The Cosmological Constant Problem and Gravity in the Extreme IR

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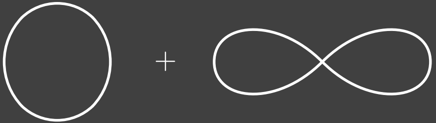
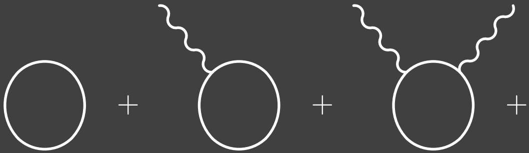
THE COSMOLOGICAL CONSTANT PROBLEM

- We observe a cosmological horizon $\sim 10^{26}$m
- Total CC in our universe does not exceed $(\text{meV})^4$
- However CC receives contributions from vacuum fluctuations



$$+ \; \dots \; = V_{\text{vac}}$$



$$+ \; \dots \; = -\sqrt{-g}\, V_{\text{vac}}^{\text{1-loop}}$$

THE COSMOLOGICAL CONSTANT AND GR

- Define a space-time average as

$$\langle Q \rangle = \frac{\int d^4x \sqrt{-g}\, Q}{\int d^4x \sqrt{-g}} \qquad \longrightarrow \qquad \Lambda = \langle \Lambda \rangle$$

- Let $T^{\mu}{}_{\nu} = \tau^{\mu}{}_{\nu} - \delta^{\mu}{}_{\nu}(\Lambda_c + V_{\rm vac})$

$$\begin{aligned} M_{pl}^2 \left(R^{\mu}{}_{\nu} - \frac{1}{4}\delta^{\mu}{}_{\nu} R \right) &= \tau^{\mu}{}_{\nu} - \frac{1}{4}\delta^{\mu}{}_{\nu}\tau^{\alpha}{}_{\alpha} \\ M_{pl}^2 (R - \langle R \rangle) &= \langle \tau^{\alpha}{}_{\alpha} \rangle - \tau^{\alpha}{}_{\alpha} \end{aligned}$$

$$\boxed{M_{pl}^2 \langle R \rangle = 4(\Lambda_c + V_{\rm vac}) - \langle \tau^{\alpha}{}_{\alpha} \rangle}$$

VACUUM ENERGY SEQUESTERING

- Aim: fix $\langle R \rangle$ in the IR to decouple vacuum fluctuations from gravity

- An example

$$
\begin{aligned}
S &= \int d^4x\sqrt{-g}\left[\frac{\kappa^2(x)}{2}R - \Lambda(x) - \mathcal{L}_m(g^{\mu\nu}, \Phi)\right] \\
&+ \int dx^\mu dx^\nu dx^\lambda dx^\rho \left[\sigma\left(\frac{\Lambda(x)}{\mu^4}\right)\frac{F_{\mu\nu\lambda\rho}}{4!} + \hat{\sigma}\left(\frac{\kappa^2(x)}{M_{Pl}^2}\right)\frac{\hat{F}_{\mu\nu\lambda\rho}}{4!}\right]
\end{aligned}
$$

- where $F_{\mu\nu\lambda\rho} = 4\partial_{[\mu}A_{\nu\lambda\rho]}, \quad \hat{F}_{\mu\nu\lambda\rho} = 4\partial_{[\mu}\hat{A}_{\nu\lambda\rho]}$

- Not all fields couple to $g_{\mu\nu}$!

EQUATIONS OF MOTION

$$\kappa^2 G^{\mu}{}_{\nu} = T^{\mu}{}_{\nu} - \delta^{\mu}{}_{\nu}\Lambda_c$$

$$\frac{\sigma'}{\mu^4} F_{\mu\nu\lambda\rho} = \frac{1}{4}\sqrt{-g}\,\epsilon_{\mu\nu\lambda\rho}, \qquad \frac{\hat{\sigma}'}{M_{pl}^2}\hat{F}_{\mu\nu\lambda\rho} = -\frac{1}{2\cdot 4}\sqrt{-g}\,R\,\epsilon_{\mu\nu\lambda\rho}$$

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$$\begin{aligned} \kappa^2 G^\mu{}_\nu &= T^\mu{}_\nu - \delta^\mu{}_\nu \Lambda_c \\ \frac{1}{4}\kappa^2 \langle R \rangle &= -\frac{\mu^4}{2}\frac{\kappa^2 \hat{\sigma}'}{M_{pl}^2 \sigma'}\frac{\int \hat{F}}{\int F} = \Delta\Lambda \end{aligned}$$

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$$\Lambda_c = \frac{1}{4}\langle T^\alpha{}_\alpha\rangle + \frac{1}{4}\kappa^2\langle R\rangle = \frac{1}{4}\langle T^\alpha{}_\alpha\rangle + \Delta\Lambda$$

$$\Longrightarrow \boxed{\kappa^2 G^\mu{}_\nu = T^\mu{}_\nu - \frac{1}{4}\delta^\mu{}_\nu\langle T^\alpha{}_\alpha\rangle - \delta^\mu{}_\nu\Delta\Lambda}$$