Mar 2 2018

Hamiltonian interpretation of Vacuum energy sequestering

George Zahariade
Arizona State University, Beyond Center

GC2018 Yukawa Institute Kyoto

Intro and Outline

- Cosmological constant fine-tuning problem
- Vacuum energy sequestering proposal (Kaloper, Padilla 2013-2015)
- Localized sequestering model (Kaloper, Padilla, Stefanyszyn, Zahariade 2015)
- Hamiltonian discussion (Svesko, Zahariade, work in progress)

The cosmological constant problem

Of vacuum energy, phase transitions, bubbles and radiative corrections

Vacuum energy

- Equivalence principle: ALL energy gravitates

$$\langle \Omega | T_{\mu\nu} | \Omega \rangle = V_{vac}\, g_{\mu\nu}$$

- Two contributions
  - Classical minimum of the potential
  - Zero-point energy of quantum fluctuations

- Vacuum energy and the cosmological constant

$$\Lambda = \Lambda_{bare} + V_{vac}$$

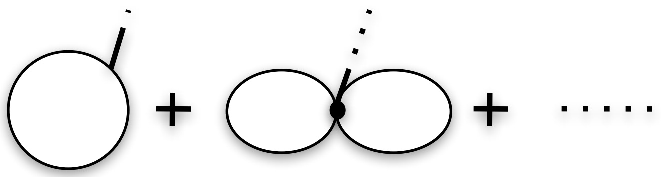
- Problem: high accuracy cancellation!!!

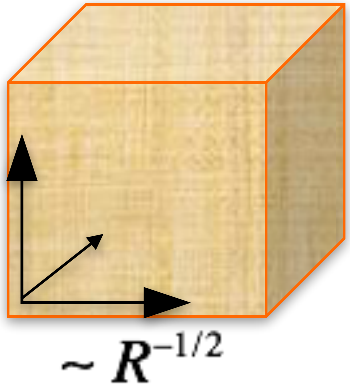
Radiative Instability

- Background solution of the EOMs

$$\begin{cases} M_P^2\left(R^{\mu}{}_{\nu}-\frac{1}{4}R\,\delta^{\mu}{}_{\nu}\right)=T^{\mu}{}_{\nu}-\frac{1}{4}T^{\rho}{}_{\rho}\delta^{\mu}{}_{\nu} \\ M_P^2\,R=4\Lambda-T^{\rho}{}_{\rho} \end{cases}$$

- Vacuum energy corrections to Λ : QFT in the locally flat frame (Zel'dovich 1968)
  - e.g. scalar ϕ^4 theory





- Backreaction spoils the background geometry

Problems to solving the problem

- Radiative instability = knowledge of the UV details of the theory necessary
- Not enough supersymmetry in the world…
  - Technically natural value of $\Lambda \sim (M_{SUSY})^4$ too big
- No-Go theorem (Weinberg 1989)
  - No local, equivalence principle compatible, self adjustment mechanisms for Poincaré invariant vacua
- Would imposing global constraints help?

Localized sequestering mechanism

Or how to enforce global constraints with local degrees of freedom

(Local) Sequestering action

- Idea: Planck mass and CC dynamical and local

- Local action

$$S = \int d^4x\sqrt{-g}\left[\frac{\kappa^2}{2}R - \Lambda - L_m(g^{\mu\nu}, \phi)\right] + \int \sigma\left(\frac{\Lambda}{\mu^4}\right)F + \int \tau\left(\frac{\kappa^2}{M_P^2}\right)H$$

  - Λ, κ : local fields
  - $F = dA,\ H = dB$: 4-forms
  - σ, τ : smooth functions
  - μ mass scale $\lesssim M_P$

Equations of motion

- Einstein equations

$$\kappa^2 G^{\mu}{}_{\nu} = \left(\nabla^{\mu}\nabla_{\nu} - \delta^{\mu}{}_{\nu}\nabla^2\right)\kappa^2 + T^{\mu}{}_{\nu} - \Lambda\delta^{\mu}{}_{\nu}$$

- Variation of the 4-forms

$$\partial_{\mu}\Lambda = 0 = \partial_{\mu}\kappa^2$$

- Variation of Λ and κ^2

$$\begin{cases} \dfrac{\sigma'}{\mu^4} F = \star 1 \\ -\dfrac{\tau'}{M_P^2} H = \star 1 \, \dfrac{R}{2} \end{cases}$$

Vacuum energy sequestering

- Spacetime average $\langle \dots \rangle \equiv \frac{\int d^4x\sqrt{-g}\,(\dots)}{\int d^4x\sqrt{-g}}$
- Cosmological constant equation

$$\Lambda = \frac{1}{4}\langle T^{\rho}{}_{\rho}\rangle - \frac{1}{2}\frac{\kappa^2\mu^4\tau'}{M_P^2\sigma'}\frac{\int H}{\int F}$$

- Key equation

$$\kappa^2 G^{\mu}{}_{\nu} = T^{\mu}{}_{\nu} - \frac{1}{4}\langle T^{\rho}{}_{\rho}\rangle\delta^{\mu}{}_{\nu} + \frac{1}{2}\frac{\kappa^2\mu^4\tau'}{M_P^2\sigma'}\frac{\int H}{\int F}\delta^{\mu}{}_{\nu}$$

- Residual cosmological constant component

Discussion

- σ , τ smooth: quantum corrections give at most $O(1)$ corrections as long as $\kappa \sim M_P$
- Form sector insensitive to UV details
  - Volume integrals: IR quantities
- New residual cosmological constant component also radiatively stable: to be measured
- GR recovered locally (globally, different theories)
- Weinberg No-Go evaded: equivalence principle broken globally, vacuum energy sector non-gravitating

Hamiltonian discussion

The CC and the initial value problem…

Hamiltonian analysis

- Hamiltonian form (finite region)

$$L = \pi^{ij}\,\dot{h}_{ij} + p\dot{\phi} + H_{GR} + H_m(\phi)$$
$$+\sigma\left(\frac{\Lambda}{\mu^4}\right)\partial_t u^0 + u^i\partial_i\sigma\left(\frac{\Lambda}{\mu^4}\right) + \tau\left(\frac{\kappa^2}{M_P^2}\right)\partial_t v^0 + v^i\partial_i\tau\left(\frac{\kappa^2}{M_P^2}\right)$$
$$+ \text{boundary terms}$$

- Integrate out bulk u^i and v^i: $\Lambda(t), \kappa^2(t)$
- Define $u = \int d^3x\, u^0$ and $v = \int d^3x\, v^0$

Hamiltonian analysis

- Action

$$\int dt\, d^3x\, \left(\pi^{ij}\, \dot{h}_{ij} + p\dot{\phi} + H_{GR}(h_{ij}, \pi^{ij}, \Lambda, \kappa^2) + H_m(\phi, p)\right)$$

$$+ \int dt\, \left(\sigma\left(\frac{\Lambda}{\mu^4}\right)\partial_t u\, + \tau\left(\frac{\kappa^2}{M_P^2}\right)\, \partial_t v + \sigma\left(\frac{\Lambda}{\mu^4}\right)\oint u^i ds_i\right.$$

$$\left. + \tau\left(\frac{\kappa^2}{M_P^2}\right)\oint v^i ds_i\right)$$

- Λ and κ^2 variation + Hamiltonian and momentum constraints + spacelike hypersurface integration: new constraint-like equation

HAMILTONIAN ANALYSIS

- New on-shell equation

$$\Lambda(t) + \frac{\int d^3x\, H_m}{\int d^3x\, N\sqrt{h}} + \frac{\kappa^2\mu^4}{M_P^2}\frac{\tau'\left(\oint v^i ds_i + \dot{v}\right)}{\sigma'\left(\oint u^i ds_i + \dot{u}\right)} = 0$$

Average energy density $= -V_{vac} + \rho_{local}$

- Plus $\dot{\Lambda} = 0$
- $\Lambda = \Lambda(t=0) = -\frac{\int d^3x\, H_m}{\int d^3x\, N\sqrt{h}} - \frac{\kappa^2\mu^4}{M_P^2}\frac{\tau\prime\left(\oint v^i ds_i + \dot{v}\right)}{\sigma\prime\left(\oint u^i ds_i + \dot{u}\right)}$ at t=0

$$\Rightarrow \Lambda + V_{vac} = UV\ insensitive\ residual\ CC$$

Conclusion

- Vacuum energy sequestering: mechanism for cancelling loop corrections exhaustively via global constraints
- Vacuum energy "sequestered" via tertiary constraint-like equation
- Equivalence principle broken globally
- Graviton loops can also be included!

Thank you for your attention