Quantum loop corrections to quintessence potentials

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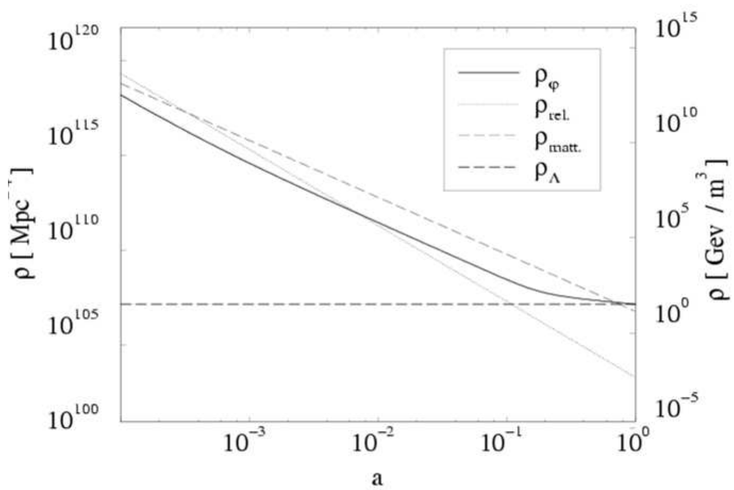
Outline

- What is quintessence ?
- Why loops ?
- Calculating loops
- Scalar loops
- Coupling to fermions – fermion loops
- Graviton induced interactions

What is quintessence ?



K. Freese et.al (1987), C. Wetterich (1988), B. Ratra & P.J. Peebles (1988), R. R. Caldwell et. al. (1997), P. G. Ferreira & M. Joyce (1997)

Why loops ?

- Quintessence calculations usually performed with **classical** field equations
- Potential often „inspired“ by some fundamental theory
- However, this still is a low energy effective **quantum** field theory.
- Therefore,“low energy“ (¿ M_p) quantum fluctuations **a priori not included**.

➡ Cosmological evolution uses wrong potential!

A word of caution

- Potentials discussed are non-renormalizable ➔ strong cut-off dependence.
- We discard constant terms which would in principle amount to a cosmological constant.
- Some symmetry expected to force vanishing cosmological constant.
- Same symmetry could cancel loop.
- SUSY is broken too badly to do this.

H. Kolda and D. Lyth (1998), R. D. Peccei (2000)

Calculating loops

In QFT, effective action $\Gamma[\Phi_{Cl}]$ replaces the classical action.

E.O.M. for field then given by

$$\delta\Gamma[\Phi_{Cl}]_{|\Phi_{Cl}=\Phi^{\star}_{Cl}} = 0$$

Calculating loops

- To calculate loop, look at generating functional for connected n-point functions

$$W[j] = \ln \int \mathcal{D}\phi \, \exp(-S(\phi) + j\phi)$$

- Expand

$$S(\phi) = S(\Phi_{\rm cl}) + S'\chi + \frac{1}{2}\left(\frac{\delta^2 S}{\delta\phi^2}\right)_{|\phi=\Phi_{\rm cl}} \chi^2$$

Calculating loops

- Now go over to $\Gamma[\Phi_{cl}] = -W[j] + j\,\Phi_{cl}$
- Factor out space-time volume,

$$\Gamma[\Phi_{cl}] = U\, V(\Phi_{cl})$$

$$\Rightarrow \quad V(\Phi_{\rm cl}) = V_{\rm cl} + \frac{1}{2}\,{\rm STr}\,\ln S^{(2)}$$

The action

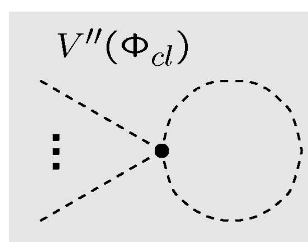
For the quintessence field Φ and some fermion Ψ, possibly coupled to Φ, the action is:

$$S = \int d^4x\sqrt{g}\{M_P^2\mathcal{R} + \frac{1}{2}\partial_\mu\Phi\partial^\mu\Phi + V(\Phi) + \bar{\Psi}[i\not\nabla + \gamma^5 m(\Phi)]\Psi\}$$

Scalar loops

Leading order scalar loop:

$$\Delta V = \frac{\Lambda^2}{32\pi^2}V'' \quad \Longleftrightarrow$$



Exponential potentials

Consider $V_{\mathrm{cl}} = \exp(-\alpha\Phi)$

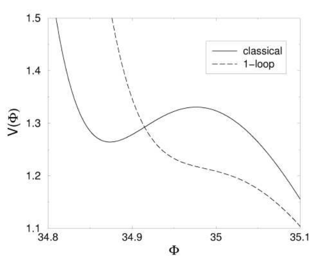
$$V + \Delta V = \left(1 + \frac{\Lambda^2}{32\pi^2}\alpha^2\right)\exp(-\alpha\Phi)$$

$\Downarrow$

Form Stable !!!

Scalar loops :: stability

- Pure exponentials ✓
- Nambu-Goldstone cosine ✓
- Inverse power laws ✓✗ P. Brax & J. Martin (2000)
- Sugra inspired potentials ✓✗
- Modified exponentials ✓✗



Albrecht & Skordis (2000)

Fermion loops

Coupling of quintessence to fermions

$$S_{\text{coup}} = \int d^4x \, \bar{\Psi} m(\Phi) \Psi$$

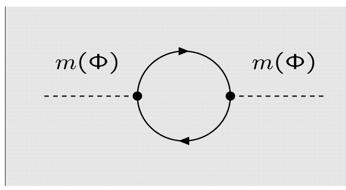
Is actually quintessence dependent fermion mass term:

$$m(\Phi)|_{today} \sim 10^{-16}$$

Fermions rule!

$$\Delta V = \frac{\Lambda^2_{\text{ferm}}}{8\pi^2}[m(\Phi_{\text{cl}})]^2$$

⟺



- V ¼ ρ_{crit} = 3 H^2
- H = 8.9 £ 10^{-61} h^2

$$\frac{\Delta V}{V} \sim 10^{80}$$

Coupling and effective potential connected!

Why bother ?

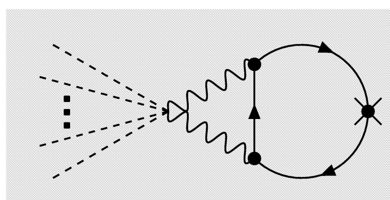
Loophole for both scalar and fermion loops:

View action as fully effective, all fluctuations integrated out

However: For coupled quintessence, one needs to guess *both* the effective potential and the effective coupling! Highly unlikely to guess right!

Could gravitons do the coupling ?

In principle, processes like



occur.

They arise from using

$$\nabla\!\!\!/ = e^{\mu}_{a}(x)\,\gamma^{a}\left(\partial_\mu + \tfrac{i}{4}\sigma_{bc}\omega^{bc}_{\mu}\right)$$

and $\sqrt{g} = 1 + \frac{1}{2}h^{\mu\mu} - \frac{1}{4}(h^{\mu\nu})^2 + \frac{1}{8}(h^{\mu\mu})^2$ multiplying the matter Lagrangian.

Puh, lucky…

- Fermion mass + coupling: $m(\Phi) = m_f + c(\Phi)$
- In order to contribute Φ-dependent part to Ψ mass, gravitons starting from Ψ-h Vertices (complicated as they may be) have to touch Φ-h vertices.
- Φ-h vertices are / $V(\Phi_{cl})$, hence $c(\Phi)$ / $V(\Phi_{cl})$

$$\Delta V = \frac{\Lambda^2_{\mathrm{ferm}}}{8\pi^2}[m(\Phi_{\mathrm{cl}})]^2 = \frac{\Lambda^2_{\mathrm{ferm}}}{4\pi^2} m_{\mathrm{f}}\, c(\Phi) + \ldots$$

Potential correction / V

Conclusions

- Uncoupled quintessence is *stable*
- Coupled quintessence severely restricted
- Bound on coupling so tight, one needs to consider graviton-induced couplings – corrections are small and can be absorbed.