The fate of horizons under quantum corrections.

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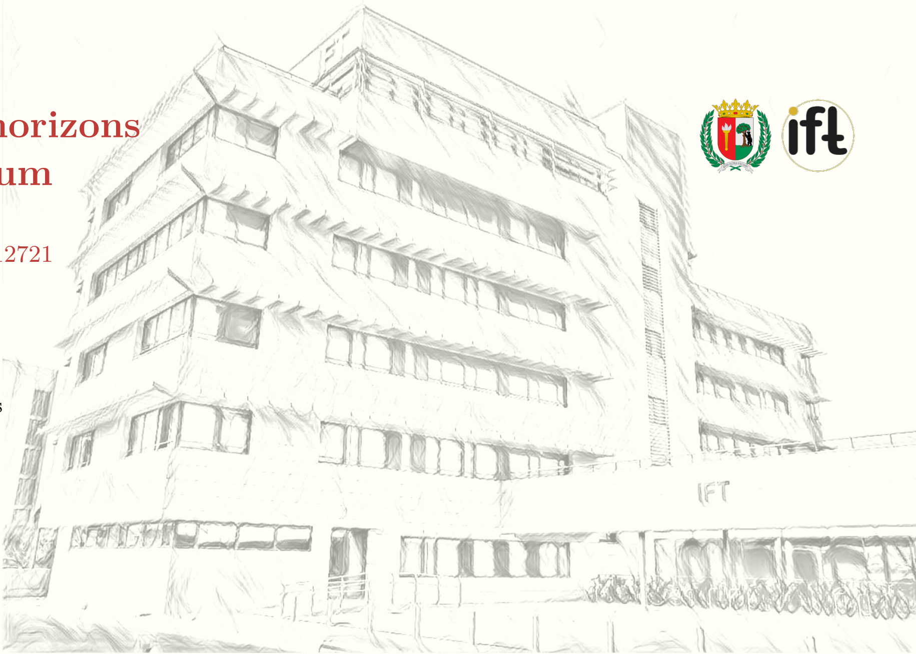

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Table of Contents

Introduction

Higher-derivative Gravity

- Gravity as an EFT
  - Einstein-Hilbert Lagrangian is the lowest order term.
  - Higher operators in curvature giving the corrections from an unknown UV theory.

Introduction

Renormalization of GR.

- Renormalization of GR to one[1] and two loops[2] "introduces" the counterterms,

$$L_{\infty}^{(1)} \propto \int d^4x \sqrt{|g|} \left(\frac{1}{60} R^2 + \frac{7}{10} R^2{}_{\mu\nu} \right) \xrightarrow{On-shell} 0$$

$$L_{\infty}^{(2)} \propto \int d^4x \sqrt{|g|} R_{\mu\nu\zeta\xi} R^{\zeta\xi\rho\sigma} R_{\rho\sigma}{}^{\mu\nu} \xrightarrow[On-shell]{} \int d^4x \sqrt{|g|} W_{\mu\nu\zeta\xi} W^{\zeta\xi\rho\sigma} W_{\rho\sigma}{}^{\mu\nu},$$

with $W_{\mu\nu\zeta\xi}$ the Weyl tensor.

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[1] G. 't Hooft and M. J. G. Veltman, 'One loop divergencies in the theory of gravitation', Ann. Inst. H. Poincare Phys. Theor. 20, 69–94 (1974).

[2] M. H. Goroff and A. Sagnotti, 'Quantum gravity at two loops', Physics Letters B 160 (1985).

Introduction

Spherically-symmetric spacetimes I

- The action we considered is

$$S = \int d^4x \sqrt{|g|} \Big\{ -\frac{1}{2\kappa^2} R + \omega\kappa^2 W_{\mu\nu\zeta\xi} W^{\zeta\xi\rho\sigma} W_{\rho\sigma}{}^{\mu\nu} \Big\}$$

- **QUESTION:** Are Schwarzschild's solution and its horizon structurally stable under the GS perturbation?
- We only considered spherically-symmetric (S-S) spacetimes.

Introduction

Spherically-symmetric spacetimes II

- In GR there is Birkhoff's Theorem → Schwarzschild.
- Quadratic terms are compatible with Schwarzschild's solution.
- GS counterterm is Schwarzschild-excluding [3].
  - How bad is the incompatibility under small perturbations?
  - Do perturbations remove the event horizons?
  - Birkhoff?

[3] S. Deser and B. Tekin, 'Shortcuts to high symmetry solutions in gravitational theories', Classical and Quantum Gravity 20, 4877–4883 (2003).

Table of Contents

Results

Solutions to the GS EoM I.

- We could not find exact solutions to the complete EoM.
- Power series and perturbative solutions.
- Many non-trivial conformally-flat solutions to the GS counterterm.

Results

Solutions of CG I.

- Let us compare with conformal gravity (CG).

$$S = \int d^4x\sqrt{|g|}\Big\{W_{\mu\nu\zeta\xi}W^{\zeta\xi\mu\nu}\Big\}$$

vacuum solutions are related to the traceless Bach's tensor,

$$B_{\mu\nu} := \nabla^{\lambda}\nabla_{\lambda}K_{\mu\nu} - \nabla^{\lambda}\nabla_{\mu}K_{\lambda\nu} + K^{\lambda\beta}W_{\lambda\mu\beta\nu} = 0,$$

where the Schouten tensor is,

$$K_{\mu\nu} := \frac{1}{n-2}\left(R_{\mu\nu} - \frac{R}{n-1}g_{\mu\nu}\right)$$

Results
Solutions of CG II.

- The equations of motion,

$$B_{\mu\nu} := \nabla^{\lambda}\nabla_{\lambda}K_{\mu\nu} - \nabla^{\lambda}\nabla_{\mu}K_{\lambda\nu} + K^{\lambda\beta}W_{\lambda\mu\beta\nu} = 0,$$

  Admit Schwarzschild's spacetime, which is not conformally flat.
- They also admit any S-S conformally flat solution.

Results

Solutions to the GS EoM I.

- Given an S-S spacetime with the line element,

$$\mathrm{d}s^2 = B(r,t)\,\mathrm{d}t^2 - A(r,t)dr^2 - r^2\,\mathrm{d}\Omega_2^2,$$

- The GS counterterm,

$$S = \int d^4x\sqrt{|g|}\Big\{W_{\mu\nu\zeta\xi}W^{\zeta\xi\rho\sigma}W_{\rho\sigma}{}^{\mu\nu}\Big\}$$

has S-S vacuum solutions satisfying a unique condition. **The solutions have to be Weyl flat.**

Results

Solutions to the GS EoM II.

- Any S-S conformally flat metric will be a vacuum solution to the GS EoM.
- Since these solutions also belong to the set of solutions of CG, the proof for Birkhoff's theorem in CG[4] holds.
  Thus, **all the S-S vacuum solutions to the GS EoM are static**.
- This is expected to hold for contractions of $p \geq 3$ Weyl tensors.

[4] Riegert, R. J.'Birkhoff's Theorem in Conformal Gravity', In Physical Review Letters (Vol. 53, Issue 4, pp. 315–318). American Physical Society (APS) (1984).

Results

Power Series analysis.

- As a way to probe the singular behavior near $r = 0$ we considered,

$$A(r) := r^s \left(a_s + a_{s+1}\, r + \cdots\right),$$
$$B(r) := b_t r^t \left(1 + b_{t+1}\, r + \cdots\right),$$

  and see the (s, t) values that solve the EoM.

- Only,

$$(0,0) \qquad \text{and} \qquad (2,2)$$

  The GS term *dominates* the EoM for $r \to 0$. The singularity cannot be that of Schwarzschild $(1, -1)$.

Results

Perturbations of the Horizon.

- To test the horizon region we considered a perturbative expansion of the g_{00} component of the metric near the horizon.
- For arbitrarily small perturbations the horizon is just shifted.
- For a region of the parameter space there are horizonless solutions.

Table of Contents

Summary and Conclusions

- We found a unique condition that characterizes all the spherically symmetric vacuum solutions to the GS counterterm EoM.
- Quantum corrections induce the GS counterterm. This modifies the EoM. A perturbative analysis indicates that they might admit horizonless solutions.
- Open questions;
  - Can we put the absence of the horizon on solid ground with an exact solution?
  - Can we extend our conclusions to less symmetric spacetimes?

Q & A

Thanks for your attention!