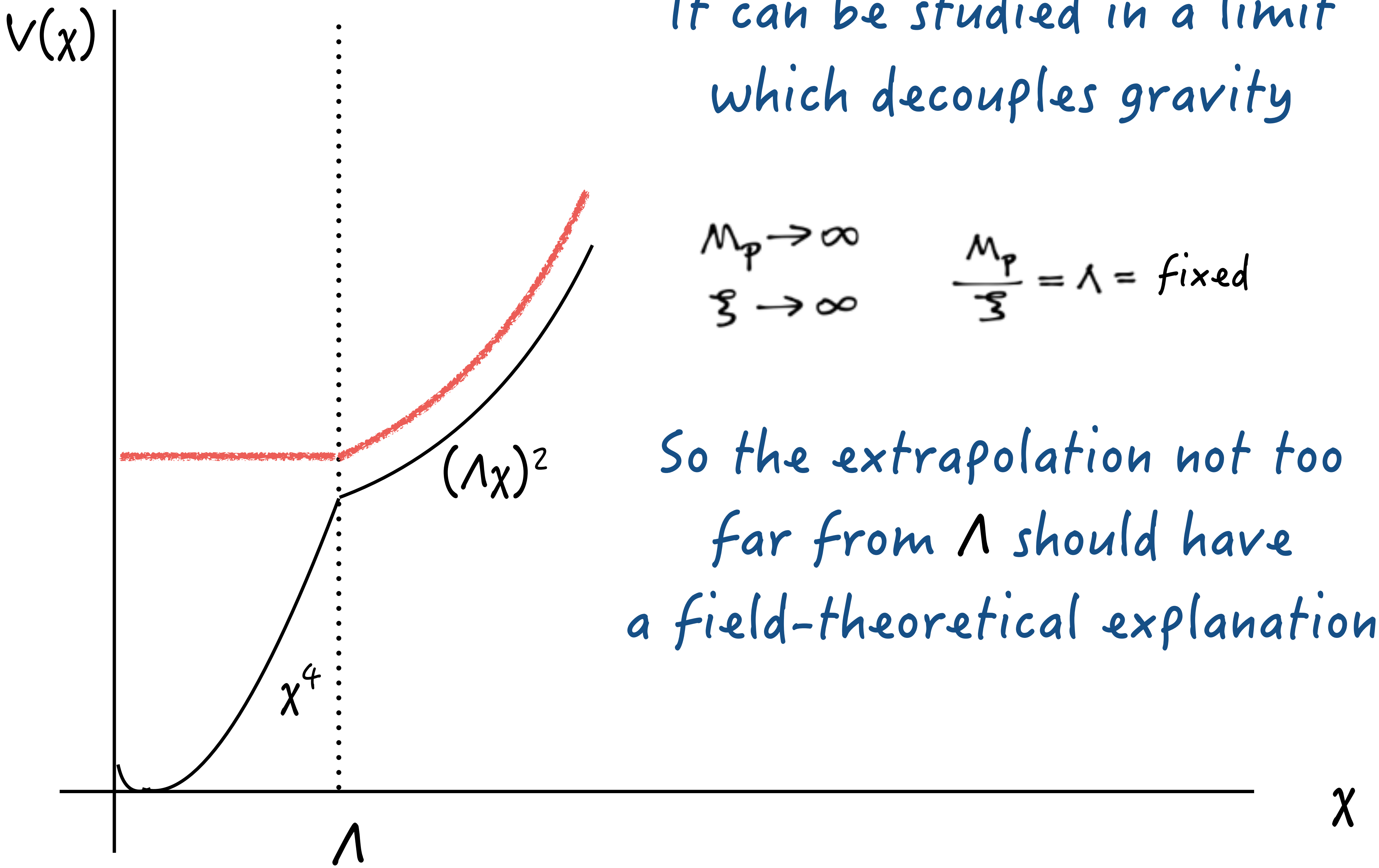

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$M_p \to \infty$ $\quad \frac{M_p}{\xi} = \Lambda = \text{fixed}$

$\xi \to \infty$

So the extrapolation not too far from Λ should have a field-theoretical explanation

Simplest interpretation:

a threshold effect from a massive d.o.f. around Λ

Goal:

Invent a toy model which does four things:

1. The low-energy theory reproduces a HI scenario under extrapolation
2. It unitarizes the Goldstones at intermediate energies
3. It does not contain large ξ types
4. It is as simple as possible

1&2 was achieved some time ago by

Giudice & Lee (2011)

Introduce a new SM singlet ϕ with mass $m \lesssim \Lambda$ and couplings

$$-g\, M_P\, \phi\, R - \mu\, \phi\, |H|^2$$

so that integrating it out at tree level immediately induces terms of type

$\vert H\vert^4$	$\xi\, \vert H\vert^2 R$	R^2
SM-like threshold effect	"Higgs-inflation" operator	"Starobinsky-inflation" operator

$$\xi = g\,\frac{\mu\, M_P}{m^2}$$

Picking parameters

$g = O(1)$ $\qquad$ $M_{Higgs} << m \sim \mu \sim \Lambda << M_P$

$$\lambda = \lambda_{low} = \lambda_{high} - \mu^2/2m^2 << \lambda_{high} = \lambda'$$

makes the low-energy model

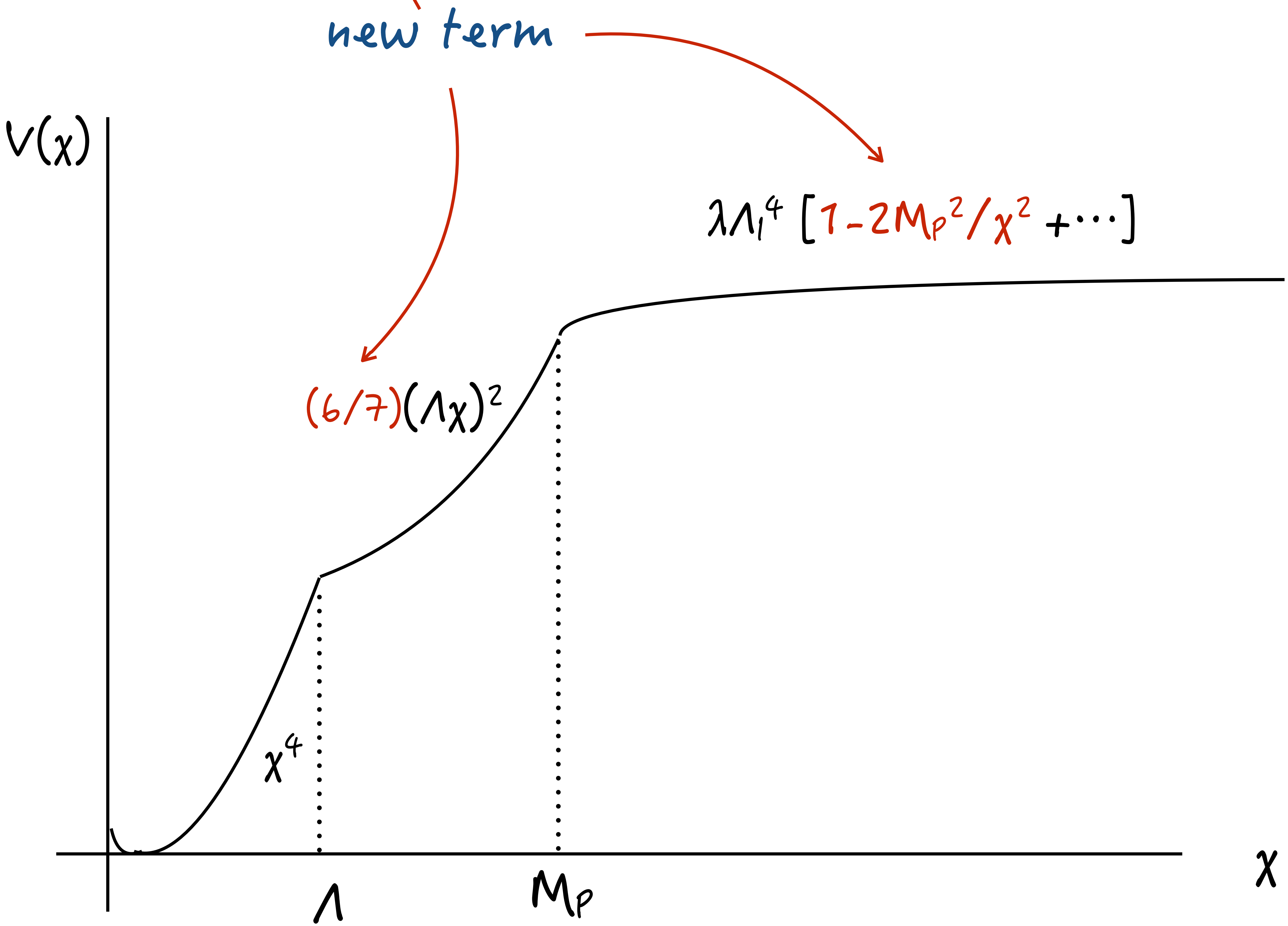
$$\mathcal{L}_h = \frac{1}{2}\left(1 + \xi^2 \frac{h^2}{M_p^2}\right)(\partial h)^2 - \frac{\lambda}{4} h^4 - \frac{1}{2}\left(M_p^2 + \xi h^2\right) R + \cdots$$

satisfying 1 to 4 above

$$\mathcal{L}_h = \frac{1}{2}\left(1 + \xi^2 \frac{h^2}{M_p^2}\right)(\partial h)^2 - \frac{\lambda}{4} h^4 - \frac{1}{2}\left(M_p^2 + \xi h^2\right) R + \cdots$$

new term

$$\mathcal{L}_h = \frac{1}{2}\left(1+\xi^2\frac{h^2}{M_p^2}\right)(\partial h)^2 - \frac{\lambda}{4}h^4 - \frac{1}{2}\left(M_p^2+\xi h^2\right)\mathcal{R} + \cdots$$



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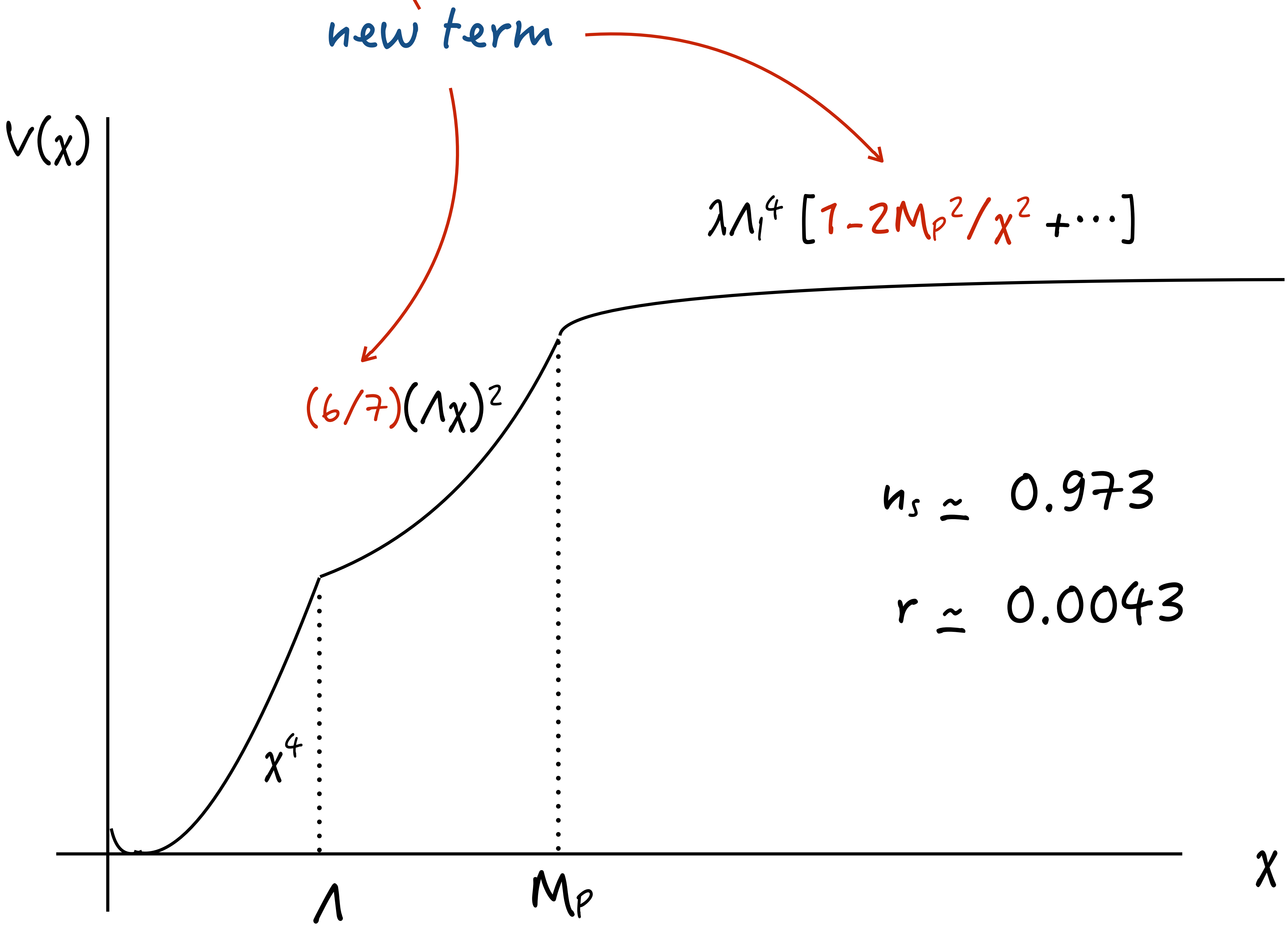
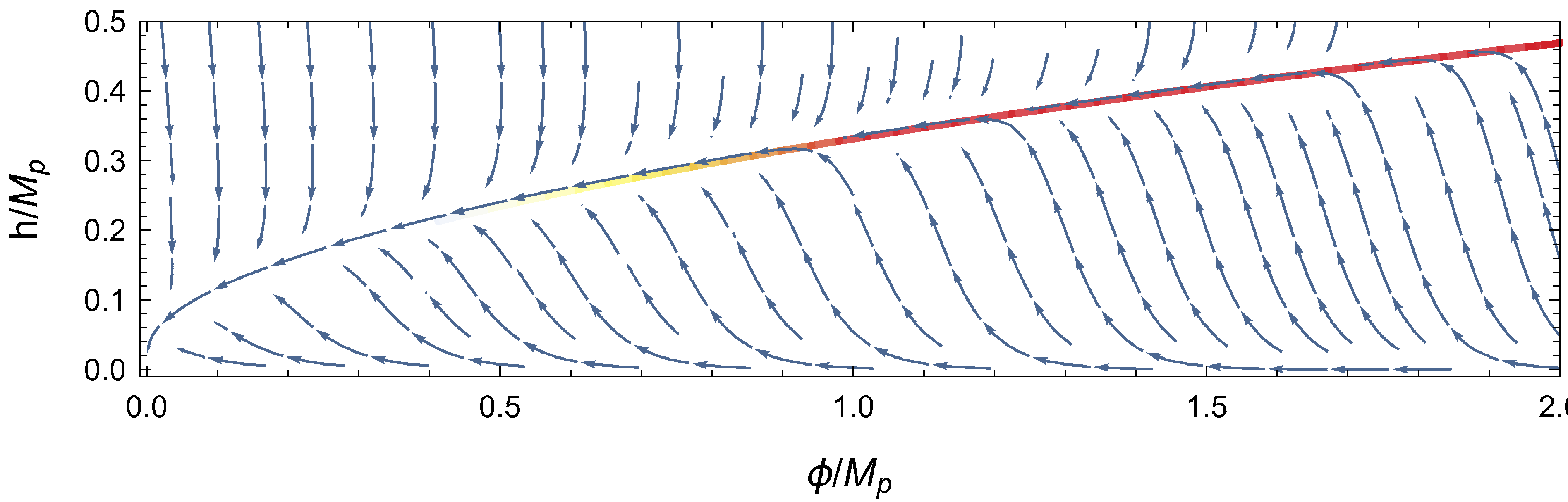


The plateau in the E-frame two-field model

$$\mathcal{L}_{h,\phi} = \frac{1}{2}\sum_{ij=h,\phi} G_{ij}\,\partial\Phi_i\,\partial\Phi_j - V(h,\phi)$$



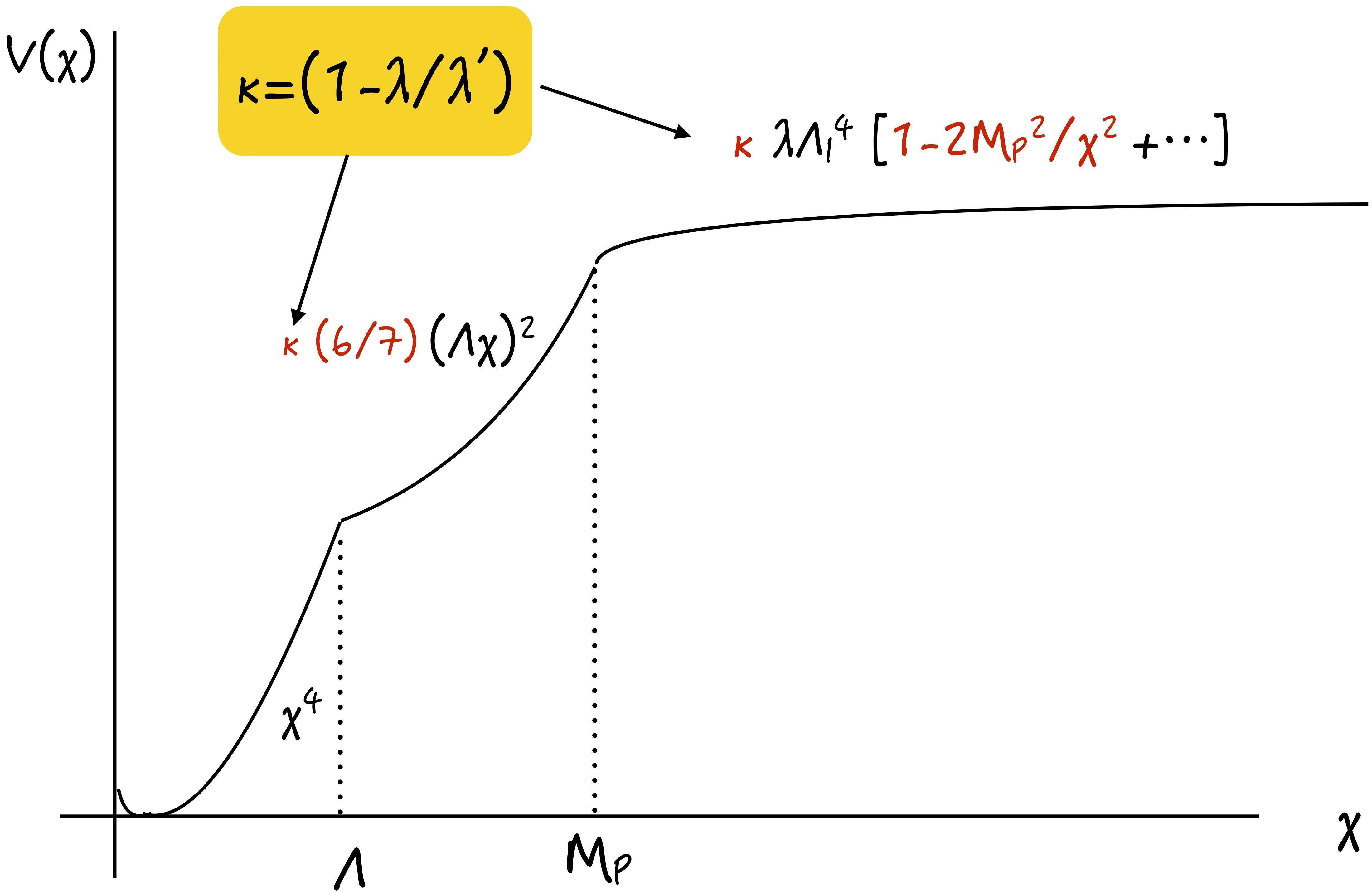
comes in at a lower height than the extrapolated model

by a factor of $\kappa = (1 - \lambda/\lambda')$

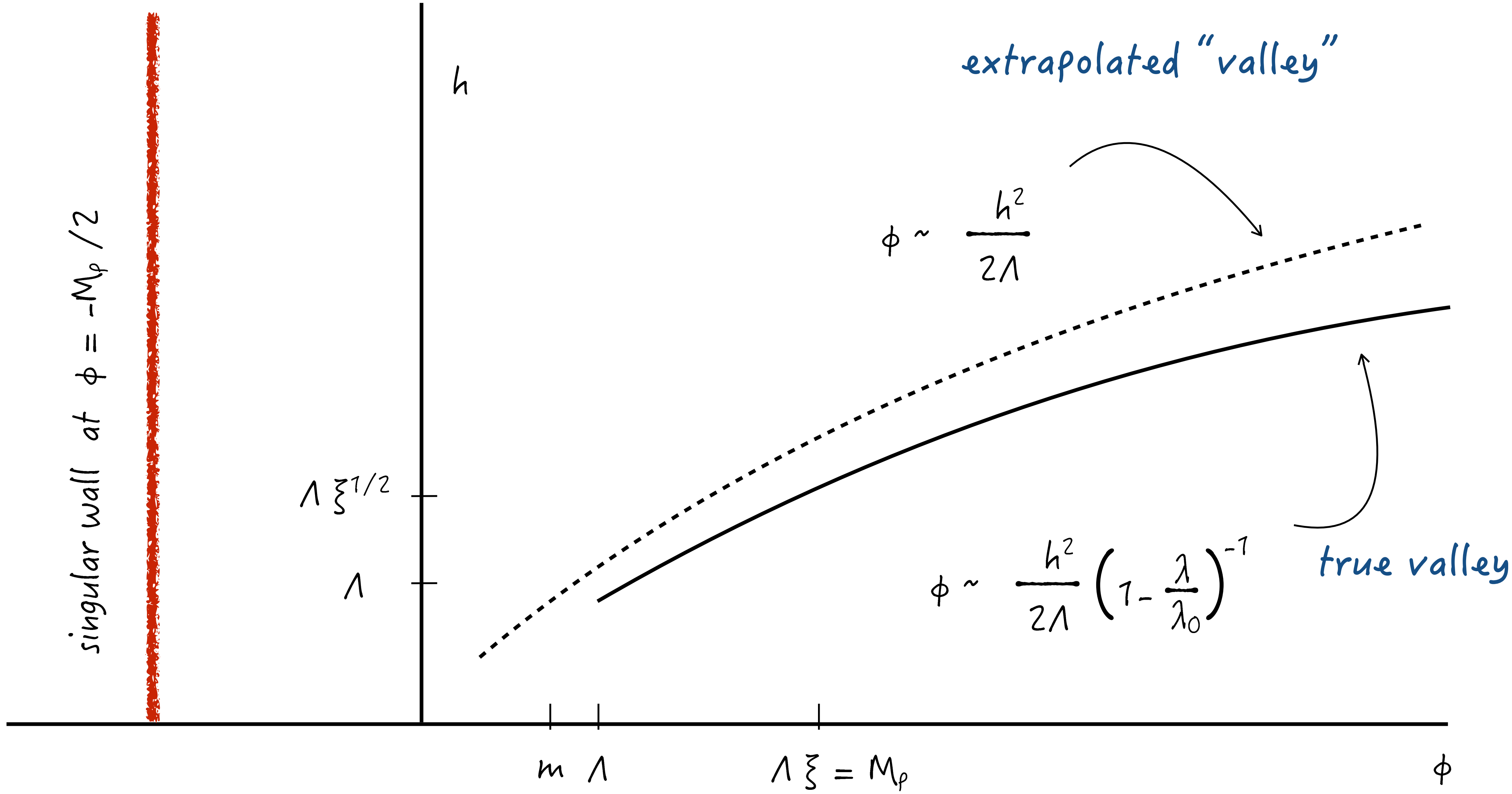
but has the SAME slow-roll parameters

In the intermediate region h is heavier than ϕ

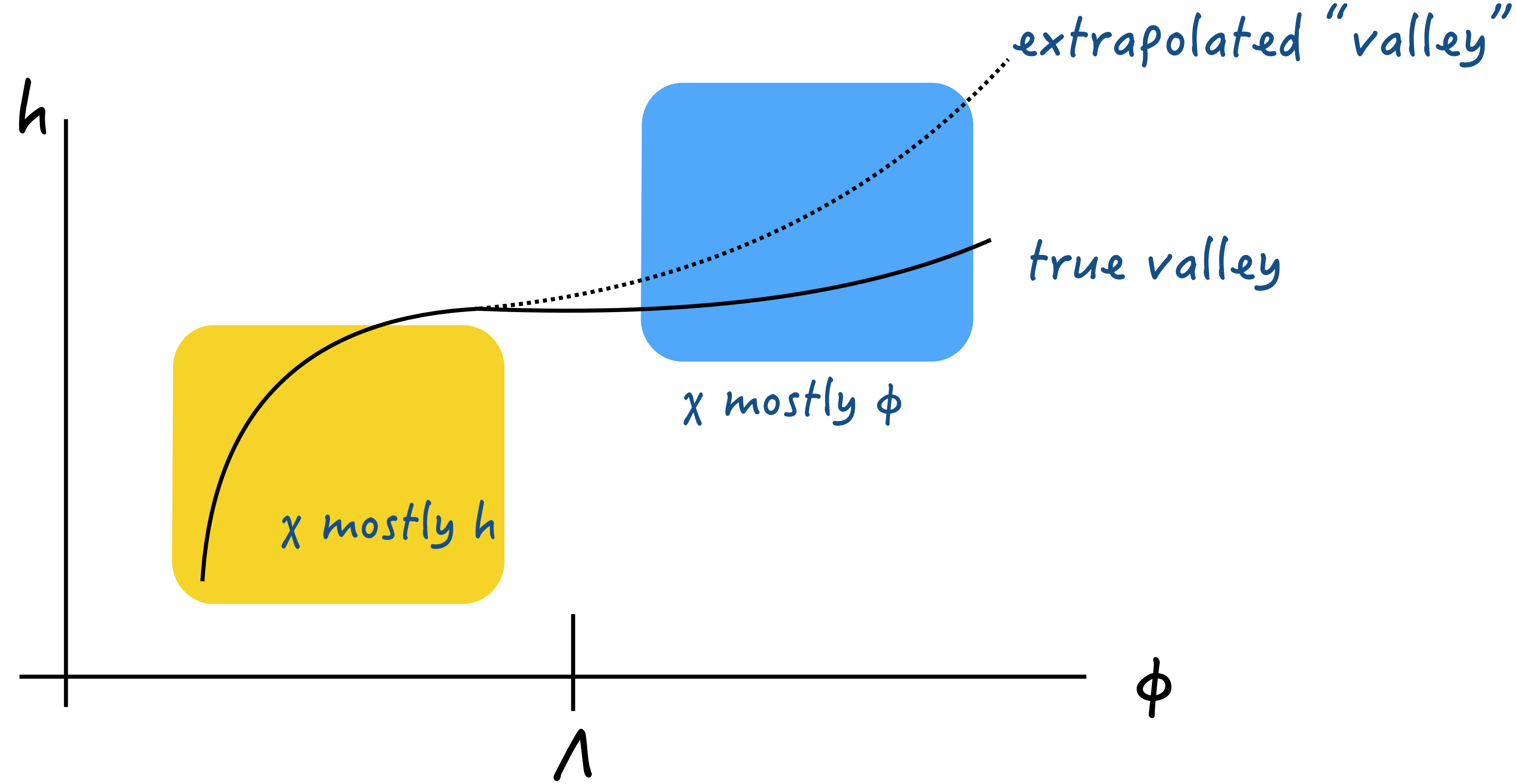
So the natural single-field projection beyond Λ involves $\chi \sim \phi$



Map of the two-field configuration space



The extrapolation is a "mirage"

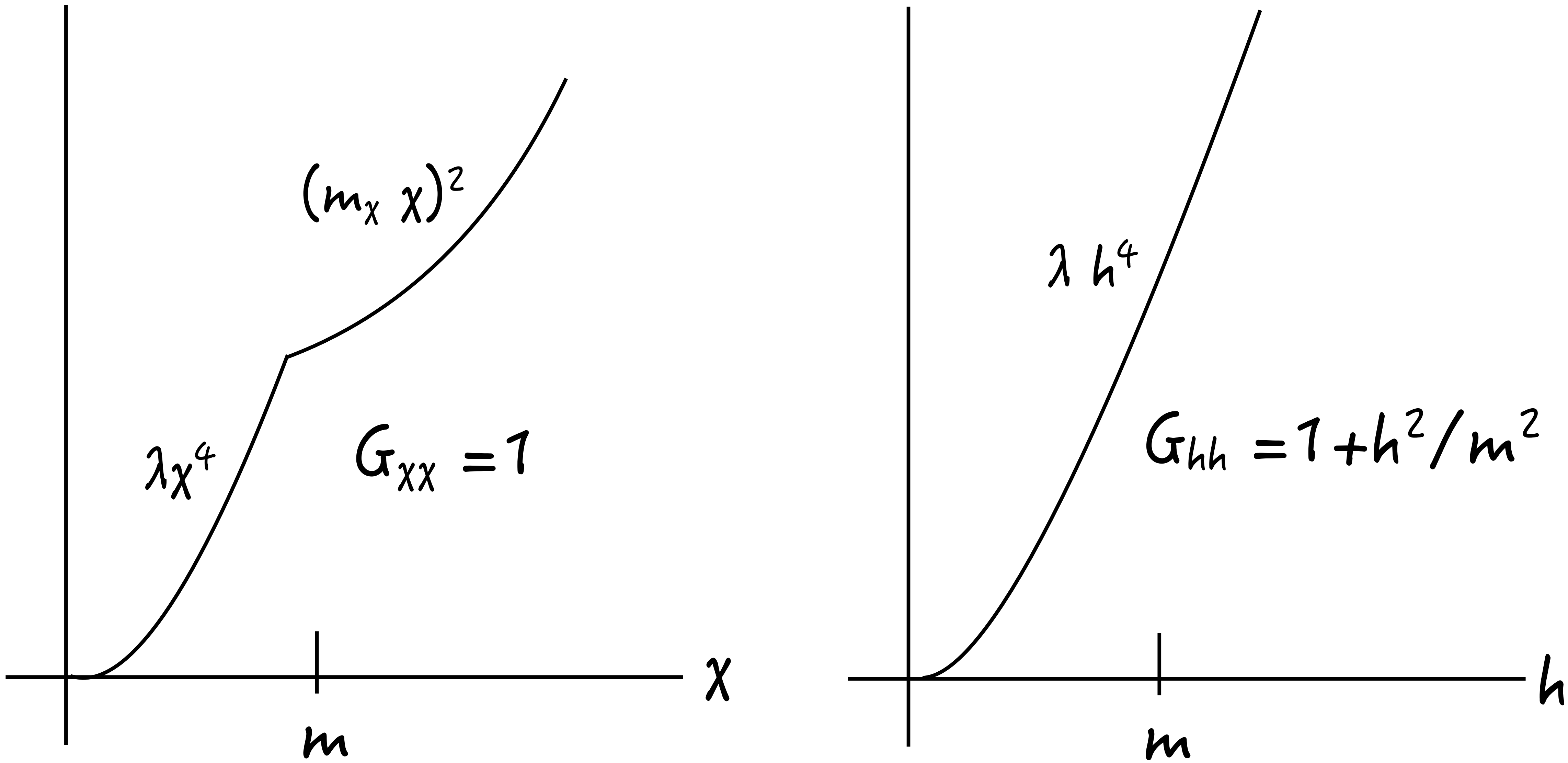


1-submanifold ⟷ single-field model up to two derivatives

Different sumanifolds correspond to different effective operators when projected onto the **h** axis

Going beyond two derivatives we could "sniff-out" the right valley

Go back to the "kink" model



The h-model, extrapolated beyond m, is given by the χ-model

$$m_\chi^2 = 2\lambda m^2$$

But we can start from the two-field model

$$\mathcal{L}_{h,\phi} = \frac{1}{2}(\partial h)^2 + \frac{1}{2}(\partial \phi)^2 - \frac{1}{2}m^2\phi^2 + \frac{1}{2}m\,\phi\,h^2 - \frac{\lambda'}{4}h^4$$

which reproduces the previous model below the scale m, integrating out ϕ in the two-derivative approximation

At large fields, this model has a quadratic valley along the submanifold

$$\phi(h) \approx \lambda' h^2/m$$

with effective mass

$$\tilde{m}^2 = m_\chi^2\left(1 - \frac{\lambda}{\lambda'}\right)$$

If we now pick all higher derivatives

$$\mathcal{L}_{exact} = \frac{1}{2}(\partial h)^2 + \frac{m^2}{8} h^2 \frac{1}{m^2+\Box} h^2 - \frac{\lambda'}{4} h^4$$

and keep the leading correction

$$\frac{1}{8m^4} h^2 \Box^2 h^2$$

we can evaluate the effect of this operator on a classical solution of the extrapolated Lagrangian

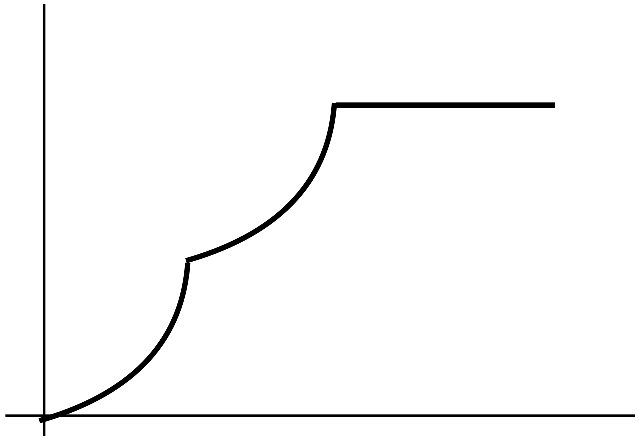
$$\Box \chi_c = - m_\chi^2 \chi_c$$

Resulting in the right shift of the effective mass

$$m_\chi^2 \longrightarrow m_\chi^2 \left(1 - \frac{\lambda}{\lambda'} + \cdots\right) = \tilde{m}^2 + O(\lambda^2)$$

CONCLUSION

The fact that the HI potential has intricate structure



suggests that it should be interpreted as the result of forcing a single-field projection on a Landscape-like potential