First-Order Quantum Corrections to Fifth Forces

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Non-linearities screen them from local tests.

The Symmetron Model

$$V_{\text{eff}}(\phi) = \frac{1}{2}\left(\frac{\rho}{M^2} - \mu^2\right)\phi^2 + \frac{1}{4}\lambda\phi^4$$

$\rho \rightarrow$ background matter density
$M \rightarrow$ matter coupling
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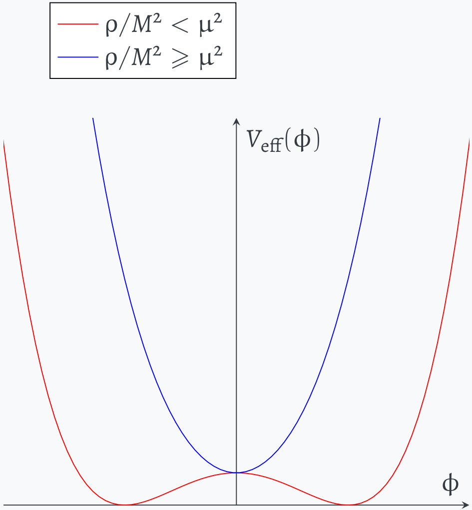
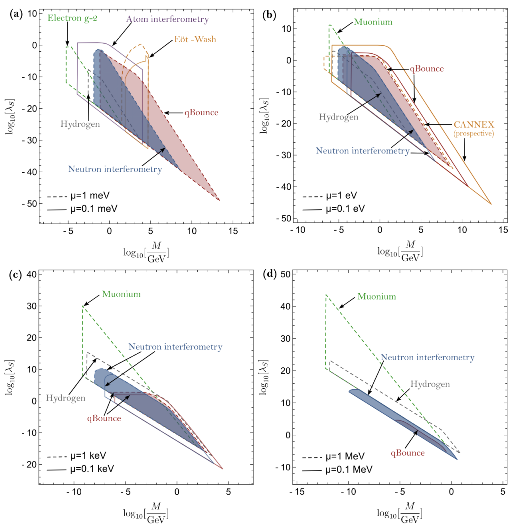


Current Constraints



- Constraints weaken as mass μ increases and coupling λ decreases.
- Some experiments claim to constrain non-perturbative self-couplings

Fischer, Käding, Pitschmann. Universe **2024**, 10(7), 297

Classical vs Quantum

- As we probe ever shorter distances in search of fifth forces, we become increasingly sensitive to quantum effects.

[1] Weinberg, Classical Solutions in Quantum Field Theory, pp. 6–37, Cambridge University Press (2012)
[2] Burrage et al JCAP08(2021)052
[3] Käding Physics of the Dark Universe, Volume 47, 2025, 101788

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- We can formally express the requirement for a given classical field theory to have small quantum corrections[1], which the symmetron model fails to satisfy in the vicinity of extremely compact sources.[2]

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- Some work has begun to consider quantum fluctuations of the symmetron and chameleon models, but only on trivial backgrounds.[3]

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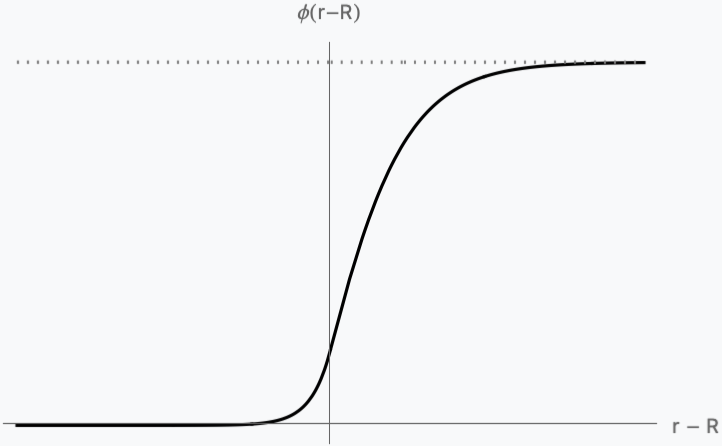
Thin-wall approximation:

$$\frac{d^2\phi}{dr^2} + \frac{2}{r}\frac{d\phi}{dr} = \frac{dV_{\text{eff}}}{d\phi} \to \frac{d^2\phi}{ds^2} = \frac{dV_{\text{eff}}}{d\phi}\,,$$

where $s = r - R$.

Non-trivial Backgorund

$$\phi_{\mathrm{cl}}(s) = v\left\{\Theta(-s)\, g\, \mathrm{csch}\left[\mathrm{arcsch}\left(\frac{\phi_0}{gv}\right) - g\gamma s\right] + \Theta(s)\tanh\left[\gamma s + \mathrm{artanh}\left(\frac{\phi_0}{v}\right)\right]\right\}$$



One-Loop Corrections

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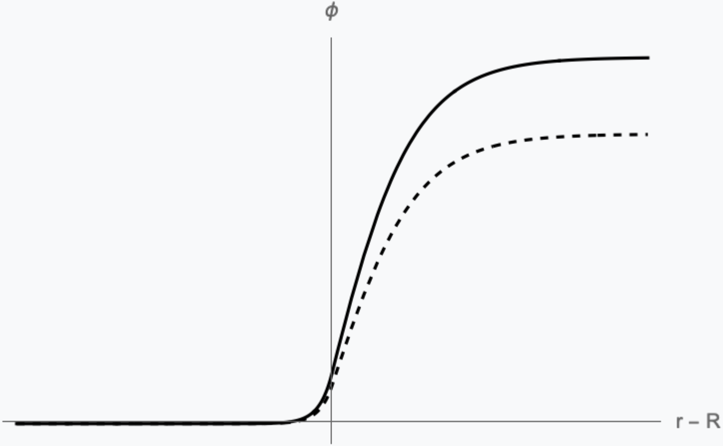
which is solved using a Green's function method

$$\delta\phi(x) = \int \mathrm{d}^4y \, G(\phi_{\text{cl}}; x, y)\Pi(\phi_{\text{cl}}; y)\phi_{\text{cl}}(y) \, ,$$

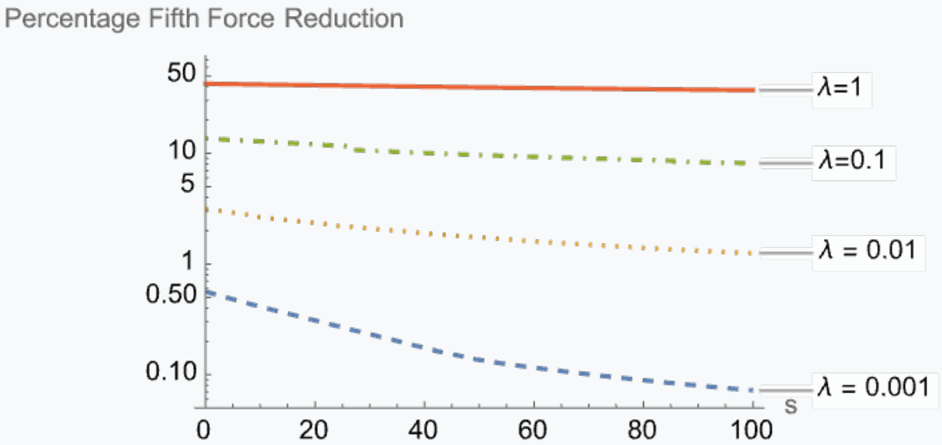
where G is the propagator and Π^R is the renormalised tadpole contribution.

One-Loop Corrections

Quantum corrections tend to flatten symmetron field profile.



Tentative Results



$\mu = 100\ \text{MeV}, M = 1\,\text{GeV}, \rho \approx 10^{-2}\,\text{GeV}^4.$

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Future Work

- A fully numerical computation could consider non-uniform sources of arbitrary size.
- Reformulation of current constraints to account for quantum effects.
- Extension to symmetron-like models and perhaps other scalar-tensor field theories.