Title: A post-quantum theory of classical gravity?

Speakers: Jonathan Oppenheim

Series: Quantum Foundations

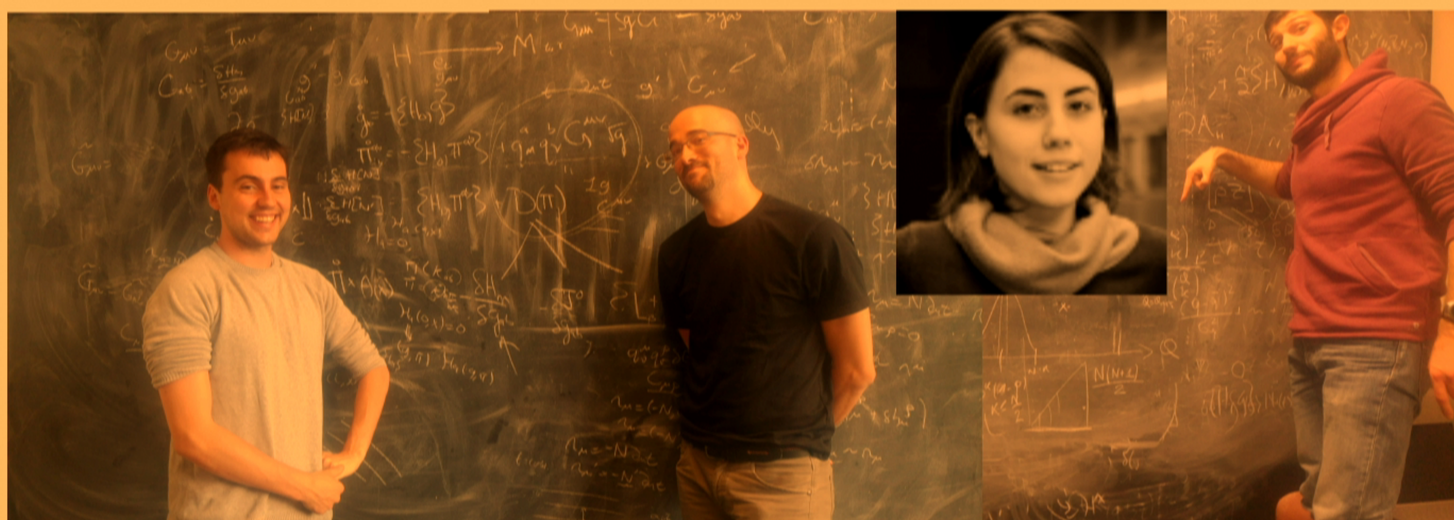
Date: November 26, 2019 - 3:30 PM

URL: http://pirsa.org/19110143

Abstract: We consider a consistent theory of classical systems coupled to quantum ones. The dynamics is linear in the density matrix, completely positive and trace-preserving. We apply this to construct a theory of classical gravity coupled to quantum field theory. The theory doesn't suffer the pathologies of semi-classical gravity and reduces to Einstein's equations in the appropriate limit. The assumption that gravity is classical necessarily modifies the dynamical laws of quantum mechanics -- the theory must be fundamentally information destroying involving finite sized and stochastic jumps in space-time and in the quantum field. Nonetheless the quantum state of the system can remain pure conditioned on the classical degrees of freedom. The measurement postulate of quantum mechanics is not needed since the interaction of the quantum degrees of freedom with classical space-time necessarily causes collapse of the wave-function. The theory can be regarded as fundamental, or as an effective theory of quantum field theory in curved space where backreaction is consistently accounted for.

A post-quantum theory of classical gravity?

- arXiv:1811.03116, ...
- w/ Camps, Soda, Sparaciari, Weller-Davies



“It from Qubit” Postdocs and studentships

To be held at:

Vijay Balasubramanian (UPenn)

Patrick Hayden (Stanford)

Alexei Kitaev(Caltech)

Don Marolf (UCSB)

Jonathan Oppenheim (University College London)

Mark Van Raamsdonk (UBC)

Other members of the collaboration include:

Horacio Casini (Bariloche)

Daniel Harlow (MIT)

Alex Maloney (McGill)

Juan Maldacena (IAS)

Rob Myers (Perimeter)

Scott Aaronson (UT Austin)

Dorit Aharonov (Jerusalem)

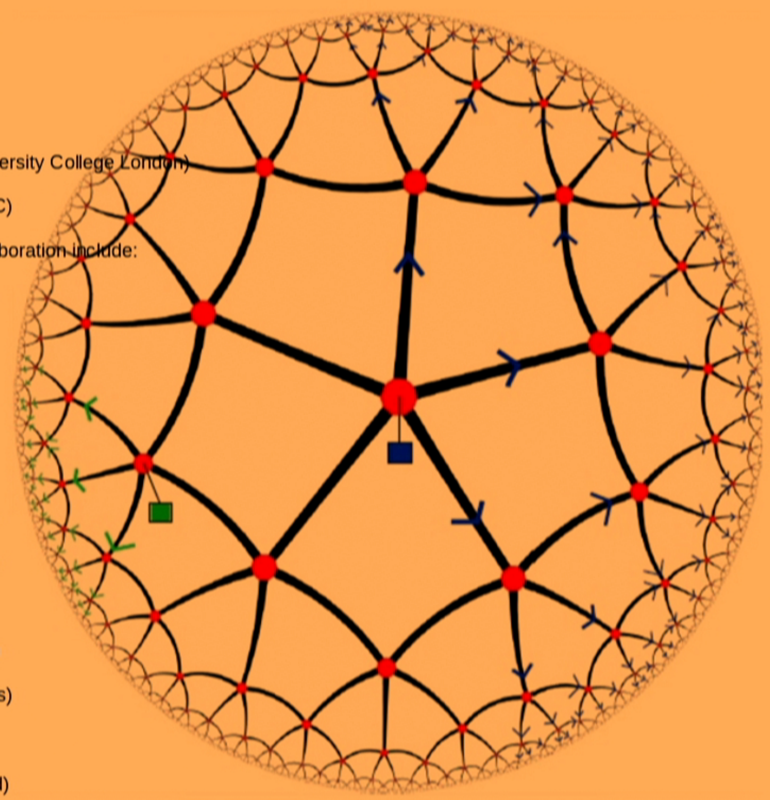
Brian Swingle (Maryland)

Tadashi Takayanagi (Kyoto)

Matthew Headrick (Brandeis)

John Preskill (Caltech)

Leonard Susskind (Stanford)



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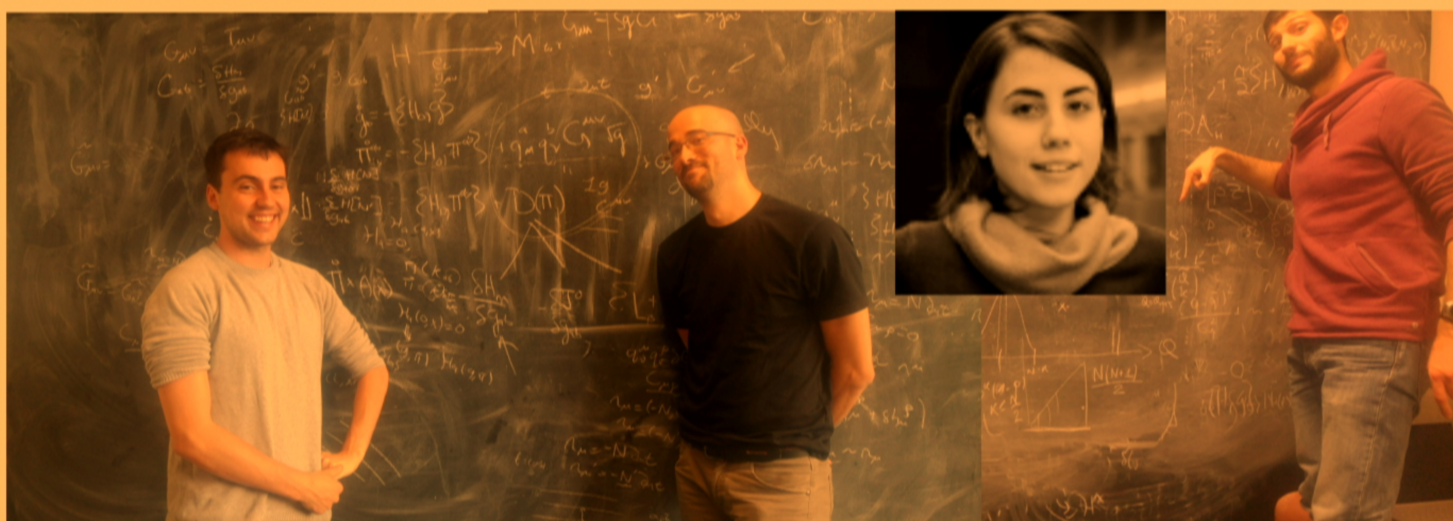
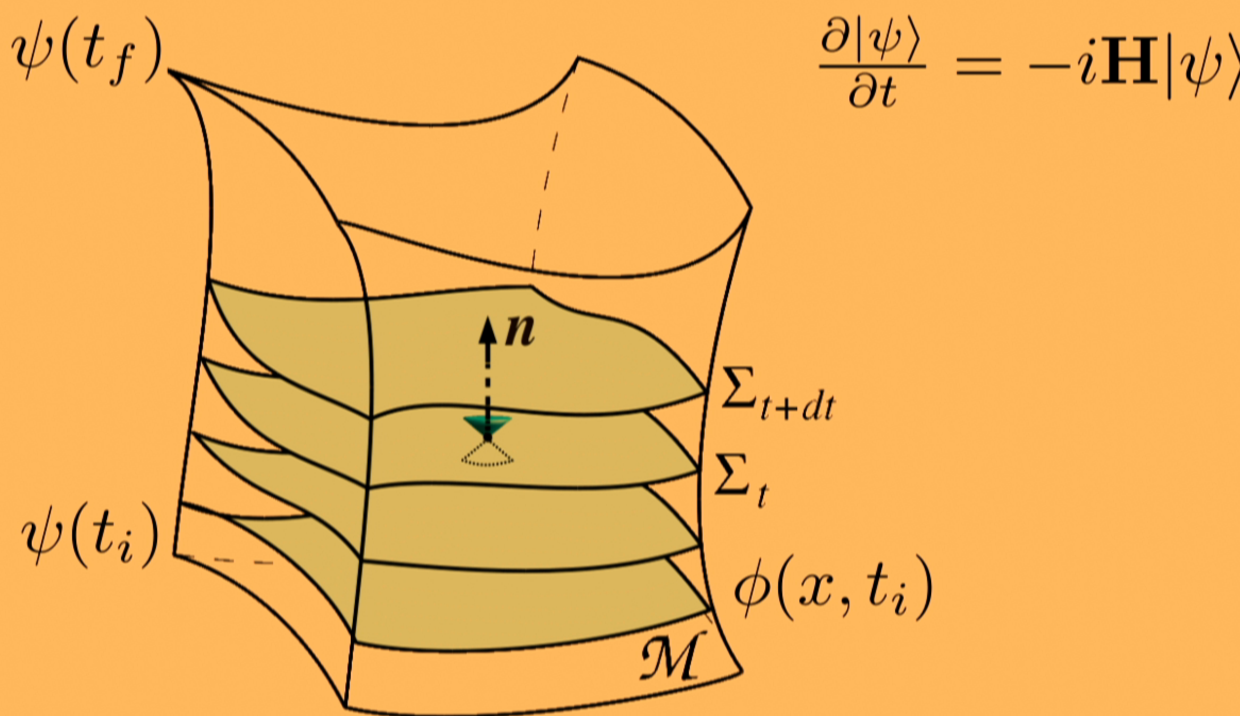
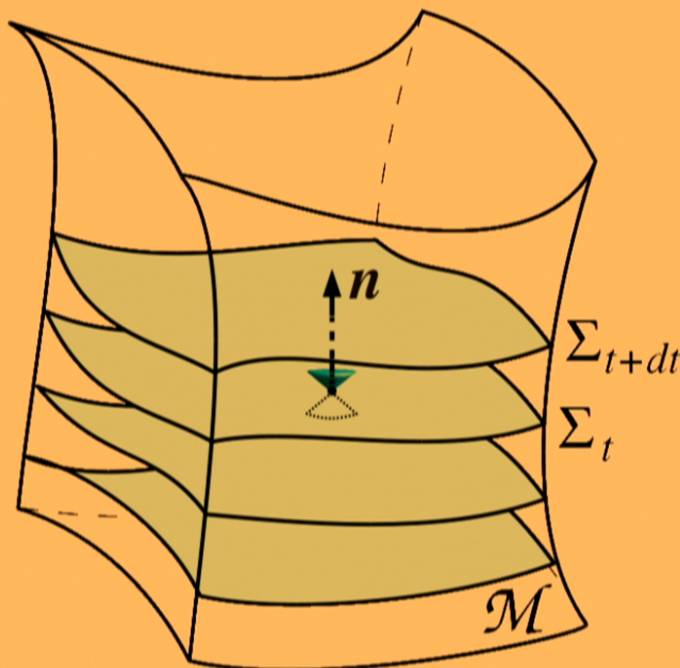


UCL

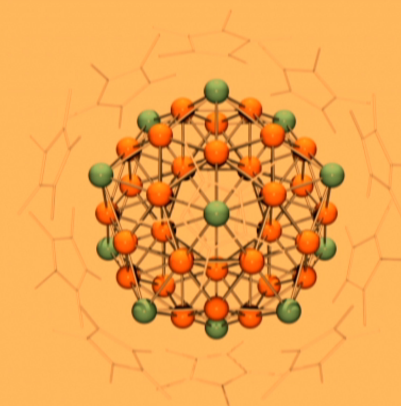
Quantum theory has a future



Should we quantise space-time?

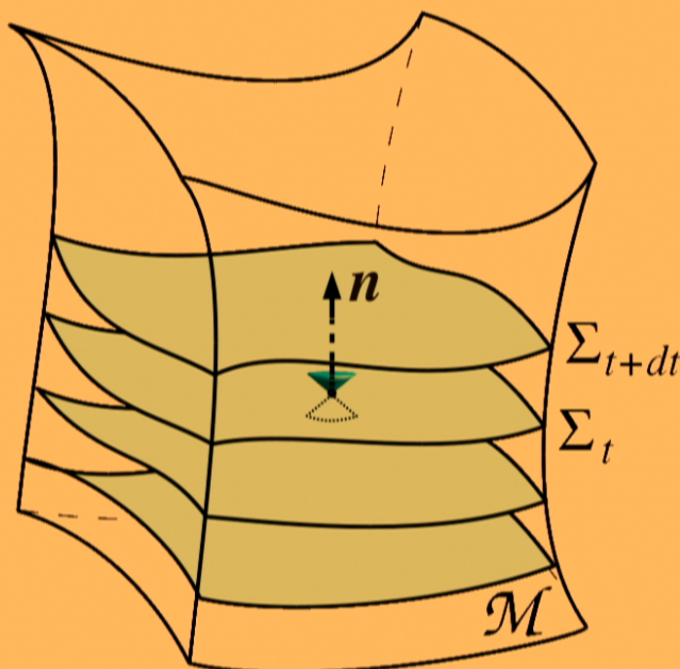


$g_{ab}(x,t)$

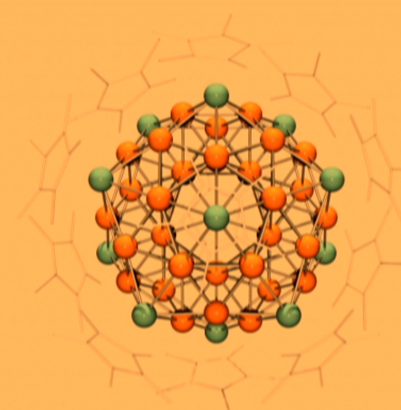


$\phi(x,t)$

Should we quantise space-time?



$g_{ab}(x,t)$



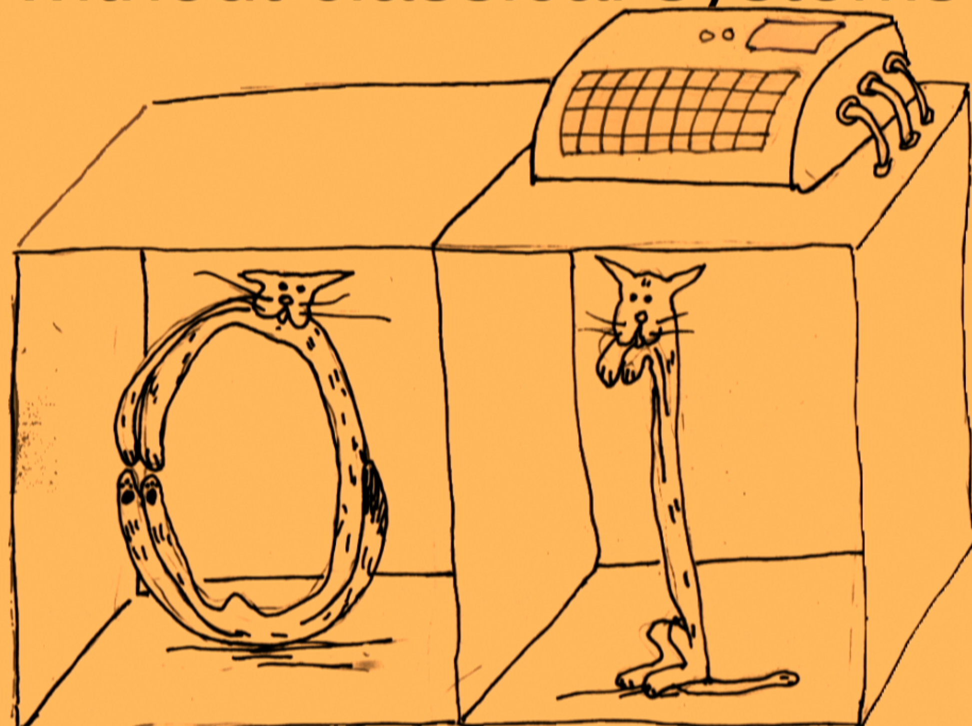
$\phi(x,t)$

Is space-time classical?

I have no idea. But….

- It can be
- It would necessarily cause “collapse of the wave-function”
- It would necessarily lead to information destruction
- Effective theory?

Does it make any sense to speak of the emergence of classicality without classical systems?



$$|\psi\rangle = \frac{1}{\sqrt{2}}\Big(|0000000...\rangle + |1111111...\rangle\Big)$$

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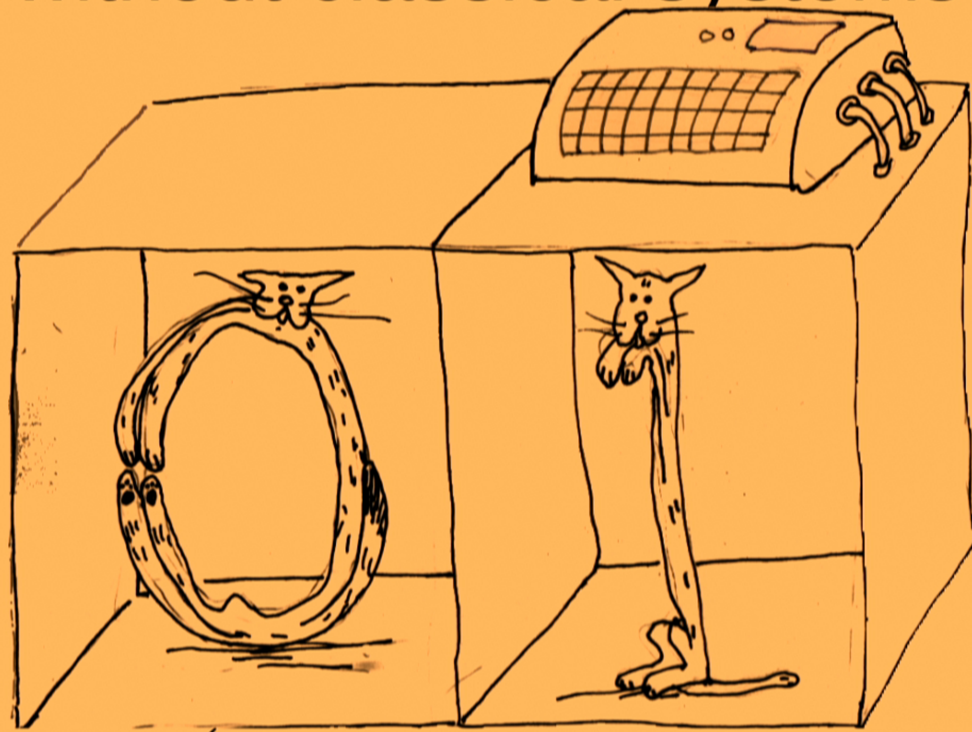
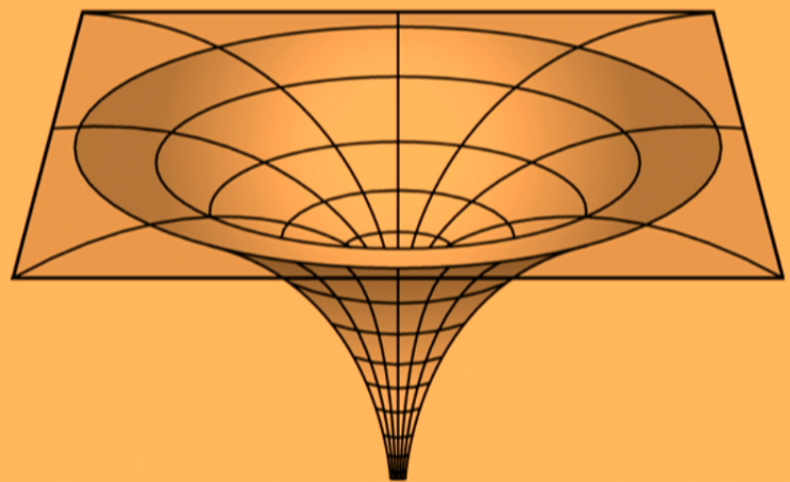


$$|\psi\rangle = \frac{1}{\sqrt{2}}\Big(|0000000...\rangle + |1111111...\rangle\Big)$$

Black hole information problem 2.0



AMPS: If information is preserved we must break the equivalence principle (a firewall).

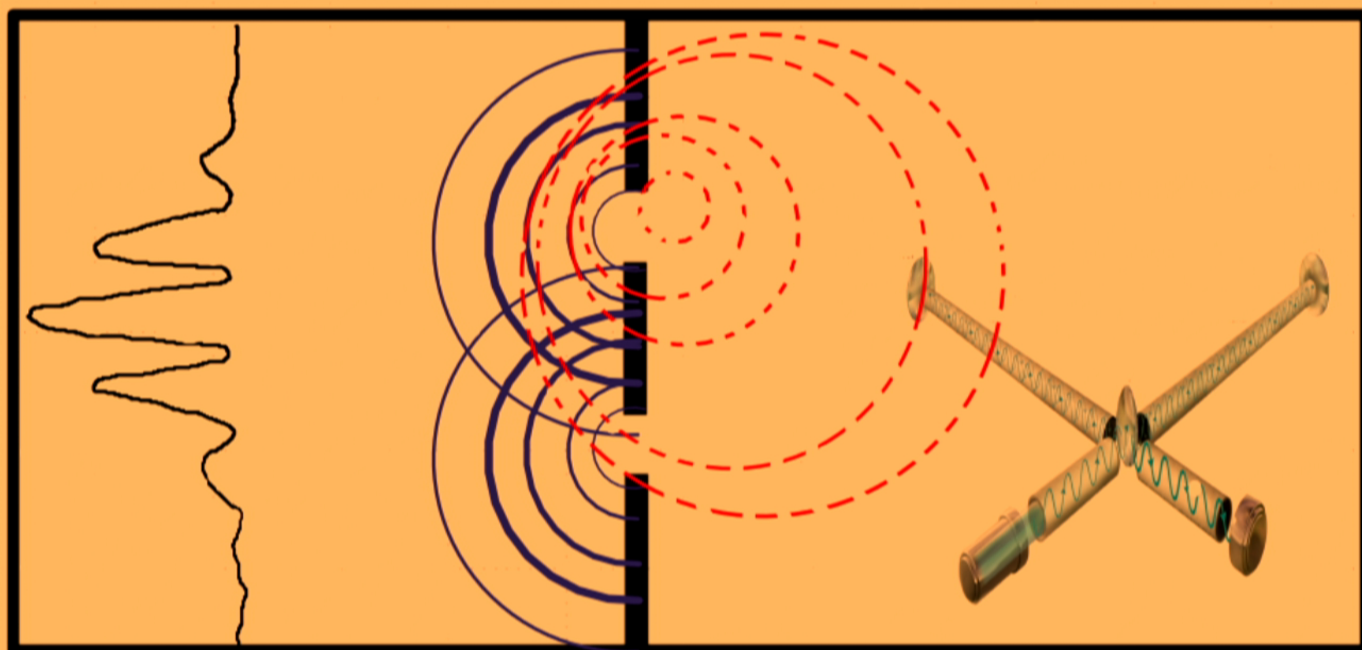
BPS: If information is destroyed we must sacrifice locality or energy conservation.

Almheiri, Marolf, Polchinski, Sully (2012)
Banks, Peskin, Susskind (1984)

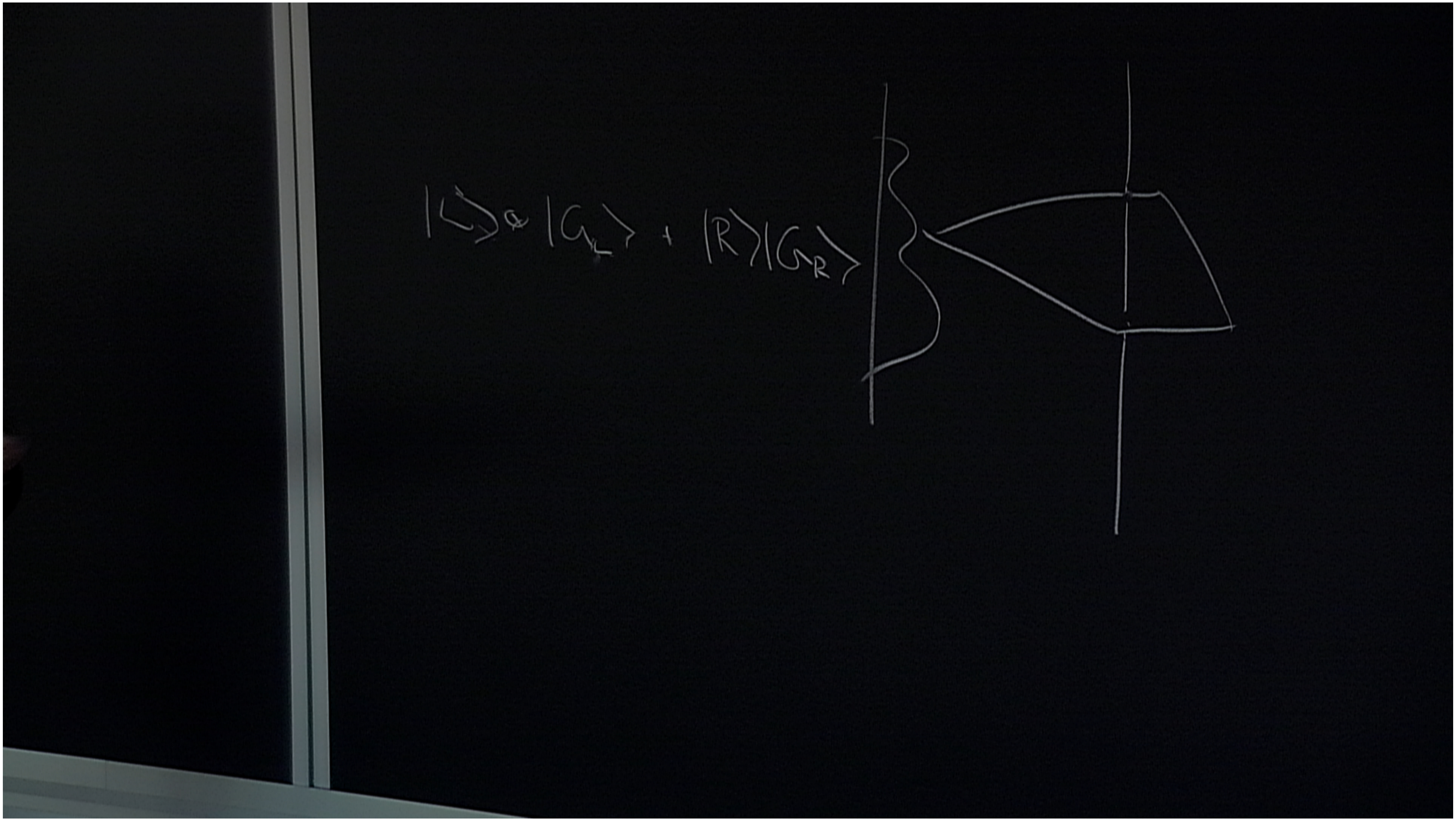
Outline

- Can we couple quantum and classical systems?
- What is the general form of this dynamics?
- Non-commuting finite difference: ∇
- Applying this to General Relativity/QFT

Can we?

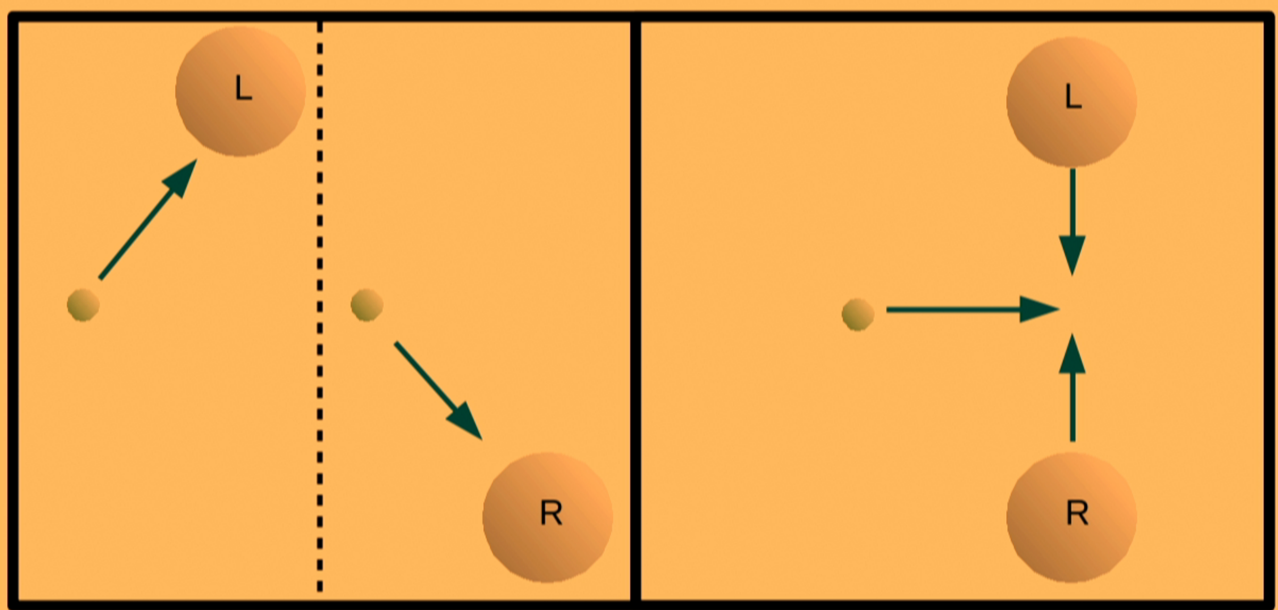


Feynman, Chapel Hill Conference (1957)
Eppley and Hannah (1977)
Marletto and Vedral (2017)


$|L\rangle \otimes |G_L\rangle + |R\rangle |G_R\rangle$

Semi-classical gravity?

$$G_{\mu\nu} = \frac{8\pi G}{c^4} \langle \mathbf{T}_{\mu\nu} \rangle$$

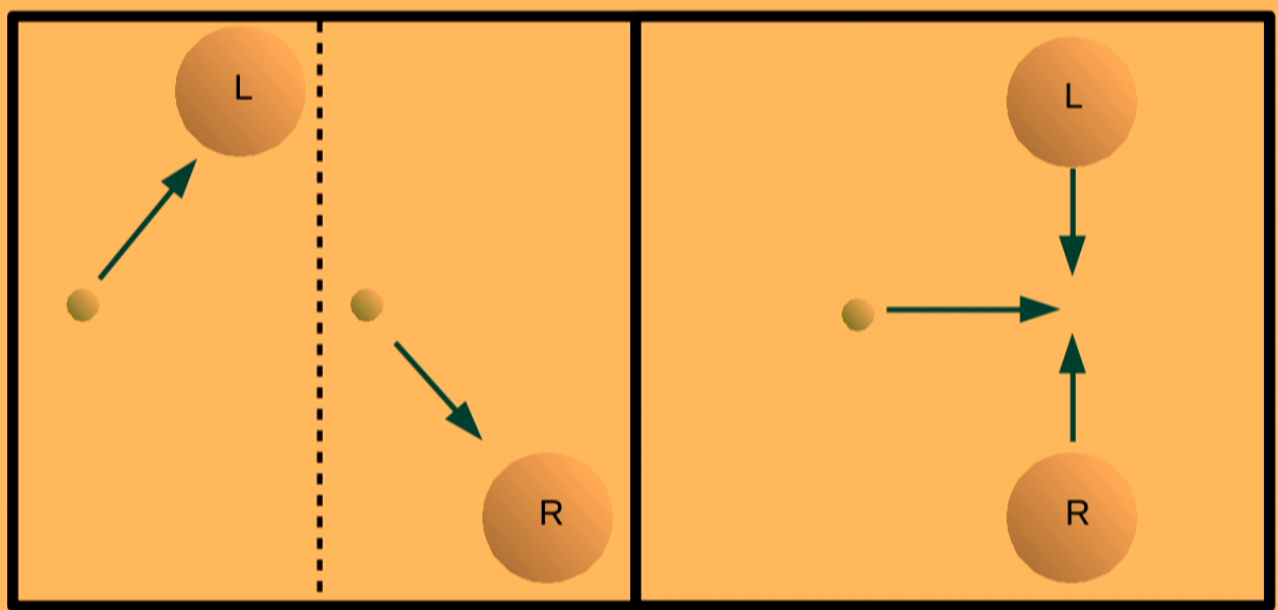


This or that

Not this!

Semi-classical gravity?

$$\cancel{G_{\mu\nu} = \frac{8\pi G}{c^4}\langle \mathbf{T}_{\mu\nu}\rangle}$$



This or that

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- Can we couple quantum and classical systems?
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What kind of dynamics is allowed?

$\sigma(t) = \sum_\mu K_\mu \sigma(0) K_\mu^\dagger \qquad K_\mu^\dagger K_\mu = \mathbb{1}$ Kraus (87)

$\rho(q,p;t) = \int dq'dp' P(q,p|q',p')\rho(q',p';0) \qquad \int dqdp P(q,p|q',p') = 1, P(q,p|q',p') \geq 0$

$$\varrho(q,p;t) = \int dq'dp' \sum K_\mu(q,p|q',p')\varrho(q',p',0)K_\mu(q,p|q',p')^\dagger$$

$$\sum_\mu \int dqdp\, K_\mu(q,p|q',p')^\dagger K_\mu(q,p|q',p') = \mathbb{1}$$

Non-commuting finite difference

$$\frac{\partial \varrho(q,p)}{\partial t} = -i[\mathbf{H}(q,p), \varrho(q,p)] + \sum_{\alpha\beta} \int dq' dp' W^{\alpha\beta}(q,p|q',p') \mathbf{L}_\alpha \varrho(q,p') \mathbf{L}_\beta^\dagger - \frac{1}{2} W^{\alpha\beta}(q,p) \{\mathbf{L}_\beta^\dagger \mathbf{L}_\alpha, \varrho(q,p)\}$$

$$\frac{\partial \rho(q,p)}{\partial t} = \{\mathbf{H}(q,p), \varrho(q,p)\} + \cdots$$

$$\mathbf{H}(q,p) = h^{\alpha\beta}(q,p) \mathbf{L}_\beta^\dagger \mathbf{L}_\alpha$$

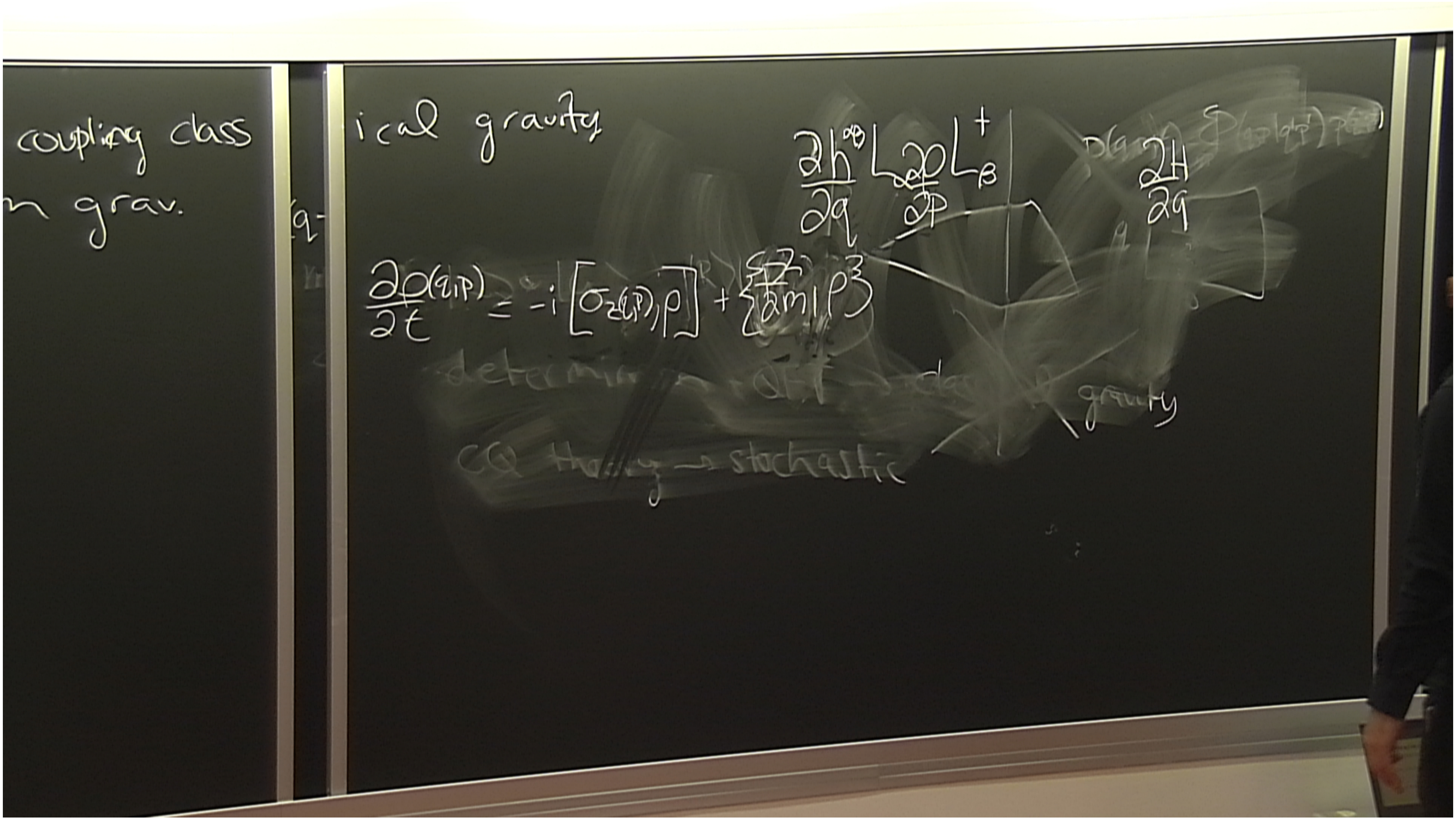
$$\boldsymbol{\nabla}_h^{\alpha\beta} \varrho(q,p) e_{\alpha\beta} = \frac{1}{\tau} \left(\mathbf{L}_\alpha e^{\tau\{h^{\alpha\beta},\cdot\}} \varrho(q,p) \mathbf{L}_\beta^\dagger - \frac{1}{2} \{\mathbf{L}_\beta^\dagger \mathbf{L}_\alpha, \varrho(q,p)\} \right)$$

Non-commuting finite difference

$$\frac{\partial \varrho(q,p)}{\partial t} = -i[\mathbf{H}(q,p), \varrho(q,p)] + \sum_{\alpha\beta} \int dq' dp' W^{\alpha\beta}(q,p|q',p')\mathbf{L}_\alpha \varrho(q,p')\mathbf{L}_\beta^\dagger - \frac{1}{2} W^{\alpha\beta}(q,p)\{\mathbf{L}_\beta^\dagger \mathbf{L}_\alpha, \varrho(q,p)\}$$

$$\frac{\partial \varrho}{\partial t} = -iBq[\begin{pmatrix} \omega & 0 \\ 0 & -\omega \end{pmatrix}, \varrho] + \{\frac{p^2}{2m}, \varrho(q,p)\} + \frac{\omega}{\tau} |\uparrow\rangle\langle\uparrow| \varrho(q, p+\tau B) |\uparrow\rangle\langle\uparrow| + \frac{\omega}{\tau} |\downarrow\rangle\langle\downarrow| \varrho(q, p-\tau B) |\downarrow\rangle\langle\downarrow| - \frac{\omega}{2\tau}\{\mathbb{1}, \varrho)\}]$$

w/ Soda, Sparaciari,Weller-Davies (2019)


coupling class
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gravity
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$$\frac{\partial h^{\alpha\beta}}{\partial q} L_\alpha \frac{\partial \rho}{\partial p} L^\dagger_\beta \qquad \frac{\partial H}{\partial q}$$

$$\frac{\partial \rho(q,p)}{\partial t} = -i\left[H(q,p),\rho\right] + \{H_c, \rho\} + \frac{\omega}{\tau}|\uparrow\rangle\langle\uparrow|\,\rho(p+\tau B)\,|\uparrow\rangle\langle\uparrow| + \frac{\omega}{\tau}|\downarrow\rangle\langle\downarrow|\,\rho(p-\tau B)\,|\downarrow\rangle\langle\downarrow|$$

gravity