Quantum Simulation of Liouville Gravity Coupled to Fermions

ENCODING SEMICLASSICAL GRAVITY IN LOW DIMENSIONS AS A GAUGE THEORY

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One of the most outstanding challenges both in quantum simulation of gauge theories and gravity is the incorporation of consistent backaction between the matter degrees of freedom and the gauge/gravitational fields. Not only the experimental implementation becomes extremely challenging but also the encoding or mapping, to the point that there are not many realistic proposals for the quantum simulation of toy models of semiclassical or quantum gravity. We propose the study of 1+1D dilaton gravity coupled to conformal matter, in particular to massless Dirac fermions. Our approach relies on the fact that General Relativity is, by construction, a gauge theory. The dynamical behaviour of spacetime is present even in the absence of a curved gravitational background. This could open the door to the exploration of semiclassical models of gravity in table-top experiments where backaction is incorporated in a natural way.

GRAVITY LANDSCAPE

GENERAL RELATIVITY (GR): A CLASSICAL FIELD THEORY

$G_{\mu\nu}$ Gravity is Spacetime Geometry

$T_{\mu\nu}$ Matter/Energy sources Gravity

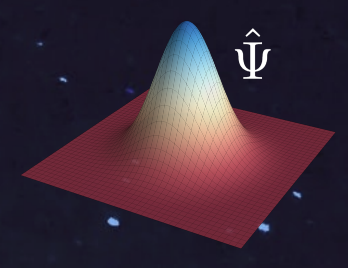
$$S_{\text{EH}} = \frac{1}{\kappa_D}\int d^D x\,\sqrt{-g}\,\Big(R + \mathcal{L}_{\text{Matter}}\Big)$$

THE LADDER OF COMPLEXITY

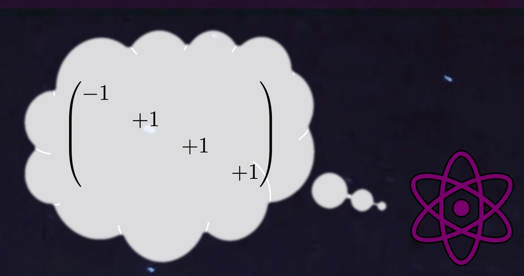
$\hat{G}_{\mu\nu} = \frac{\kappa_D}{2}\hat{T}_{\mu\nu}$	Quantum Gravity	?	
$G_{\mu\nu} = \frac{\kappa_D}{2}\langle\hat{T}_{\mu\nu}\rangle$	Semiclassical Gravity		BH Evaporation
$G_{\mu\nu} = \frac{\kappa_D}{2}T_{\mu\nu}$	Classical Gravity (GR)		Grav. Waves
$\hat{T}_{\mu\nu} + g_{\mu\nu}$	QFT in Curved Spacetime		Hawking Radiation

THE CONUNDRUM

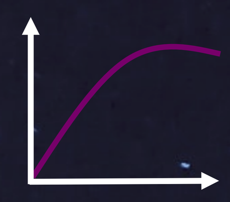
INGREDIENTS FOR THE SIMULATION OF A QFT IN CURVED SPACETIME



Quantum Field



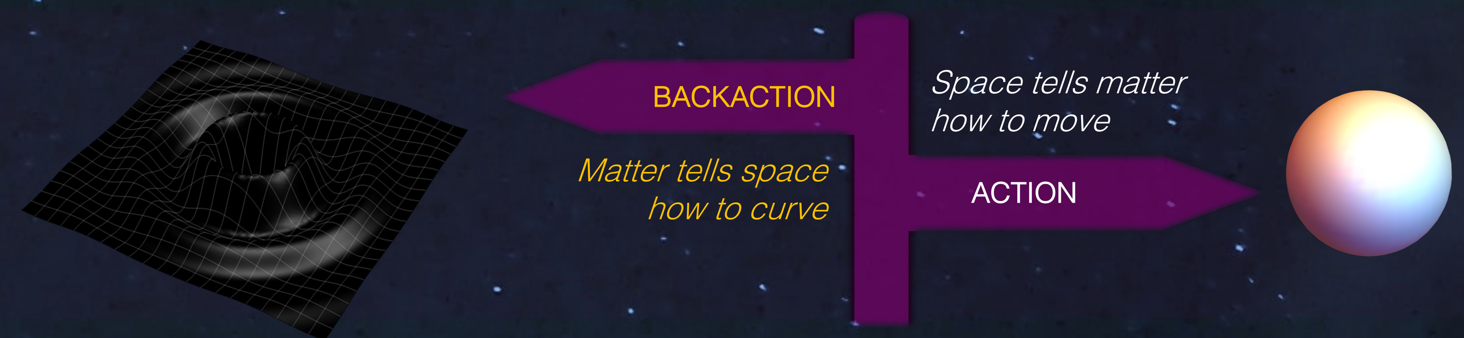
Encoding Spacetime Geometry



Linear Dispersion

Identifying Relevant Observable

DYNAMICAL GRAVITY: INCORPORATING BACKACTION ?



APPROACH: GRAVITY AS A GAUGE THEORY

Quantum Simulation of Dynamical Synthetic Gauge Fields
$S = S_{\text{G}} + S_{\text{int}} + S_{\text{M}}$

Reduce Complexity: Go to 1+1D dimensions without compromising richness
BHs, GWs, Cosmology, Strings, AdS/CFT and Quantum Gravity

Gravity in Low dimensions is topological with no local dynamics
$\int_{\mathbb{R}^2}\sqrt{-g}\,R = 4\pi\chi$

A natural way out is dilaton gravity
Imagine Newton's constant is a varying (Brans-Dicke) scalar field

LIOUVILLE GRAVITY

$$S_G[g] = -\frac{1}{2\pi\gamma^2}\int d^2x\,\sqrt{-\tilde{g}}\,\Big[\tilde{g}^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi + QR\,[\tilde{g}]\,\phi + \Lambda e^{2\phi}\Big]$$

Conformal Gauge : $g_{\mu\nu} = e^{2\phi(t,x)}\,\tilde{g}_{\mu\nu}$

- $g_{\mu\nu}$: Physical (Dynamical) Metric
- $e^{2\phi(t,x)}$: Dilaton (Scalar) Field
- $\tilde{g}_{\mu\nu}$: Fiducial (Background) Metric

RESULTS

work in progress

1 Minimally Couple Conformal Matter to Gravity $S = S_G + S_D$

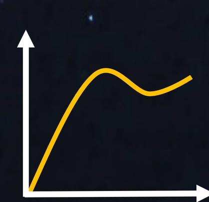
$$S_{\text{D}}[\psi, g] = \frac{i}{2}\int d^Dx\,\sqrt{|g|}\,\bar{\psi}\,\gamma^\mu \overleftrightarrow{D}_\mu\,\psi \quad \text{with} \quad \vec{D}_\mu = \partial_\mu + \frac{1}{4}\omega_\mu^{AB}\sigma_{AB}$$

Spin connection is dynamical $\quad \omega_\mu^{AB}[\tilde{g},\phi] = \tilde{\omega}_\mu^{AB}[\tilde{g}] + \Sigma_\mu^{AB}[\tilde{g},\phi]$

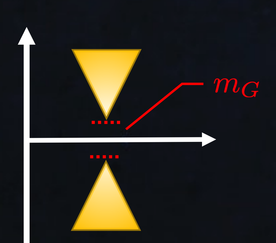
2 Equations of Motion are Coupled

Gravity: $\Box\phi = V\,[\tilde{g},\phi] + F\,[\psi;\tilde{g},\phi]$

Matter: $\Big(i\gamma^\mu\partial_\mu - m_G[\tilde{g},\phi]\Big)\psi = 0$



Phonons



Dirac cones

3 Limit Cases

Flat background geometry: $\tilde{g}_{\mu\nu} = \eta_{\mu\nu}$

Vanishing Cosmological Constant: $\Lambda = 0$

Gravity: $\partial_\mu\partial^\mu\phi = F\,[\psi;\phi]$

Matter: $m_G[\phi] = \frac{1}{2}\Big(\sigma_x\,\partial_t\phi + i\sigma_y\,\partial_x\phi\Big)$

Non-trivial backaction !

4 Further Work

Too difficult ? Try Yukawa / Dirac-Higgs / Jackiw-Rebbi

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) + i\bar{\psi}\gamma^\mu\partial_\mu\psi - g\bar{\psi}\phi\psi$$

Too easy ? Quantum Cosmology, Dynamical particle creation, Quantum Gravity, General dilaton models, Strings…

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