On the (lack of) efficiency of screening mechanisms in modified gravity due to nonlinear astrophysical phenomena


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Screening Mechanisms in Scalar-Tensor Gravity
Suppressing the Yukawa Potential

\[ \mathcal{L} = -\frac{1}{2} Z^{\mu\nu}(\phi, \partial\phi, \ldots) \partial_{\mu}\phi \partial_{\nu}\phi - V(\phi) + g(\phi) T_{\mu}^{\mu} \]

1. Weak coupling
2. Large mass
3. Large inertia

Efficiency crucial to evade gravity constraints
Constrains on Modified Gravity

Post-Newtonian Parameter

\[
\frac{\gamma - 1}{\gamma} = (2.1 \pm 2.3) \times 10^{-5}
\]

\[
\gamma - 1 = 0, \quad \text{GR}
\]

\[
\gamma - 1 = -\frac{\phi^2}{M^2} \frac{2}{\frac{\phi^2}{M^2} + 2\Psi(1 + \frac{\phi^2}{M^2})}
\]
Computing the profile of the field in the solar system

\[ S = \int d^4x \sqrt{-g} \left( \frac{M_{Pl}^2}{2} R - \frac{1}{2} (\partial \phi)^2 - V(\phi) \right) + S_{\text{matter}} \left[ A^2(\phi) g_{\mu\nu}, \psi \right] \]

- Scalar field equation of motion
  \[ \ddot{\phi} + 3H \dot{\phi} - \frac{1}{a^2} \nabla^2 \phi = -V_{\text{eff},\phi} (\rho, \phi) \]
- A damped wave equation
Quasi-static approximation
Field profile does change in virialised/quasi-static systems

- Scalar field equation of motion

\[ \frac{1}{a^2} \nabla^2 \phi = -V_{\text{eff}, \phi} (\rho, \phi) \]

- **Quasi-static** approximation

\[
S = \int d^4x \sqrt{-g} \left( \frac{M_{\text{Pl}}^2}{2} R - \frac{1}{2} (\partial \phi)^2 - V(\phi) \right) + S_{\text{matter}} [A^2(\phi)g_{\mu\nu}, \psi]
\]
Quasi-static approximation

Field profile does change in virialised/quasi-static systems

- Scalar field equation of motion

\[
\frac{1}{a^2} \nabla^2 \phi = -V_{\text{eff}}, \rho, \phi
\]

- **Quasi-static** approximation

\[
\vec{a} = -\vec{\nabla} \Phi - \frac{\mathrm{d} \ln A(\phi)}{\mathrm{d} \phi} \vec{\nabla} \phi
\]

\[
S = \int \mathrm{d}^4x \sqrt{-g} \left( \frac{M^2_{\text{Pl}}}{2} R - \frac{1}{2} (\partial \phi)^2 - V(\phi) \right) + S_{\text{matter}} \left[ A^2(\phi) g_{\mu\nu}, \psi \right]
\]
Quasi-static approximation
Field profile does change in virialised/quasi-static systems

- Scalar field equation of motion
  \[ \frac{1}{a^2} \nabla^2 \phi = -V_{\text{eff,}\phi}(\rho, \phi) \]

- **Quasi-static** approximation

\[ \gamma - 1 = -\frac{\phi^2}{M^2} \left( \frac{\phi^2}{M^2} + 2\Psi \left(1 + \frac{\phi^2}{M^2}\right) \right) \]
Thin shell effect
Screening mechanisms suppress value field and gradient

\[
\ddot{a} = -\nabla \Phi - \frac{\ln A(\phi)}{d\phi} \nabla \Phi = -\nabla \left( \Phi + \ln A(\phi) \right)
\]

\[
\Phi \propto -\frac{GM}{r}
\]

\[
F_\phi \ll F_N
\]

\[
\gamma - 1 = -\frac{\phi^2}{M^2} \left[ \frac{2}{\phi^2 M^2} + 2\Psi \left(1 + \frac{\phi^2}{M^2}\right) \right] \ll 1
\]
Waves from Supernovae

Chamelecon Potential

Profile of field

\[ E_{wave} \]
Waves from collapse of domain walls

Profile of field

\[ V_{\text{eff}}(\phi) \]

R. Hagala
\[
\gamma - 1 = -\frac{\phi^2}{M^2} \left( \frac{\phi^2}{M^2} + 2\Psi \left(1 + \frac{\phi^2}{M^2}\right) \right)
\]
\[ \gamma - 1 = -\frac{\phi^2}{M^2} \frac{\phi^2}{M^2} + 2\Psi(1 + \frac{\phi^2}{M^2}) \]
Cassini bound

Solar System

Screening disrupted!
Scalar waves increase the PPN parameter and fifth force several orders in magnitude!

Oscillations are a smoking gun!

\[ \gamma - 1 = -\frac{\phi^2}{M^2} \frac{2}{\phi^2/M^2 + 2\Psi(1 + \phi^2/M^2)} \]
Summary

- A light extra degree of freedom in the gravity sector is viable only if a screening mechanism is efficient to suppress it at local scales.

- The viability and efficiency of screening mechanism generally relies on the quasi-static approximation.

- Astrophysical events can create waves and the quasi-static approximation is no longer valid.

- Waves diminish the screening mechanism efficiency in several orders of magnitude reducing the viability of many modified gravity theories.