

The Cosmological Constant Problem and Gravity in the Extreme IR

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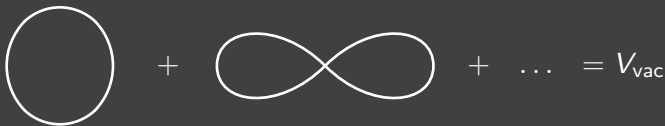
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In collaboration with Guido D'Amico,
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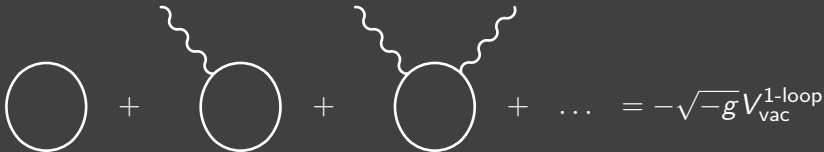
THE COSMOLOGICAL CONSTANT PROBLEM

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



A diagrammatic equation showing the sum of vacuum energy contributions. On the left is a simple circle. To its right is a plus sign, followed by a figure-eight loop. To the right of the figure-eight is another plus sign, followed by an ellipsis. This is followed by an equals sign and the symbol V_{vac} .

$$\text{circle} + \text{figure-eight} + \dots = V_{\text{vac}}$$



A diagrammatic equation showing the sum of 1-loop vacuum energy contributions. On the left is a simple circle. To its right is a plus sign, followed by a circle with one wavy line extending from its top. To the right of that is another plus sign, followed by a circle with two wavy lines extending from its top. To the right of that is another plus sign, followed by an ellipsis. This is followed by an equals sign and the expression $-\sqrt{-g}V_{\text{vac}}^{\text{1-loop}}$.

$$\text{circle} + \text{circle with 1 wavy line} + \text{circle with 2 wavy lines} + \dots = -\sqrt{-g}V_{\text{vac}}^{\text{1-loop}}$$

THE COSMOLOGICAL CONSTANT AND GR

- Define a space-time average as

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

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

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

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

VACUUM ENERGY SEQUESTERING

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

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

- where $F_{\mu\nu\lambda\rho} = 4\partial_{[\mu} A_{\nu\lambda\rho]}$, $\hat{F}_{\mu\nu\lambda\rho} = 4\partial_{[\mu} \hat{A}_{\nu\lambda\rho]}$
- Not all fields couple to $g_{\mu\nu}$!

EQUATIONS OF MOTION

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

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

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

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