Gravitational symmetries and the quantum vacuum

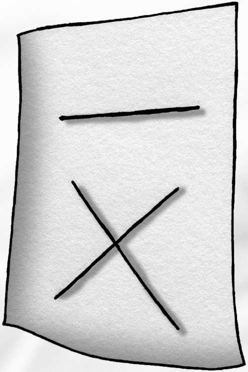
Raúl Carballo-Rubio

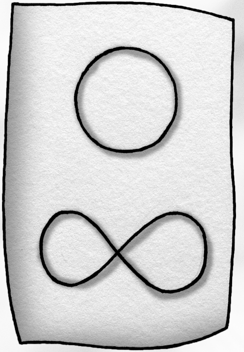
Instituto de Astrofísica de Andalucía (IAA-CSIC), Spain

IberiCOS 2015 - March 30

The quantum vacuum

- Scattering amplitudes and vacuum bubbles:

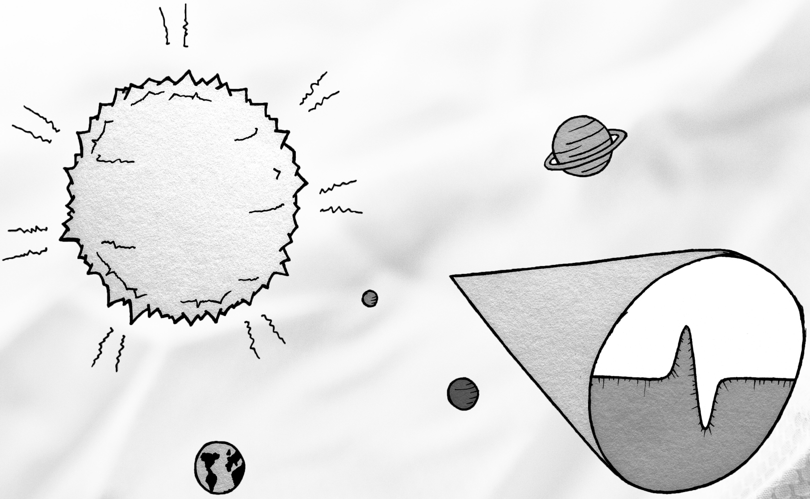




- Vacuum bubbles couple to a dynamical volume form:

$$\sqrt{|g|}\, dx^1 \wedge \ldots \wedge dx^n$$

Our solar system



The cosmological constant problem

- Natural theoretical prediction:

$$|\Lambda_{vac}| \sim 10^8 \text{ GeV}^4$$

- Measured perihelion precession of Mercury:

$$\Delta\varphi = 574.10 \pm 0.65 \text{ arc-seconds per century}$$

- It implies

$$|\Lambda| \leq 10^{-32} \text{ GeV}^4$$

Symmetry protection

- Scale transformations of the gravitational field:

$$g_{ab} \longrightarrow \zeta^2 g_{ab} \qquad\qquad \zeta \in \mathbb{R}$$

- The Einstein-Hilbert action is not invariant under this symmetry.
- Even worse: quantum effects generally spoil scale invariance (conformal anomaly).

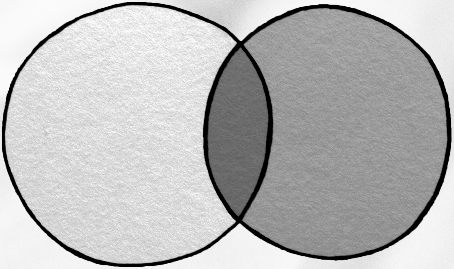
Conformal anomaly

- Diffeomorphisms:

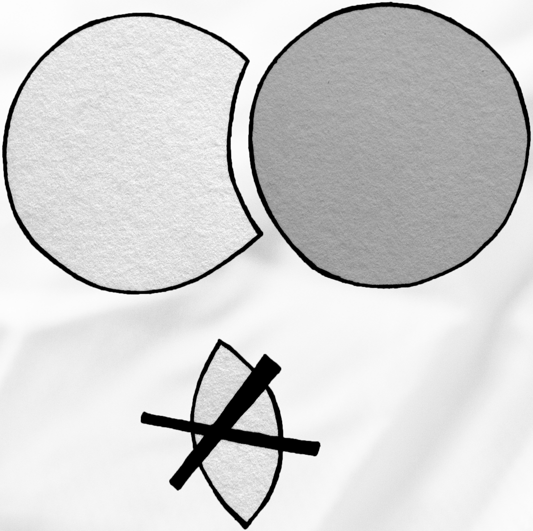
$$\delta\sqrt{|g|} \propto \nabla_a \xi^a$$

- Weyl transformations:

$$\delta\sqrt{|g|} \propto \Omega^4$$



Avoiding the anomalies



Weyl transverse gravity

$$\mathcal{A} := \frac{1}{2\kappa} \int d^n x \, R[|g|^{-1/n} g_{ab}]$$

- Gravity in a 'conformal manifold' of dimension $n \geq 4$.
- Invariant under transverse diffeomorphisms and Weyl transformations:

$$\delta_{\xi,\varphi} g_{ab} = \mathcal{L}_\xi g_{ab} + \varphi g_{ab} \qquad \partial_a \xi^a = 0$$

- Dynamical volume element forbidden by symmetries (incompressible spacetime).
- Matter couples to the composite field

$$|g|^{-1/n} g_{ab}$$

Classical theory

- In the gauge $g = 1$, one recovers the traceless Einstein equations

$$R_{ab}(g) - \frac{1}{4}R g_{ab} = \frac{8\pi G}{c^4}\left(T_{ab} - \frac{1}{4}T g_{ab}\right)$$

- These equations are equivalent to Einstein field equations in the same gauge (Ellis2010).

- The cosmological constant is a constant of integration.

Semiclassical theory

- Classical gravitational fields, quantum matter fields.
- Heat kernel expansion of the effective action leads to renormalization of gravitational couplings:

$$\frac{1}{\kappa} = \frac{1}{\kappa_0} + c_1\mu^2 + c_2 \log\left(\frac{\mu}{c_3}\right)$$

- There is no renormalization equation for the cosmological constant.
- Protected by symmetry:

$$g_{ab} \to \zeta^2 g_{ab}$$

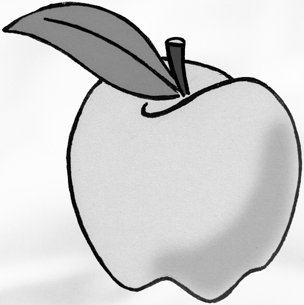
Conclusions

- Weyl transverse gravity

A theory with transverse (volume-preserving) diffeomorphisms and Weyl transformations which:

- Describes a self-interacting spin-2 particle.
- Compatible with classic gravitational experiments.
- Shows different semiclassical physics than general relativity: no CC problem.

Quantum gravity?



Thank you for your attention.

For more details: arXiv:1502.05278