Semi-classical degravitation of the Cosmological Constant

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- Solving even one aspect of this problem convincingly would be a major success.
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- The degravitation directly solves the first, implicitly solves the second, and considerably alleviates the third aspect of the C.C. problem.

Filtering gravity at long wavelengths

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- How do we actually realize this filtering of gravity?

The filtering effects of extra polarizations

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- $8\pi G_N \to \frac{8\pi G_N}{1+(\frac{m^2}{\Box})^{1-\alpha}}, \quad 0 \le \alpha < 1$

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$$\begin{aligned}\Omega^{\alpha\beta}_{\mu\nu} h_{\alpha\beta} &:= \Box h_{\mu\nu} - \eta_{\mu\nu}\Box h - \partial_\mu\partial^\alpha h_{\alpha\nu} - \partial_\nu\partial^\alpha h_{\alpha\mu} + \eta_{\mu\nu}\partial^\alpha\partial^\beta h_{\alpha\beta} \\ &+ \partial_\mu\partial_\nu h \\ &= -8\pi G_N T_{\mu\nu}\end{aligned}$$

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- Pauli-Fierz gravity: $\Omega^{\alpha\beta}_{\mu\nu} h_{\alpha\beta} - m^2[h_{\mu\nu} - \eta_{\mu\nu} h] = -8\pi G_N T_{\mu\nu}$

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We perform a Stückelberg decomposition of $h_{\mu\nu}$, and after accounting for residual gauge invariances, we integrate out these extra polarizations, to yield:

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- In order to be self-consistent, we must address the issue of non-linear completion (so we can do cosmology) as well as better understand the issue of the modified Bianchi identities.

A candidate solution to all aspects of the C.C. problem?

(Based on *arXiv* : 0801.2151) Before we continue our investigation as to how to come up with a concrete implementation of the degravitation scenario, we offer the following interlude to motivate the search. We take the functional form of the filter function corresponding to massive gravity as an example[1]

- $\frac{8\pi G_N}{1+\frac{m^2}{\Box}} = \frac{8\pi G_N \Box}{\Box + m^2} = 8\pi G_N \Box(\Box + m^2)^{-1}$

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- We see immediately how a spatial zero mode (bare c.c.) is degravitated: $\Lambda_{deg} = \Lambda(1 - \langle 1 \rangle) = 0$

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Homogeneous sources

We next consider the situation where some energy density condenses at some specific point the universes history. Consider a degravitated test step function source, in a background that is described by de Sitter space with line element: $ds^2 = \frac{1}{H^2\eta^2}(d\eta^2 - dx_i dx^i)$

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- Corresponds to a decaying step function with decay constant $\tau = m^{-1}$ (in the above $\nu^2 = 9/4 - m^2/H^2$)

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- $V(t) = V_0 + \sum_{i=1}^{N}(V_i - V_{i-1})\theta(t - t_i), \qquad t_{i-1} < t_i$

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- Scale is set by the filter scale in Planck units squared. We know that $m < H_0$. Thus $\Lambda \sim \frac{l_{pl}^2}{L^2} \sim 10^{-120},\ (L = H_0^{-1})$.

A formally exact solution for homogeneous sources

To offer us further perspective on the degravitation mechanism, and to study degravitation in other contexts, we reformulate the problem in yet another manner. We rewrite the modified Einstein equation as:

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- Gives us the degravitated step function as (for $t > t_0$) $R = -\frac{4\Delta V}{M_{pl}^2}e^{-m^2\int_{\blacktriangle} G^0[R]}$.
- Impossible to solve, but can still show $\tau = m^{-1}$ is the relevant timescale for degravitation– coincidence problem is much alleviated.

Taking stock

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- One finds that it solves the bare C.C. problem (by design)
- It offers a mechanism to explain the hierarchy of scales of the presently inferred C.C. $\sim l_{pl}^2/L^2$
- It alleviates the coincidence problem as vacuum energy is no longer a constant.

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- One finds that it solves the bare C.C. problem (by design)
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- Non-linear realization realization from massive gravity or higher co-dimensional setups is problematic.
- However the fact that it has the potential to solve 2.5/3 aspects of the C.C. problem should serve as a strong motivation to further investigate this promising idea.

Filtering as a semi-classical effect?

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- 'De-localizes' the vertex, makes the 'equations of motion' non-local

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- In the limit $m_e r \ll 1$, we find the quantum corrected potential to be $V(r) = \frac{e_0^2}{4\pi r}\left[1 + \frac{\alpha}{3\pi}\left(ln\frac{1}{m_e^2 r^2} - 2\gamma\right)\right]$ $-2\gamma \approx -1.154$

Running of couplings in gravity?

We now ask, is this possible in gravity? We begin with a suggestive toy example– Quantum gravity in two dimensions, which is a renormalizable theory (G_N in 2-d is dimensionless). Christensen and Duff (1978) working in $d = 2 + \epsilon$ dimensions found:

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- c.f. DHK: $G_N \to G(\Box) = \frac{G_N}{1+(m^2/\Box)^{1-\alpha}}$

The modified Bianchi identities

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- $L_{eff} = \frac{i}{2}\lim_{x'\to x}\int_{m^2}^\infty d\bar{m}^2 G^{DS}_F(x,x';\bar{m}^2)$, where $G^F_{DS}(x,x';\bar{m}^2)$ is the Feynman propagator for a field with mass $\bar{m}$ in the Schwinger De-Witt representation.

Can this work in 4-d?

We interject an important phenomenological point: gravity is the *only* force whose coupling we directly measure in the UV (via Cavendish type experiments $\sim \mu m$). Clearly, once we go beyond solar system scales, we have to make up sources[2]. Could it be that gravity is IR free and runs towards $1/M_{pl}^2$ at all other cosmologically accessible scales?

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- However, the most we can degravitate is to $G_N \to \frac{1}{M_{pl}^2} \cdot \frac{1}{1 + \frac{3m_v^2}{12\pi M_{pl}^2} \; ln \frac{\mu_0^2}{m_V^2}}$. Does not work.

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Consider how Newton's constant is renormalized by integrating out matter fields:

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- Given the proof of concept, could we motivate it better through some underlying fundamental physics setup?