Gravity and Stability of the EW vacuum

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References :

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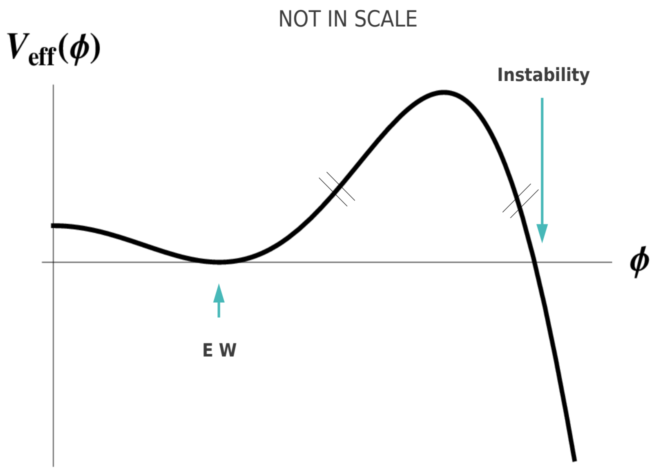
Top loop-corrections to the Higgs Effective Potential

destabilize the electroweak vacuum...

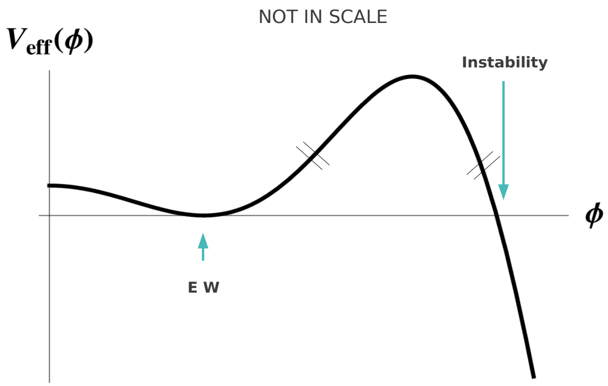


EW Scale $= v \sim 246$ GeV

For $M_H \sim 125$ GeV , $M_t \sim 173$ GeV :

Instability Scale $\sim 10^{11}$ GeV

Higgs One-Loop Effective Potential $V^{1l}(\phi)$

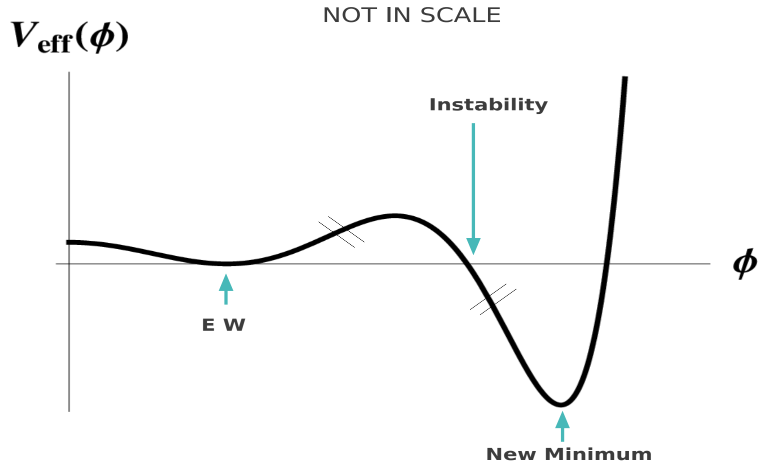


$$V^{1l}(\phi) = \frac{1}{2}m^2\phi^2 + \frac{\lambda}{24}\phi^4 + \frac{1}{64\pi^2}\left[\left(m^2+\frac{\lambda}{2}\phi^2\right)^2\left(\ln\left(\frac{m^2+\frac{\lambda}{2}\phi^2}{\mu^2}\right)-\frac{3}{2}\right)\right.$$

$$+3\left(m^2+\frac{\lambda}{6}\phi^2\right)^2\left(\ln\left(\frac{m^2+\frac{\lambda}{6}\phi^2}{\mu^2}\right)-\frac{3}{2}\right)+6\,\frac{{g_1}^4}{16}\phi^4\left(\ln\left(\frac{\frac{1}{4}{g_1}^2\phi^2}{\mu^2}\right)-\frac{5}{6}\right)$$

$$\left.+3\,\frac{\left({g_1}^2+{g_2}^2\right)^2}{16}\phi^4\left(\ln\left(\frac{\frac{1}{4}\left({g_1}^2+{g_2}^2\right)\phi^2}{\mu^2}\right)-\frac{5}{6}\right)-12\,h_t^4\phi^4\left(\ln\frac{g^2\phi^2}{\mu^2}-\frac{3}{2}\right)\right]$$

RG Improved Effective Potential $V_{RGI}(\phi)$



Depending on M_H and M_t, the second minimum can be : (1) lower than the EW minimum (as in the figure) : This is the case for $M_H \sim 125$ GeV , $M_t \sim 173$ GeV ; (2) at the same level ... ; (3) higher ...

When the potential at the New Minimum is lower than the potential at the EW Minimum ... EW vacuum Metastable State $\Rightarrow$

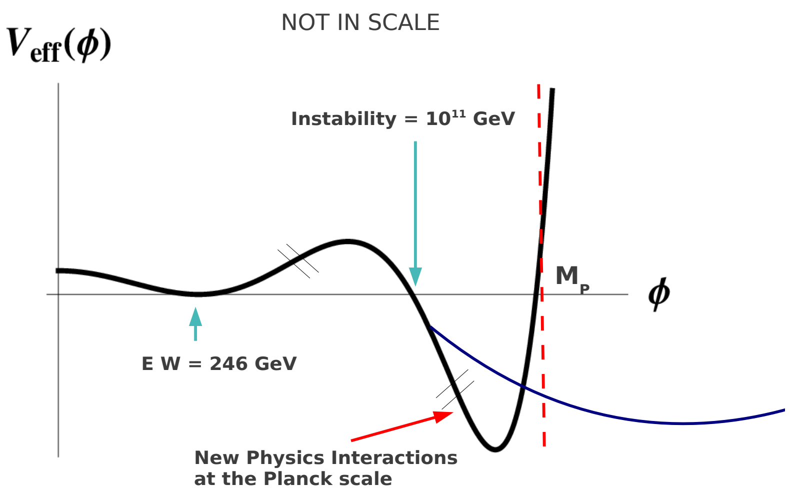
... Calculate the Tunneling Time ...

Tunneling time usually computed under the assumption

that New Physics Interactions although expected around the Planck scale do not affect the EW vacuum lifetime τ (can be neglected when computing τ). Argument:

Instability scale, $\Lambda_{inst} \sim 10^{11}$ GeV, much lower than Planck scale $\Rightarrow$

$$\Rightarrow \quad \text{suppression} \quad \left(\frac{\Lambda_{inst}}{M_P}\right)^n \quad \text{expected}$$



Flat Spacetime

Euclidean action for a single component real scalar field ϕ:

$$S[\phi] = \int d^4x \left[\frac{1}{2}(\partial_\mu \phi)^2 + V(\phi) \right]$$

$V(\phi)$ potential with (*false vacuum*) at $\phi = \phi_{\rm fv}$, and *true vacuum* at $\phi = \phi_{\rm tv}$.

Bounce Solution

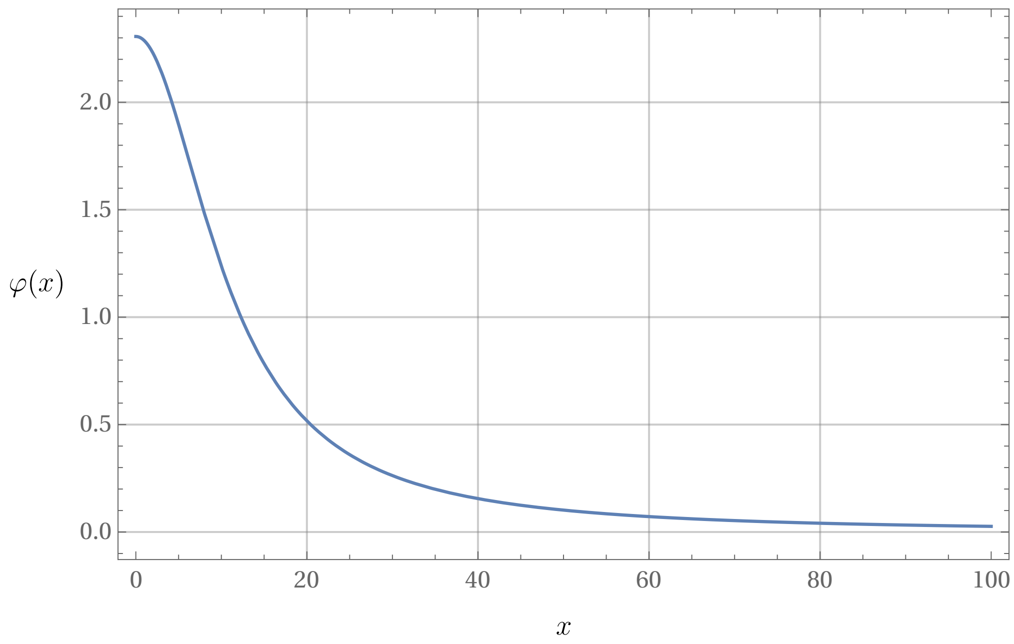
to the Euclidean Euler-Lagrange equation with $O(4)$ symmetry. If r is the radial coordinate, the equation takes the form (**bounce equation**):

$$\ddot{\phi}(r) + \frac{3}{r}\dot{\phi}(r) = \frac{dV}{d\phi}\,,$$

where the dot indicates derivative with respect to r, and the boundary condition are:

$$\phi(\infty) = 0 \qquad \dot{\phi}(0) = 0\,.$$

Bounce Solution



Decay rate Γ (of the false vacuum):

$$\Gamma = \frac{1}{\tau} = De^{-(S[\phi_b]-S[\phi_{\rm fv}])} \equiv D\, e^{-B}$$

$B \equiv S[\phi_b] - S[\phi_{\rm fv}]$ is the so called **Tunneling Exponent**.

The exponential of $-B$ gives the "tree-level" contribution to the decay rate.

If $V(\phi_{\rm fv}) = 0$, $S[\phi_{\rm fv}]$ vanishes, and the tunneling exponent is simply $B = S[\phi_b]$.

D is the quantum fluctuation determinant.

Size $\mathcal{R}$ of the bounce. Defined as the value of r such that:

$$\phi_b(\mathcal{R}) = \frac{1}{2}\phi_b(0)$$

Good approximation to the prefactor: in terms of the bounce size $\mathcal{R}$ and of T_U, the age of the Universe. The EW vacuum tunneling time $\tau = \Gamma^{-1}$ turns out to be:

$$\tau \simeq \left(\frac{\mathcal{R}^4}{T_U^3}\right) e^B$$

Curved spacetime. Including the Einstein-Hilbert term, the Euclidean action is:

$$S[\phi, g_{\mu\nu}] = \int d^4x\sqrt{g}\left[-\frac{R}{16\pi G} + \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\;\partial_\nu\phi + V(\phi)\right]$$

where R is the Ricci scalar and G is the Newton constant. Requiring again $O(4)$ symmetry, the (Euclidean) metric takes the form:

$$ds^2 = dr^2 + \rho^2(r)d\Omega_3^2$$

where $d\Omega_3^2$ is the unit 3-sphere line element and $\rho(r)$ is the volume radius of the 3-sphere at fixed r coordinate. The **bounce** is now given by $\phi_b(r)$ and $\rho_b(r)$, solutions of the coupled equations: $(\kappa \equiv 8\pi G)$:

$$\ddot{\phi} + 3\,\frac{\dot{\rho}}{\rho}\,\dot{\phi} = \frac{dV}{d\phi} \qquad \dot{\rho}^2 = 1 + \frac{\kappa\rho^2}{3}\left(\frac{1}{2}\dot{\phi}^2 - V(\phi)\right)$$

The first equation replaces the equivalent equation in the flat spacetime background, while the second is the only Einstein equation left by the symmetry. For the decay of a Minkowski false vacuum to a true AdS vacuum, the case of interest to us, the boundary conditions are:

$$\phi_b(\infty) = 0 \qquad \dot{\phi}_b(0) = 0 \qquad \rho_b(0) = 0\,.$$

Renormalization Group Improved Higgs Effective Potential

ϕ is the Higgs field and $V(\phi)$ is the Higgs renormalization group improved potential:

$$V_{\rm SM}(\phi) \sim \frac{1}{4}\lambda_{\rm SM}(\phi)\phi^4 \,,$$

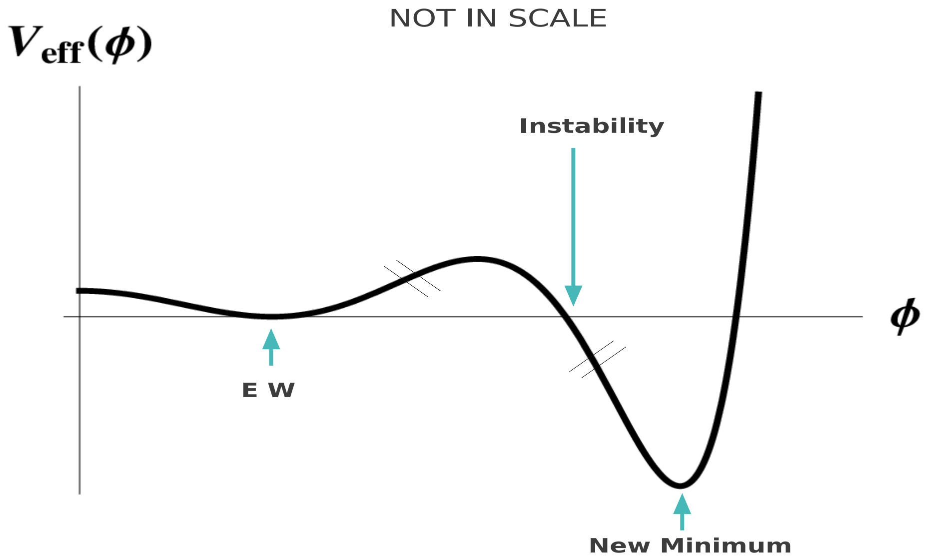
where $\lambda_{\rm SM}(\phi)$ is the running coupling $\lambda_{\rm SM}(\mu)$ with $\mu = \phi$, obtained by running the system of RG equation of the SM couplings.

Flat Spacetime case

$$\tau_{\rm flat} \sim 10^{639} T_U$$

Obtained with $M_H \sim 125$ **GeV,** $M_t \sim 173$ **GeV**

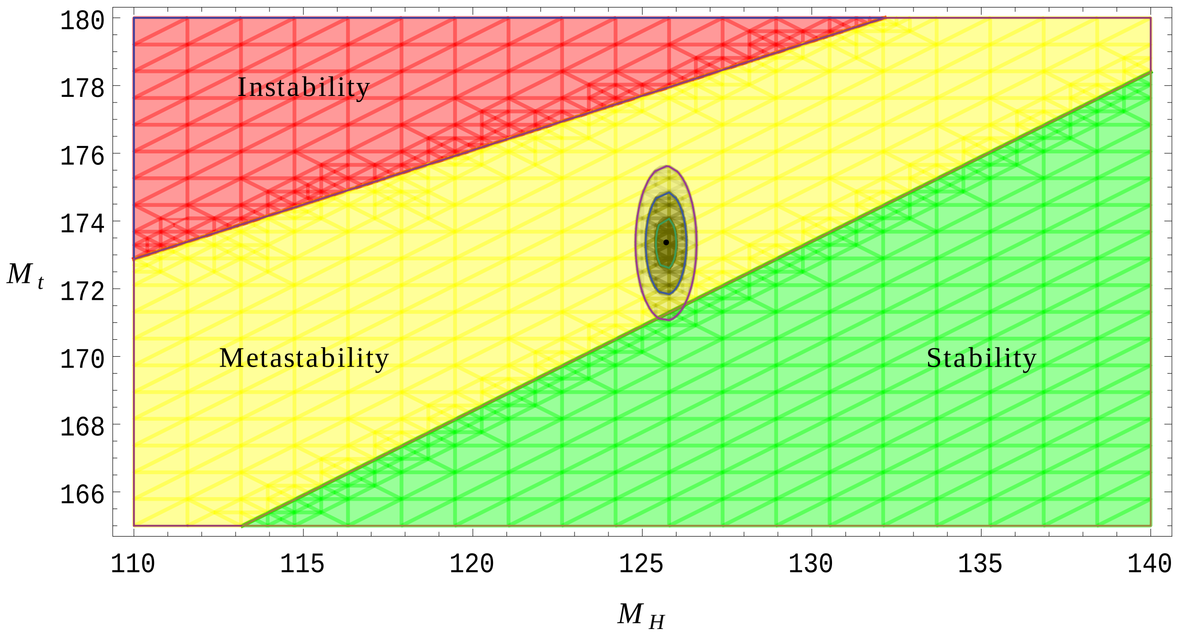
More Generally we can explore the M_H, M_t parameter space



Depending on M_H and M_t , the second minimum can be : (1) lower than the EW minimum (as in the figure) : This is the case for $M_H \sim 125$ GeV , $M_t \sim 173$ GeV ; (2) at the same level ... ; (3) higher ...

Considering these different cases, we can draw the Stability Diagram

Stability Diagram in the $M_H - M_t$ plane



Stability region : $V_{eff}(v) < V_{eff}(\phi^{(2)}_{min})$.

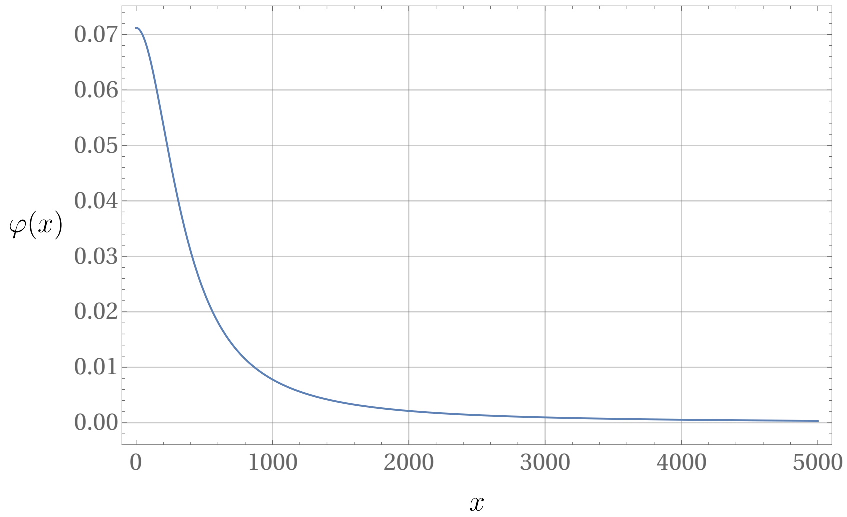
Meta-stability region : $V_{eff}(\phi^{(2)}_{min}) < V_{eff}(v)$ and $\tau > T_U$.

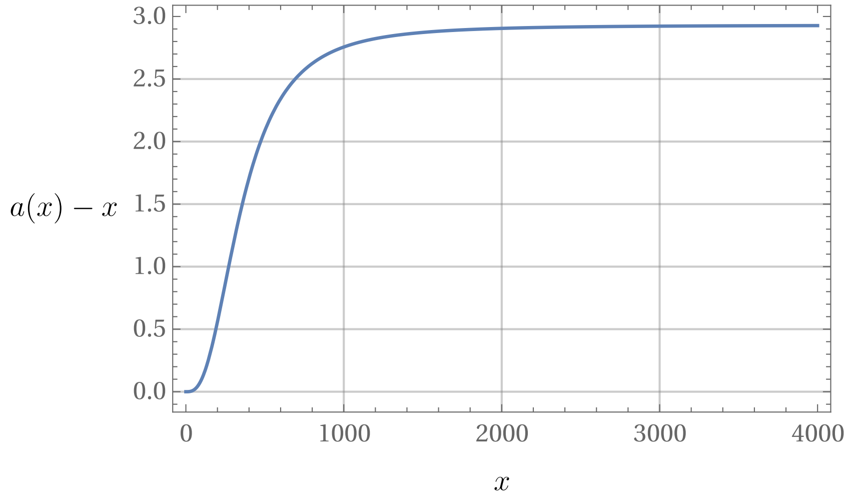
Instability region : $V_{eff}(\phi^{(2)}_{min}) < V_{eff}(v)$ and $\tau < T_U$.

Stability line : $V_{eff}(v) = V_{eff}(\phi^{(2)}_{min})$.

Instability line : M_H and M_t such that $\tau = T_U$.

Curved Spacetime case



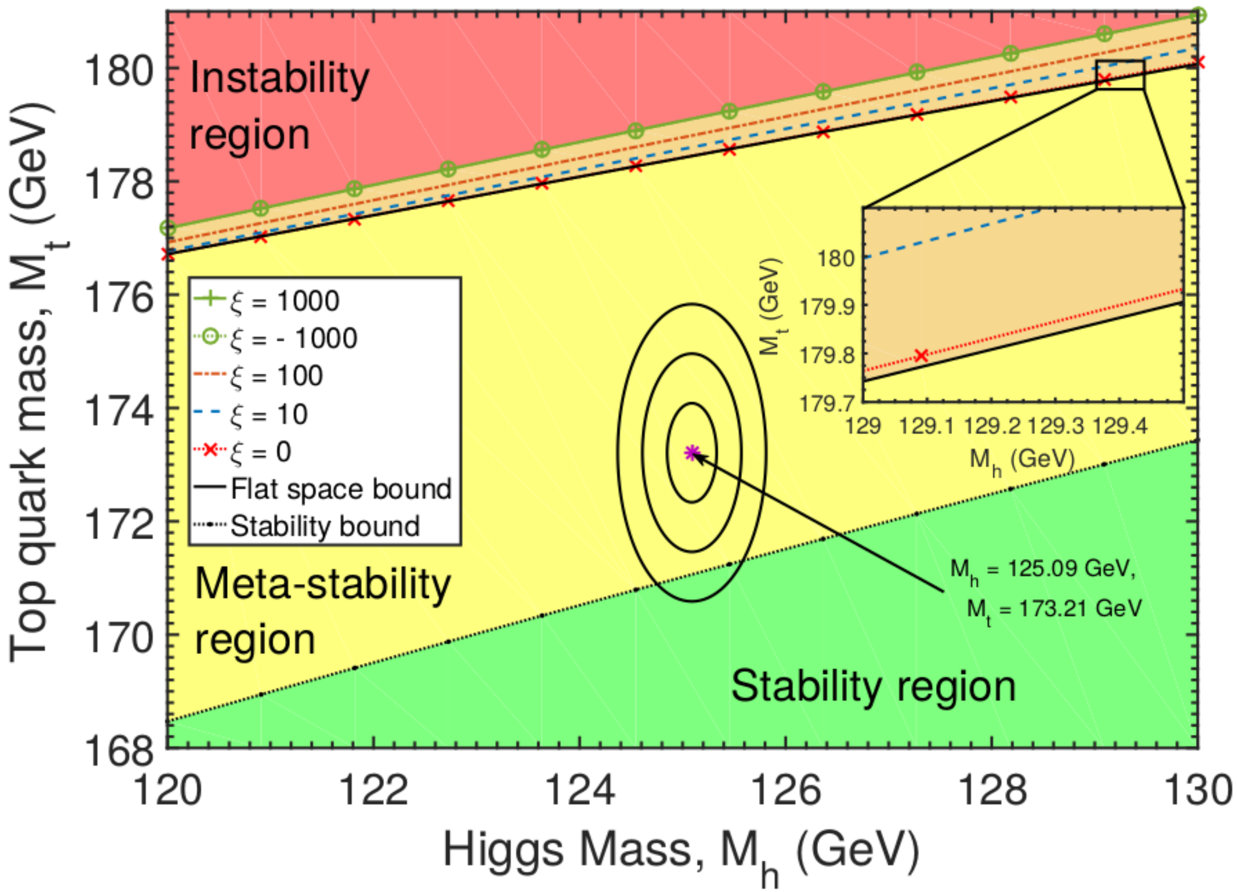


Profile of the bounce $\varphi_b(x)$ in the presence of gravity and of the difference between the curvature radius and its asymptotic value, $a_b(x) - x$.

Asymptotically $a_b(x)$ reaches the Minkowskian $a_M(x) \sim x + Const.$

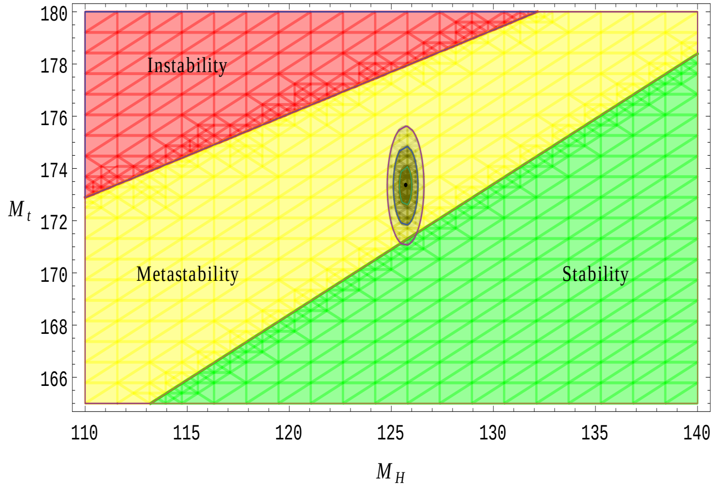
$$\tau_{\rm grav} \sim 10^{661}\, T_U$$

Stability Diagram with and without gravity



Rajantie et al.

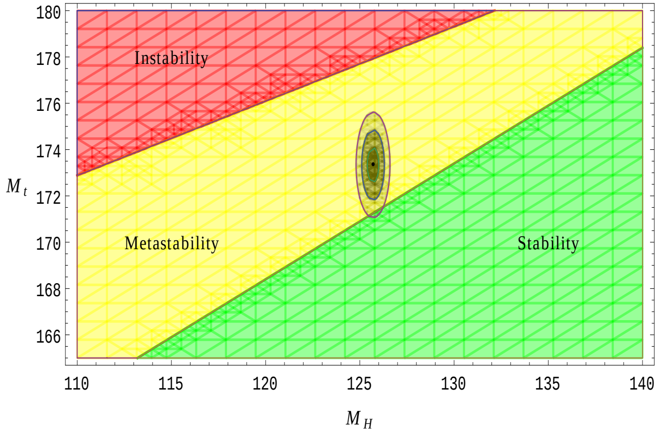
Summary up to now ...



- It was argued that even if at the **Planck scale** (or at some other **very high energy scale**) **New Physics** is expected, the latter has **no influence** on the **Stability Diagram**.
- Accordingly, the **Tunnelling Time** for the **experimental values**, $M_H \sim 125$ GeV, $M_t \sim 173$ GeV :

$$\tau_{flat} \sim 10^{639}\, T_U \qquad \tau_{grav} \sim 10^{661}\, T_U$$

... However ... it has been shown that ...



contrary to this expectation, the Stability Diagram above is not universal: even if New Physics shows up only at very high energies, the Stability Diagram depends on it ...

VB, E. Messina, *Phys.Rev.Lett.111, 241801 (2013)*;

VB, E. Messina, A. Platania, *JHEP 1409 (2014) 182*;

VB, E. Messina, M. Sher, *Phys.Rev.D91 (2015) 1, 013003*;

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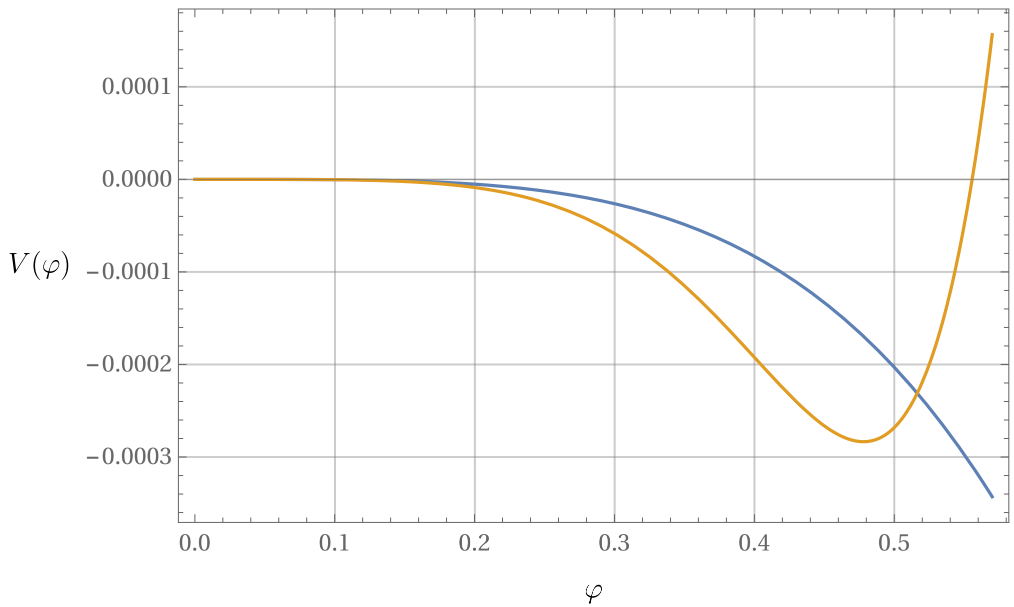
E. Bentivegna, VB, F. Contino, D. Zappalà, *Impact of New Physics on the EW vacuum stability in a curved spacetime background*, (arXiv:1708.01138), to be published in JHEP.

... **and in fact ...**

Let's add New Physics around M_P

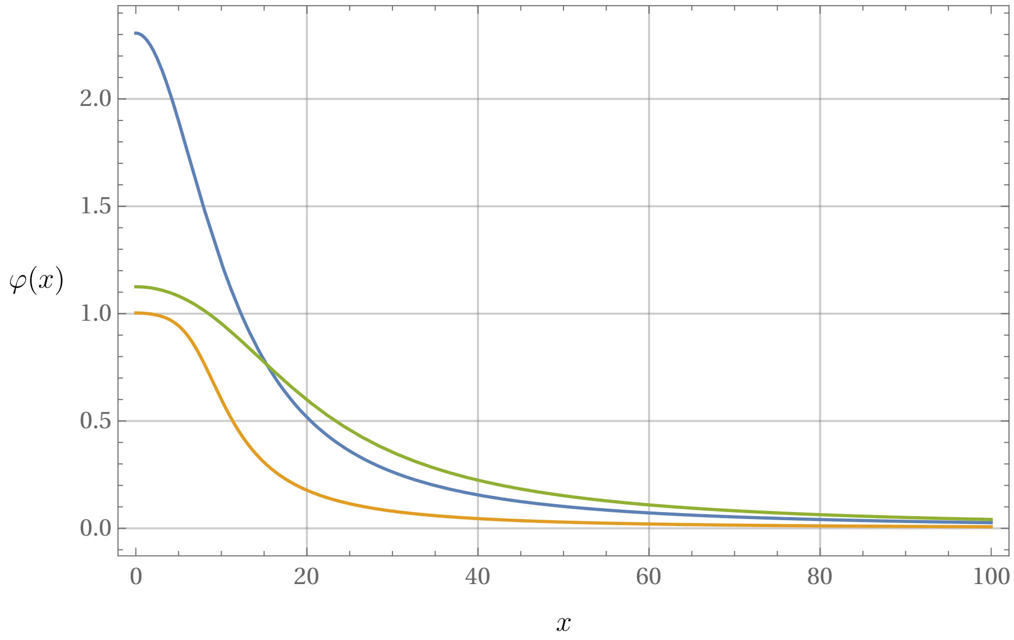
One way of parametrizing New Physics around M_P :

$$V(\phi) \;=\; \frac{\lambda(\phi)}{4}\phi^4 + \frac{\lambda_6}{6}\frac{\phi^6}{M_P^2} + \frac{\lambda_8}{8}\frac{\phi^8}{M_P^4}$$



Potential obtained with $\lambda_6 = -0.4$ and $\lambda_8 = 2$.

Bounce profiles in the Flat Spacetime background



The blue curve is the profile of the bounce solution obtained for the potential with $\lambda_6 = 0$ and $\lambda_8 = 0$, i.e. in the absence of new physics. The yellow curve is the profile of the bounce solution for $\lambda_6 = -0.3$ and $\lambda_8 = 0.3$, while the **green curve** is the profile of the bounce obtained for $\lambda_6 = -0.01$ and $\lambda_8 = 0.01$.

Tunneling times for different values of λ_6 and λ_8

λ_6	λ_8	$\tau_{\rm flat}/T_U$
0	0	10^{639}
-0.05	0.1	10^{446}
-0.1	0.2	10^{317}
-0.3	0.3	10^{-52}
-0.45	0.5	10^{-93}
-0.7	0.6	10^{-162}
-1.2	1.0	10^{-195}
-2.0	2.1	10^{-206}

Remember : $\tau \sim e^{S[\phi_b]}$

New bounce $\phi_b^{(new)}(r)$, New action $S[\phi_b^{(new)}]$, New τ

These results were however challenged

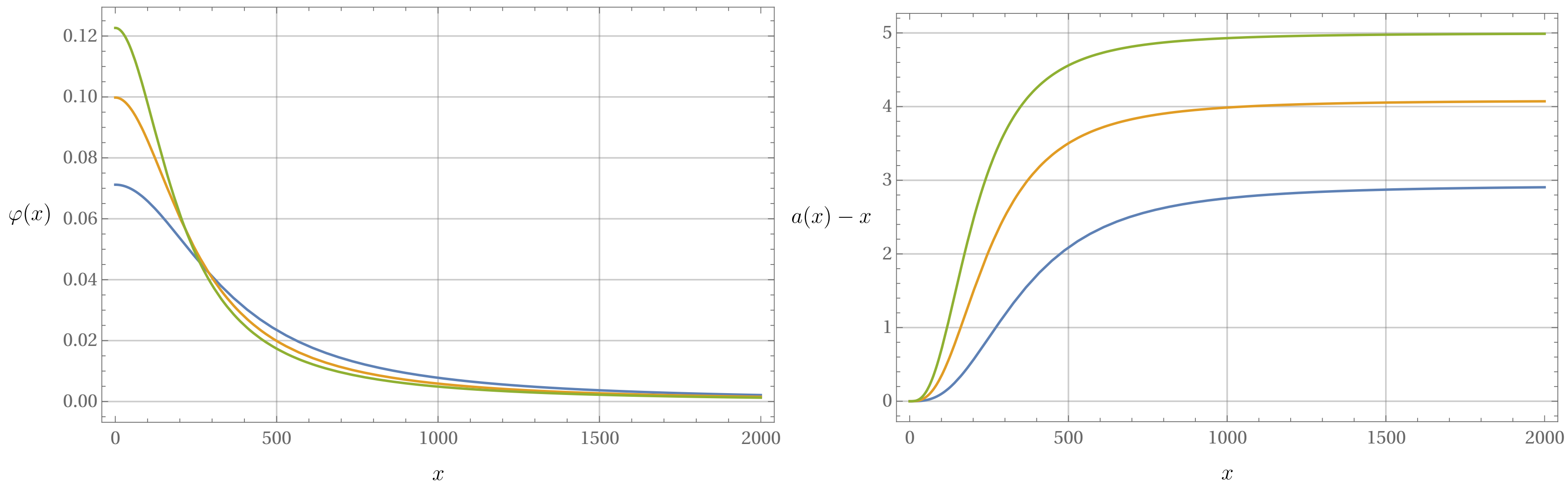
The two following points were raised

- Point 1 -

Flat Spacetime background → Curved Spacetime background

It was argued that when the presence of gravity is taken into account, the decay rate induced by the new bounce solutions presented above is suppressed.

Bounce profiles obtained in the presence of Gravity



Left Panel. - Blue curve: profile of the bounce solution with $\lambda_6 = 0$ and $\lambda_8 = 0$, i.e. in the absence of new physics. Yellow curve: profile of the bounce solution for $\lambda_6 = -0.03$ and $\lambda_8 = 0.03$. Green curve: profile of the bounce solution for $\lambda_6 = -0.04$ and $\lambda_8 = 0.04$.

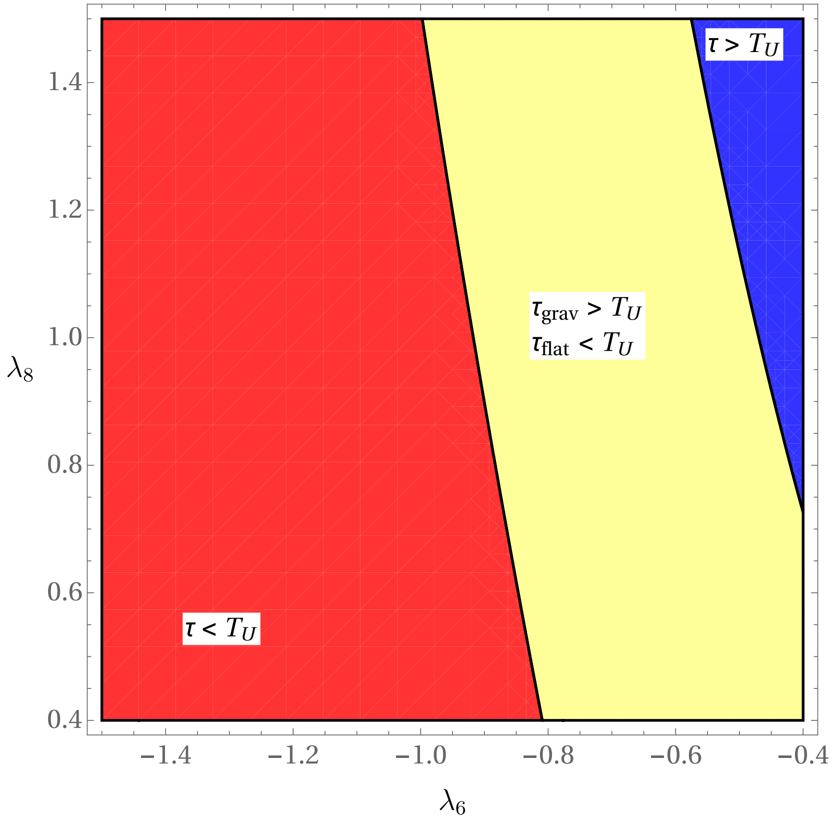
Right Panel: Profile of the difference between the curvature radius and its asymptotic value, $a(x) - x$.

Tunneling times for different values of λ_6 and λ_8

λ_6	λ_8	τ_{flat}/T_U	τ_{grav}/T_U
0	0	10^{639}	10^{661}
-0.05	0.1	10^{446}	10^{653}
-0.1	0.2	10^{317}	10^{598}
-0.3	0.3	10^{-52}	10^{287}
-0.45	0.5	10^{-93}	10^{173}
-0.7	0.6	10^{-162}	10^{47}
-1.2	1.0	10^{-195}	10^{-58}
-2.0	2.1	10^{-206}	10^{-121}

It is true that Gravity tends to stabilize the EW vacuum (τ_{grav} always higher than τ_{flat}). However, New Physics has always a strong (that can be even devastating) impact.

Stability Diagram



In the blue region $\tau > T_U$ both for the flat and curved spacetime analysis. In the yellow region $\tau < T_U$ for the flat spacetime background. In the red region $\tau < T_U$ in both cases.

Non-Renormalizable New Phyisics $\rightarrow$ Renormalizable New Physics

... It was also argued that the fact that New Physics was parametrized in terms of Non-Renormalizable operators actually could invalidate these results ...

New Physics around M_P in terms of renormalizable operators

Add to the SM potential a "New Boson S" and a "New Fermion ψ" :

$$\Delta V(\phi, S, \psi) = \frac{M_S^2}{2} S^2 + \frac{\lambda_S}{4} S^4 + \frac{g_S}{4} \phi^2 S^2 + M_f \bar{\psi}\psi + \frac{g_f}{\sqrt{2}} \phi \bar{\psi}\psi$$

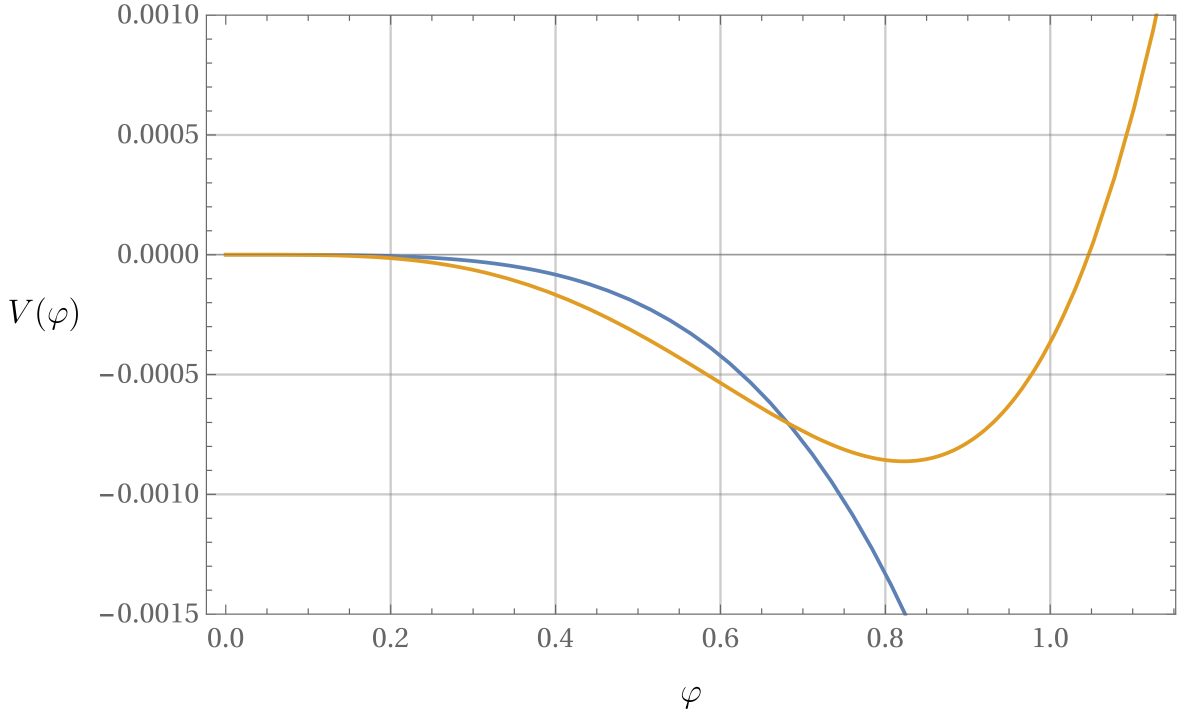
with $M_f \sim 10^{17}$ GeV and $M_S \sim 10^{18}$ GeV.

Integrating out this new scalar and fermion fields we get the

Modified Higgs Potential

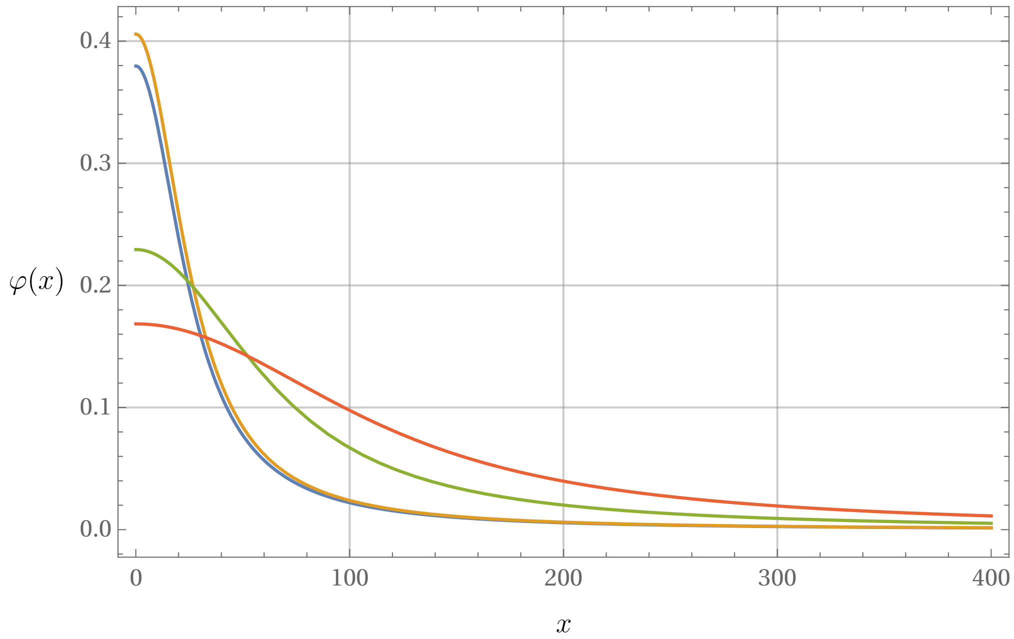
$$\begin{aligned} V(\phi) &= \frac{1}{2} m^2 \phi^2 + \frac{\lambda}{4} \phi^4 + \frac{1}{64\pi^2} \left(M_S^2 + \frac{g_S}{2} \phi^2 \right)^2 \left[\ln \left(\frac{M_S^2 + \frac{g_S}{2} \phi^2}{\mu^2} \right) - \frac{3}{2} \right] \\ &- \frac{1}{16\pi^2} \left(M_f^2 + \frac{g_f^2}{2} \phi^2 \right)^2 \left[\ln \left(\frac{M_f^2 + \frac{g_f^2}{2} \phi^2}{\mu^2} \right) - \frac{3}{2} \right] \end{aligned}$$

Modifided potential (yellow) against SM potential (blue)



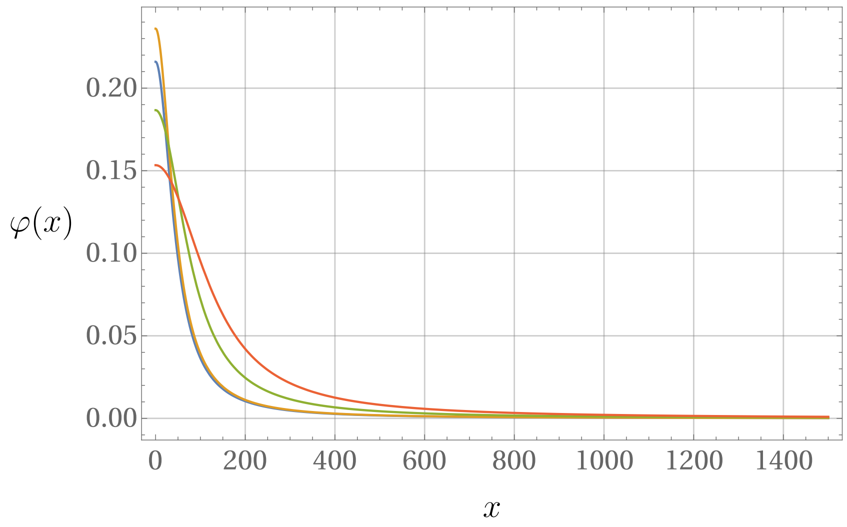
The values of the parameter are: $M_S = 2.0 \times 10^{-1} M_P$, $M_f = 10^{-3} M_P$, $g_S = 0.95$, $g_f^2 = 0.4$.

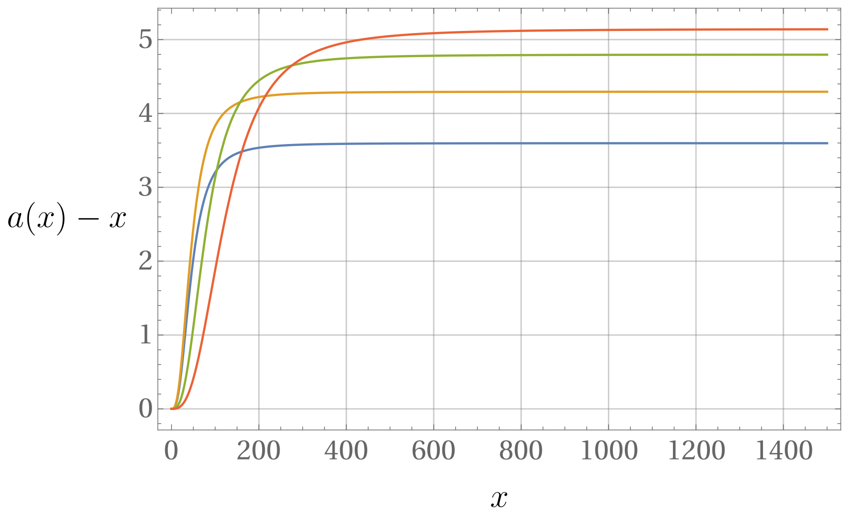
Bounce profiles for the Flat Spacetime Case



Profile of the bounce solutions $\varphi(x)$ relative to the four cases: $M_S = 2.5 \times 10^{-1}$, $M_f = 3 \times 10^{-4}$, $g_S = 0.96$, $g_f^2 = 0.5$ (yellow) ; $M_S = 2.0 \times 10^{-1}$, $M_f = 10^{-4}$, $g_S = 0.9$, $g_f^2 = 0.5$ (blue); $M_S = 2.0 \times 10^{-1}$, $M_f = 10^{-3}$, $g_S = 0.95$, $g_f^2 = 0.4$ (green); $M_S = 1.5 \times 10^{-1}$, $M_f = 5 \times 10^{-3}$, $g_S = 0.92$, $g_f^2 = 0.4$ (red).

Bounce profiles for the Curved Spacetime Case





Left panel: Profile of the bounce solutions $\varphi(x)$ relative to the four cases: $M_S = 2.5 \times 10^{-1}$, $M_f = 3 \times 10^{-4}$, $g_S = 0.96$, $g_f^2 = 0.5$ (yellow) ; $M_S = 2.0 \times 10^{-1}$, $M_f = 10^{-4}$, $g_S = 0.9$, $g_f^2 = 0.5$ (blue); $M_S = 2.0 \times 10^{-1}$, $M_f = 10^{-3}$, $g_S = 0.95$, $g_f^2 = 0.4$ (green); $M_S = 1.5 \times 10^{-1}$, $M_f = 5 \times 10^{-3}$, $g_S = 0.92$, $g_f^2 = 0.4$ (red).

Right panel: difference between the curvature radius and its asymptotic value, $a(x) - x$, for the same parameters as in the left panel.

Tunneling times for different values of the parameters

M_S	M_f	g_S	g_f^2	τ_{flat}/T_U	τ_{grav}/T_U
0	0	0	0	10^{639}	10^{661}
$1.5 \times 10^{-1} M_P$	$5 \times 10^{-3} M_P$	0.92	0.4	10^{293}	10^{307}
$2.0 \times 10^{-1} M_P$	$10^{-3} M_P$	0.95	0.4	10^{80}	10^{94}
$2.5 \times 10^{-1} M_P$	$3 \times 10^{-4} M_P$	0.96	0.5	10^{-80}	10^{-65}
$2.0 \times 10^{-1} M_P$	$10^{-4} M_P$	0.9	0.5	10^{-103}	10^{-93}

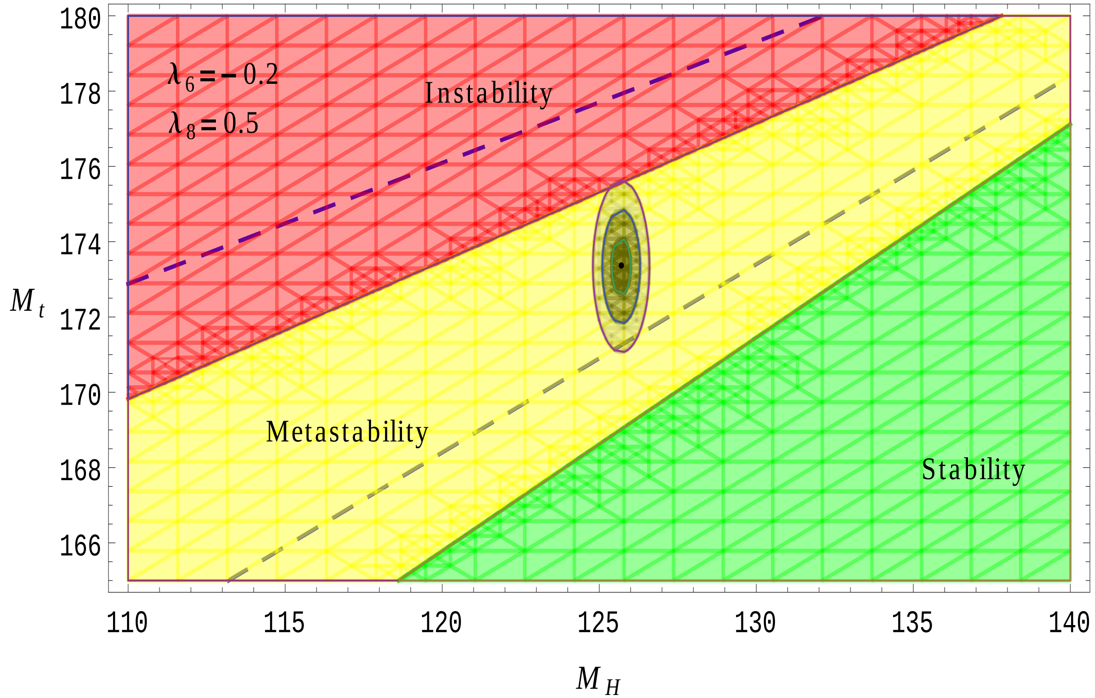
As for the case of the parametrization of New Phyiscs with

$$V_{NP}(\phi) = \frac{\lambda_6}{6}\frac{\phi^6}{M_P^2} + \frac{\lambda_8}{8}\frac{\phi^8}{M_P^4}$$

we again observe that Gravity tends to stabilize the EW vacuum (τ_{grav} always higher than τ_{flat}). However, New Physics has always a strong (that can be even devastating) impact.

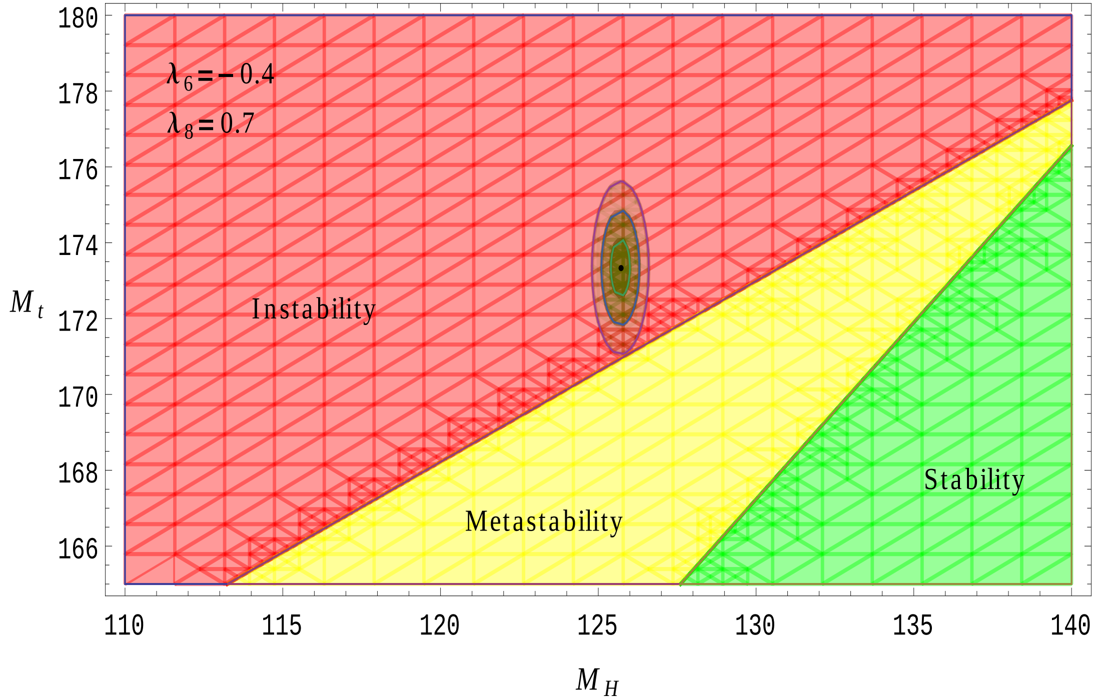
Back to the λ_6 - λ_8 parametrization

Phase diagram with $\lambda_6 = -0.2$ and $\lambda_8 = 0.5$



The strips move downwards ... The Experimental Point no longer at $3\,\sigma$ from the stability line ... Stability Diagram depends on new physics.

Phase diagram with $\lambda_6 = -0.4$ and $\lambda_8 = 0.7$



Stability Diagram depends on new physics.

As previously said ... These results came as a surprise ...

It was thought, in fact, that New Physics that lives at very high energies (Planck Mass, or GUT scale, or ...) should not have an impact in the computation of the tunnelling time and more generally in establishihg the Stability Diagram

Why is that new physics at M_P has such an impact on τ ?

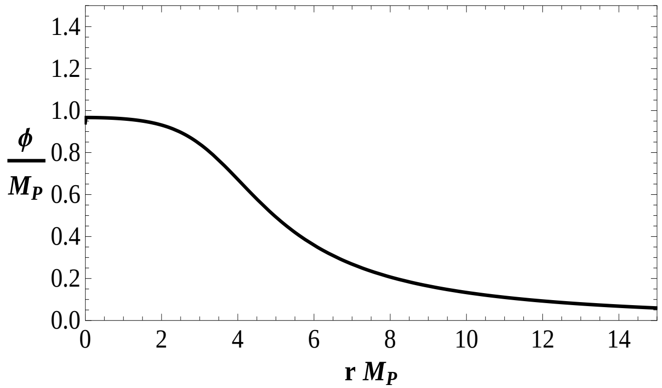
Why the decoupling arguments do not apply ?

1. New physics in terms of higher dimension operators $\frac{\phi^n}{M_P^n}$. Observing that $\Lambda_{inst} \sim 10^{11}$ GeV, a decoupling effect was expected, so that their contribution was expected to be suppressed as $(\frac{\Lambda_{inst}}{M_P})^n$. However: Tunnelling is a non-perturbative phenomenon. We first select the saddle point, i.e. compute the bounce (tree level), and then compute the quantum fluctuations (loop corrections) on the top of it.

Suppression in terms of inverse powers of M_P (power counting theorem) concerns the loop corrections, not the selection of the saddle point (tree level).

Remember : $$\tau \sim e^{S[\phi_b]}$$

New bounce $\phi_b^{(new)}(r)$, New action $S[\phi_b^{(new)}]$, New τ



Non-minimal coupling to gravity

Curved Spacetime. Non-minimal coupling

$$S[\phi] = \int d^4x\sqrt{g}\left[-\frac{R}{2\kappa} + \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\;\partial_\nu\phi + V(\phi) + \frac{1}{2}\xi\phi^2 R\right]$$

Again $O(4)$ symmetry:

$$\ddot{\phi} + 3\;\frac{\dot{\rho}}{\rho}\;\dot{\phi} = \frac{dV}{d\phi} + \xi\phi R \qquad \dot{\rho}^2 = 1 - \frac{\kappa}{3}\rho^2\;\frac{-\frac{1}{2}\dot{\phi}^2 + V(\phi) - 6\xi\frac{\dot{\rho}}{\rho}\phi\dot{\phi}}{1-\kappa\xi\phi^2}\,,$$

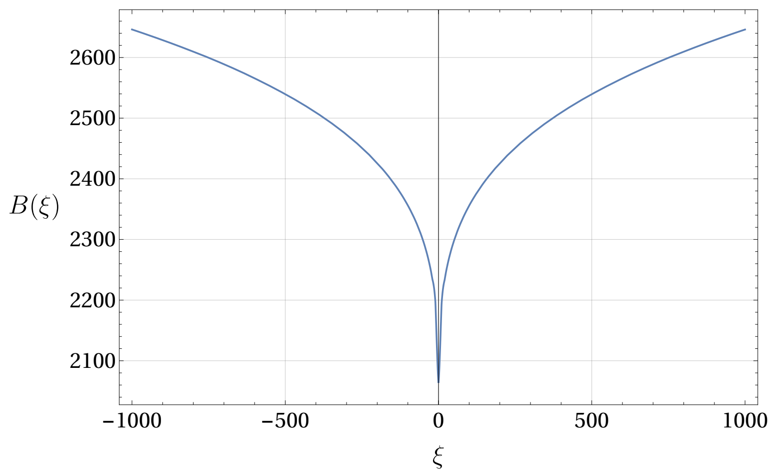
with R given by:

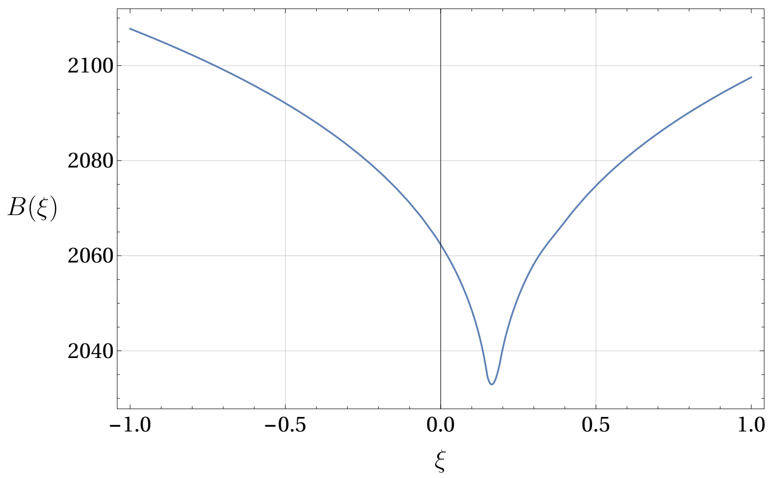
$$R = \kappa\;\frac{\dot{\phi}^2(1-6\xi) + 4V(\phi) - 6\xi\phi\,dV/d\phi}{1-\kappa\xi(1-6\xi)\phi^2}\,.$$

For $\xi = 0$ these Equations become the minimal coupling ones.

Asymptotics: For $r \to \infty$, $\dot{\rho}_b^2 = 1$, so $\rho(r)$ approaches the flat spacetime metric. In the same limit, $R \to 0$.

Curved Spacetime. Non-minimal coupling





B very sensitive to ξ. Outside the range $[\xi = 0, \xi = 1/3]$, $B(\xi)$ is greater than $B(\xi = 0)$, and non-minimal coupled gravity stabilizes the EW vacuum more than minimally coupled gravity.

Minimum at $\xi_{min} \simeq 0.17$, close to the conformal value $\xi = 1/6$. Actually for the scale invariant potential $V(\phi) = \frac{\lambda}{4}\phi^4$ (constant λ) the minimum is reached at $\xi = 1/6$.

Tunneling exponent B for the flat space-time case and for the conformal case $\xi = 1/6$:

$$B_{flat} \equiv B(\xi = 0) = 2025.27 \qquad B(\xi = 1/6) = 2025.15\,.$$

What happens now if we Add New Physics at M_P ?

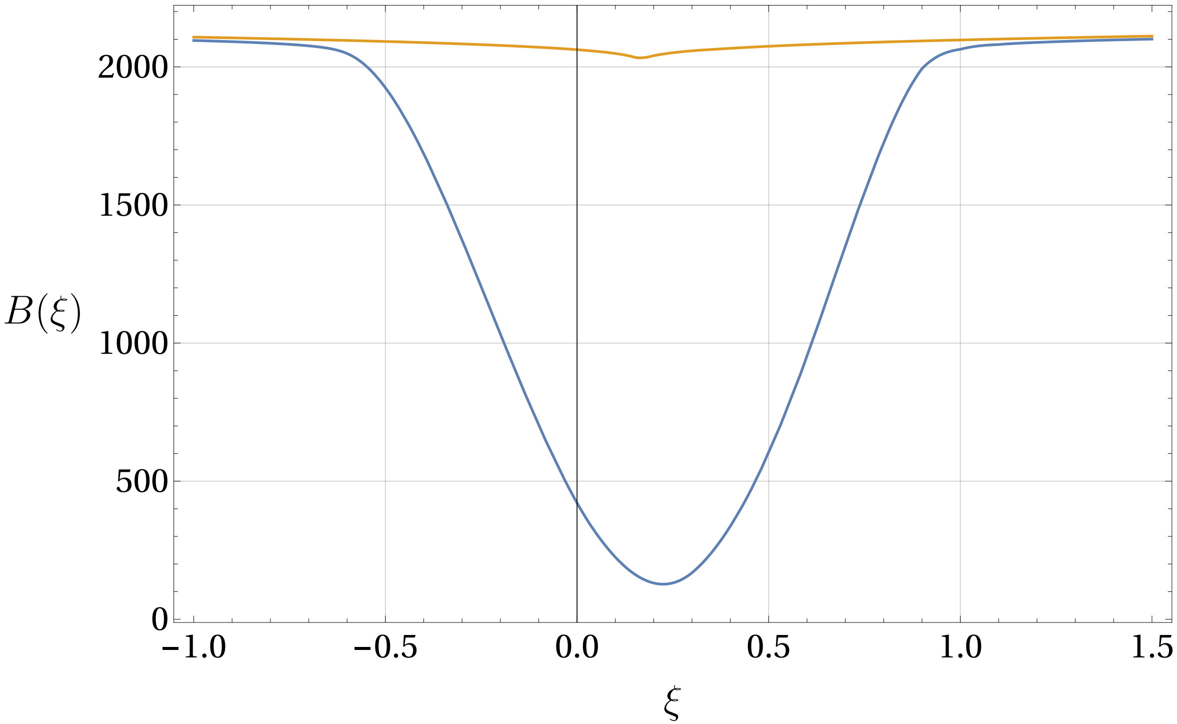
Add New Physics in the λ_6 and λ_8 case

ξ	$(\tau/T_U)_{SM}$	$(\tau/T_U)_{NP}$
-15	10^{736}	10^{736}
-10	10^{726}	10^{726}
-5	10^{710}	10^{710}
-1	10^{684}	10^{680}
-0.5	10^{677}	10^{600}
-0.3	10^{672}	10^{358}
-0.1	10^{666}	10^{65}
0	10^{661}	10^{-58}

ξ	$(\tau/T_U)_{SM}$	$(\tau/T_U)_{NP}$
0.3	10^{660}	10^{-167}
0.5	10^{668}	10^{23}
0.7	10^{674}	10^{346}
0.8	10^{676}	10^{512}
1	10^{679}	10^{666}
5	10^{709}	10^{709}
10	10^{725}	10^{725}
15	10^{735}	10^{735}

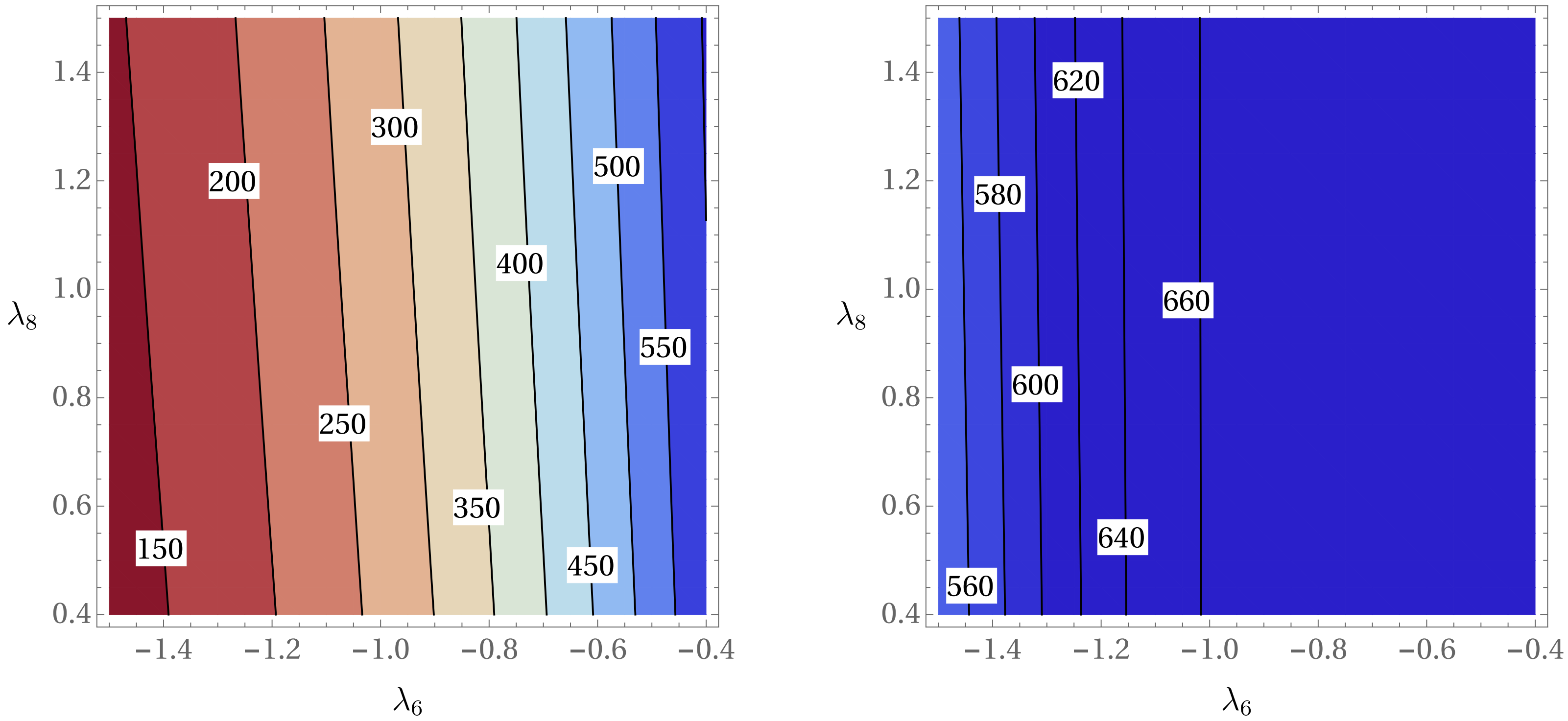
Values of τ with and without New Physics for different values of ξ, where $\lambda_6 = -1.2$ and $\lambda_8 = 1$.

Tunneling exponent as a function of ξ



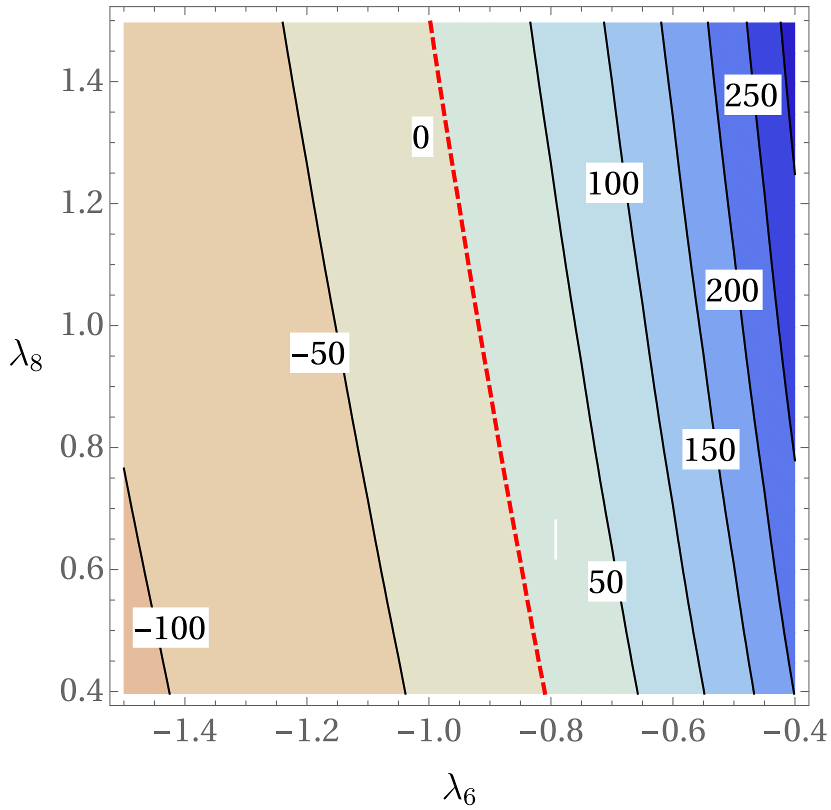
Yellow: $B(\xi)$ when the SM potential alone is considered. Blue: $B(\xi)$ when the New Physics potential with $\lambda_6 = -1.2$ and $\lambda_8 = 1$ is considered (questa e' la coppia di valori dive si ha il passaggio da maggiore a minore di TU).

Stability Diagrams for $\xi = -0.2$ and $\xi = 0.9$



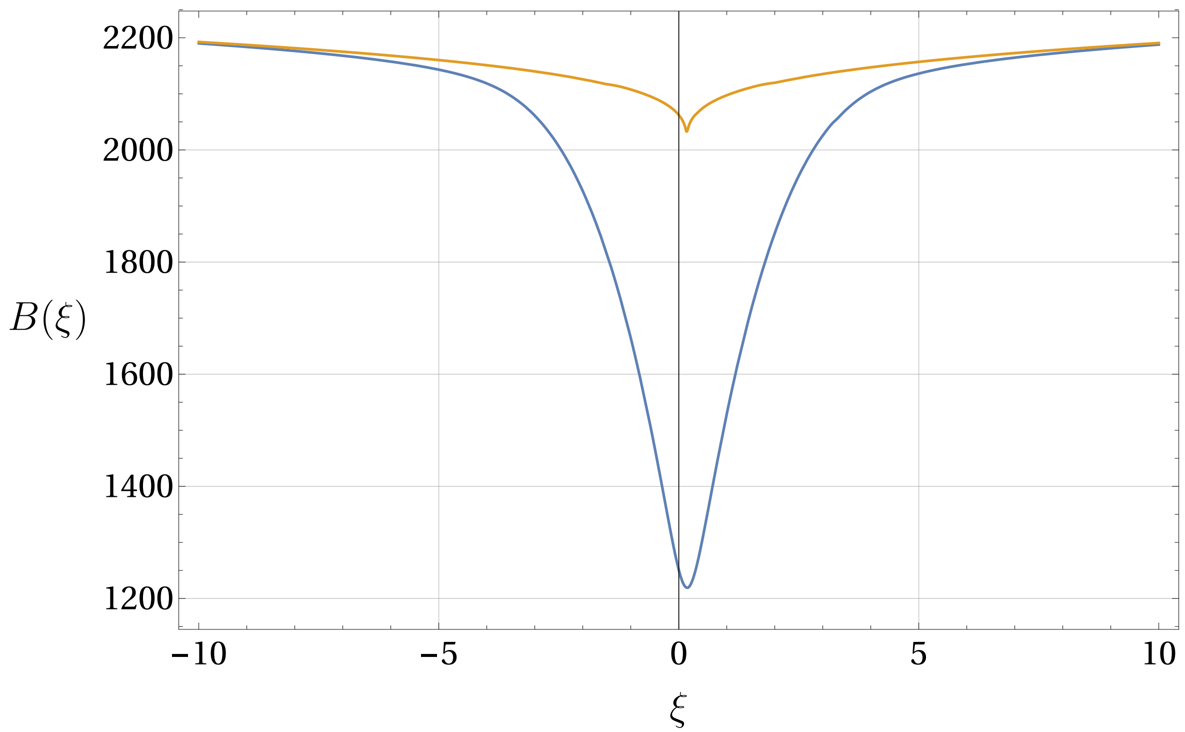
Stability diagrams in the (λ_6, λ_8) plane with non-minimal coupling to gravity: $\xi = -0.2$ (left), $\xi = 0.9$ (right). In both cases, for the range of λ_6 and λ_8 showed, the EW vacuum is always stable ($\tau > T_U$), unlike the minimal coupling case.

The $\xi = 0$ case for comparison



The same range of values of λ_6 and λ_8 as in the previous slide.

B as a function of ξ in the Boson-Fermion case



Yellow: $B(\xi)$ when the SM potential alone is considered. Blue: $B(\xi)$ when the New Physics potential with $M_S = 1.5 \times 10^{-1}$, $M_f = 5 \times 10^{-3}$, $g_S = 0.92$, $g_f^2 = 0.4$ is considered.

... Rescue from New Physics destabilization ...

Non-minimal coupling of gravity with the Higgs field ... Note that:

- the dimension four operator $\xi\phi^2 R$ naturally arises when quantization is carried out in a curved space-time background ... in the SM the term $\xi\, R\, H\, H^*$ is required in order to make the theory multiplicatively renormalizable in curved spacetime.
- from an effective field theory point of view, this is just the leading order term in an expansion of the action in the curvature, although very little is known about the value of the dimensionless coupling ξ.

With the discovery of the Higgs boson it was possible to put only a very high upper bound on its absolute value, $|\xi| < 2.6 \times 10^{15}$ (X. Calmet) $\Rightarrow$ this allows for different scenarios that depend on different choices of ξ ... Higgs inflation requires a large value of ξ ...

In view of the enormous stabilizing effect induced by the $\xi\,\phi^2\,R$ term for values of ξ outside the tiny range of values $-1 \lesssim \xi \lesssim 1$, and under the assumption that the physical (yet unknown) value of ξ lies outside this range, we can be lead to formulate the following

“Direct Coupling Stability Conjecture”

... The quantum nature of physical laws and the very existence of gravity provide an intrinsic stabilization mechanism that protects our universe against any potential destabilization that could come from yet unknown New Physics ...

Actually one important and several times considered question is whether or not the presence of new physics at high energy can destabilize the EW vacuum ...

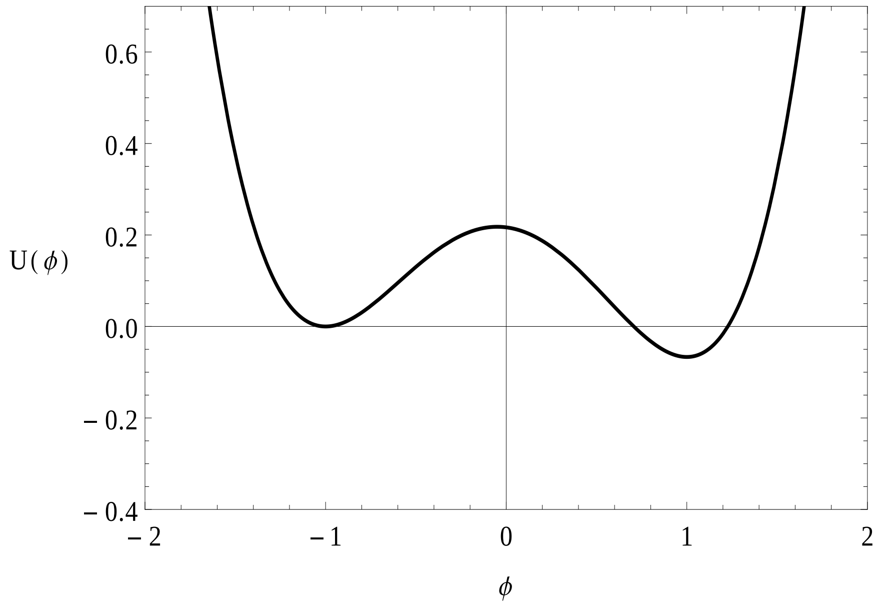
The analysis presented above shows that, without taking into account the presence of the term $\xi\,\phi^2\,R$, this is a possibility. We have seen that when the Higgs field is non-minimally coupled to gravity (except for a tiny range of values of ξ) the possible destabilizing effect of unknown New Physics is washed out by the presence of the non-minimal coupling.

Conclusions and Outlook

- **New Physics at very high (Planckian) energy scales can destabilize the EW vacuum. Stability analysis performed in a flat spacetime background.**
- **Very recent work confirmed that the same is true even when the analysis is performed in a curved spacetime background. Minimal coupling to gravity shows a tendency toward stabilization, but for large portions of New Physics parameter space, the destabilizing effect of New Physics still wins against the stabilization effect of gravity.**
- **Non-minimal coupling to gravity, dictated by field quantization in a curved spacetime background, except for a tiny range of values of ξ, provides a very strong stabilization mechanism.**
- **This lead us to formulate a "Direct Coupling Stabilization Conjecture".**
- **Search for other Stabilization Mechanisms.**

BACK UP SLIDES

False Vacuum Decay



Coleman analysis in flat space-time (1977)

Later (1980) Coleman - De Luccia considered the impact of gravity

In both cases... "Thin Wall" ...

In a gravitational background - Thin Wall Approximation

Comparing the action B in the gravitational background with the action B_0 in flat space-time

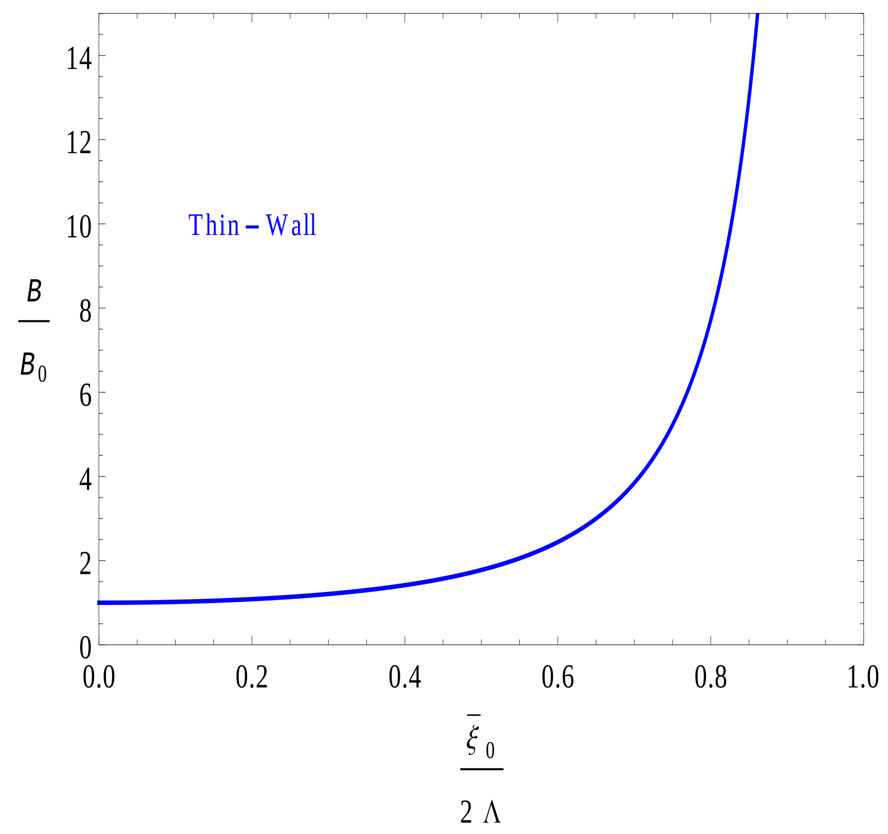
$$B = \frac{B_0}{\left[1 - \left(\bar{\xi}_0/(2\Lambda)\right)^2\right]^2}$$

with

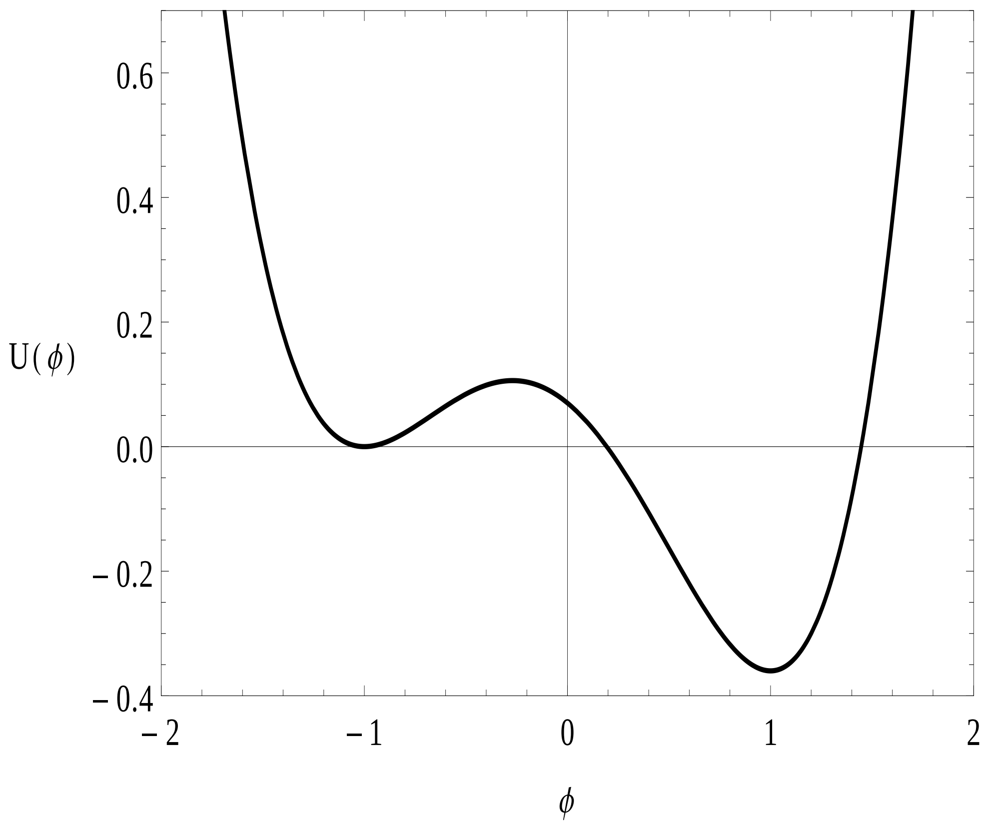
$$\Lambda = (8\pi\, G \cdot \Delta U/3)^{-1/2}$$

and

$$\Delta U = U(\phi_{fv}) - U(\phi_{tv})$$

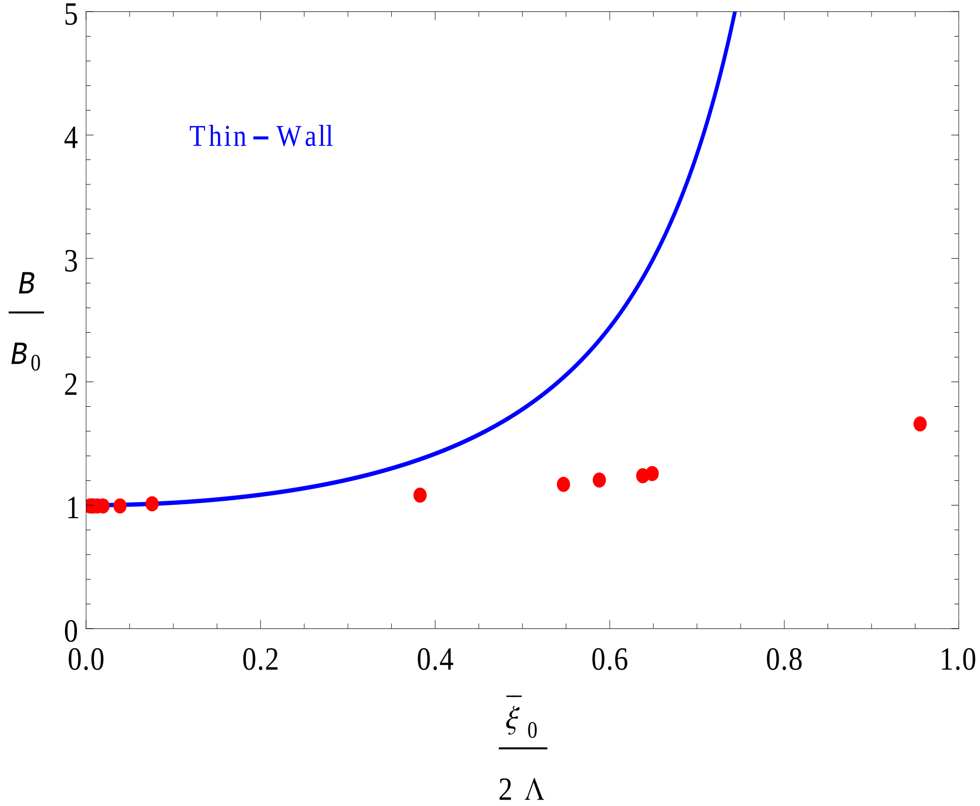

Thin − Wall
$\frac{B}{B_0}$
$\frac{\bar{\xi}_0}{2\Lambda}$
0
2
4
6
8
10
12
14
0.0
0.2
0.4
0.6
0.8
1.0

Out of Thin Wall



Comparing the action B in the gravitational background with the action B_0 in flat space-time

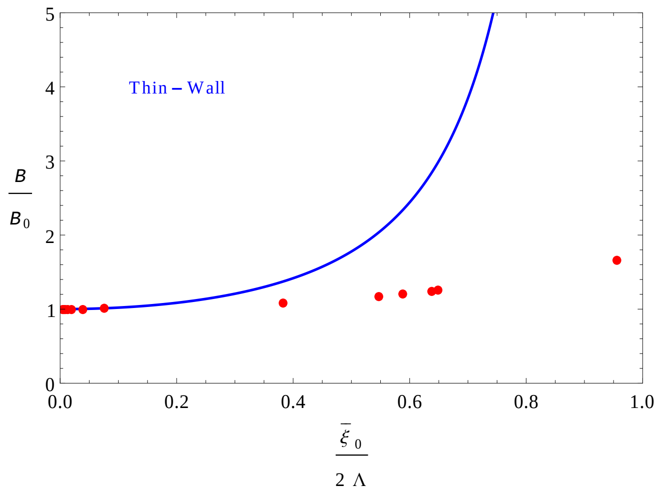
In the Thin Wall Approximation and Out of "Thin Wall"



LESSON

When $U(\phi_{fv}) - U(\phi_{tv})$ is not small, the intuition that we have developed from the Coleman-DeLuccia analysis on the Impact of Gravity does not apply !

It is no longer true that when the Bounce becomes larger and larger, the probability of materialization of the bounce becomes smaller and smaller ... eventually vanishing ...



... “Old Ideas” ...

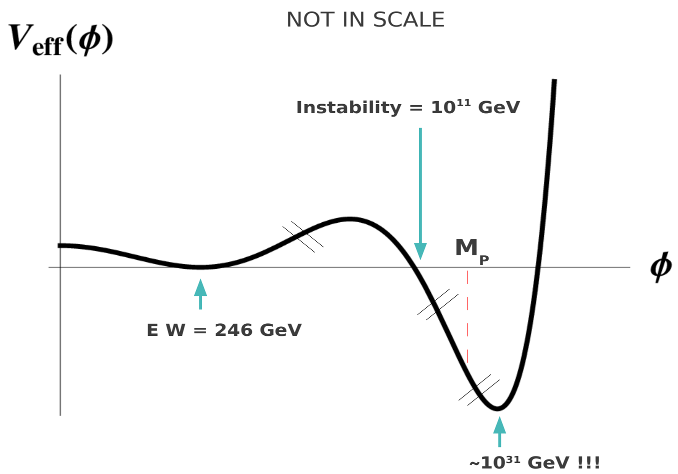
From: **J.R. Espinosa, G.F. Giudice, A. Riotto, JCAP 0805 (2008) 002**

“For most of the relevant values of the top and Higgs masses, the instability scale Λ_{inst} is sufficiently smaller than the Planck mass, **justifying the hypothesis of neglecting effects from unknown Planckian physics**.”

From: **Isidori, Ridolfi, Strumia, Nucl.Phys. B609 (2001) 387**

“The SM potential is eventually stabilized by unknown new physics around M_P : because of this uncertainty, we cannot really predict what will happen after tunnelling has taken place. **Nevertheless, a computation of the tunnelling rate can still be performed, this result does not depend on the unknown new physics at the Planck scale.**”

Turning points...



This is QFT with "very many" dof, not 1 dof QM $\Rightarrow$ the potential is not $V(\phi)$ in figure with 1 dof, but...

$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) = \frac{1}{2}\dot{\phi}^2 - \frac{1}{2}(\vec{\nabla}\phi)^2 - V(\phi) = \frac{1}{2}\dot{\phi}(\vec{x},t)^2 - U(\phi(\vec{x},t))$

where $U(\phi(\vec{x},t))$ is : $\quad U(\phi(\vec{x},t)) = V(\phi(\vec{x},t)) + \frac{1}{2}(\vec{\nabla}\phi(\vec{x},t))^2$

Very many dof, not 1 dof... The Potential is : $\sum_{\vec{x}} U(\phi(\vec{x},t))$

The bounce is not a constant configuration ... Gradients do matter a lot.