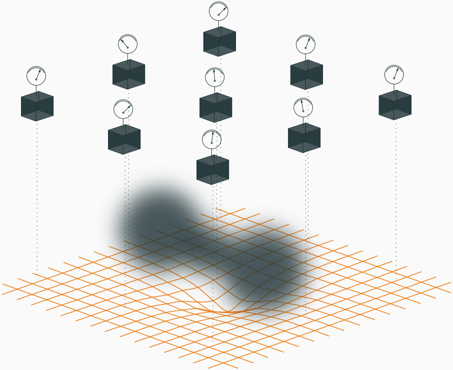
An alternative to Schrödinger-Newton



Antoine Tilloy
Max Planck Institute of Quantum Optics, Germany

Fundamental Problems In Quantum Physics ICTS, Bangalore, India
December 9, 2016

MPQ

Ultimate question:

Is it possible to construct a theory of quantum matter and classical space time –“**fundamental semi-classical gravity**”– without running into conceptual problems?

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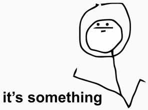
Easier but doable:

Is is possible in the non-relativistic limit?



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$$\partial_\mu \to D_\mu$$

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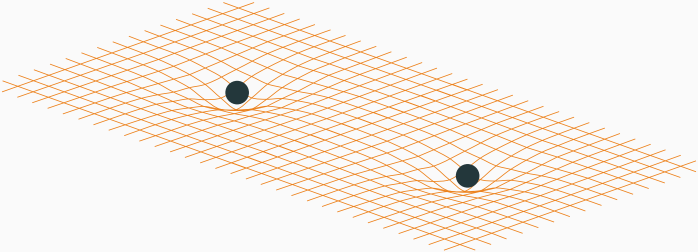
2. **Matter** curves **space-time**:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R \propto T_{\mu\nu}$$



Semi-classical gravity should work in the same way:

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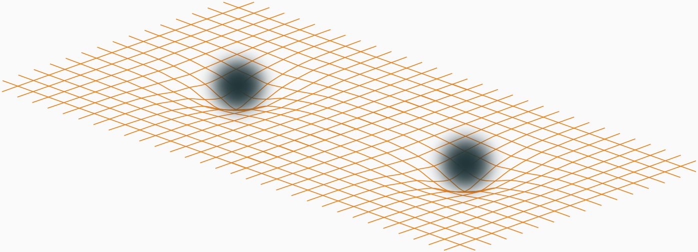
2 **Quantum matter** curves space-time:

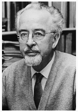
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R \overset{??}{\propto} \underbrace{\hat{T}_{\mu\nu}}_{\text{operator}}$$



Standard approach

The old **choice** (1963), due to Møller and Rosenfeld, is to take $\langle \cdot \rangle$ to get operator$\rightarrow$ scalar:

$$\hat{T}_{\mu\nu}(x) \rightarrow \langle \Psi | \hat{T}_{\mu\nu}(x) | \Psi \rangle$$



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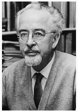

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$$\hat{T}_{\mu\nu}(x) \rightarrow \langle\Psi|\hat{T}_{\mu\nu}(x)|\Psi\rangle$$

In the non-relativistic limit :

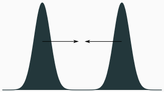
$$\nabla^2\varphi(x) \propto |\psi|^2(x)$$

which gives the **Schrödinger-Newton** equation:

$$i\hbar\partial_t\psi = -\frac{\hbar^2}{2\,m}\nabla^2\psi - G\,m^2 \int d^3y\,\frac{\psi(y)^2}{|x-y|}\,\psi$$

Subtleties with S-N:

The two blobs of the wave function attract each other.



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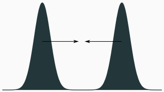

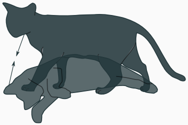

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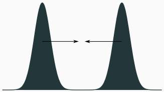

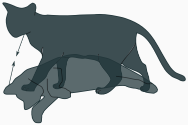

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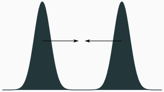

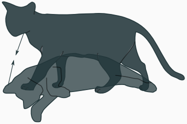

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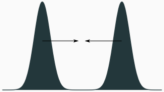

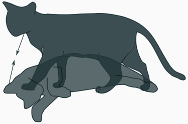

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⇒ So to make sense of **S-N**, one needs some form of macroscopic collapse, a clear primitive ontology, maybe a preferred frame and then it's still not entirely obvious.

Changing of implicit ontology

S-N consists in sourcing the gravitational potential from the matter density ontology, why not try the flash ontology instead?

$$\nabla^2 \varphi(x) \propto S(x)$$

where $S(x)$ is a continuous stochastic field which is the continuous version of the flashes in CSL [also called “signal”].

Fundamental Stochastic Master Equation

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\, i[H + \hat{V}_{\text{pair}}, \rho] + ID + IC + GD + GN$$

Intrinsic decoherence

$$ID = \frac{\gamma}{4} \int \mathrm{d}x\, \mathcal{D}[\hat{M}_\sigma(x)](\rho),$$

Intrinsic collapse

$$IC = \frac{\sqrt{\gamma}}{2} \int \mathrm{d}x\, \mathcal{H}[\hat{M}_\sigma(x)](\rho)\, w(x),$$

Gravitational decoherence

$$GD = \frac{1}{\gamma} \int dx\, \mathcal{D}[\hat{\Phi}(x)](\rho),$$

Gravitational noise

$$GN = \frac{1}{\sqrt{\gamma}} \int \mathrm{d}x\, \mathcal{H}[i\hat{\Phi}(x)](\rho)\, w(x),$$

Pair potential

$$\hat{V}_{\text{pair}} = -\frac{1}{2} G \int \mathrm{d}x\, \mathrm{d}y\, \frac{\hat{M}_\sigma(x)\hat{M}_\sigma(y)}{|x-y|}$$

notations:

$\mathcal{D}[\mathscr{O}](\rho) = \mathscr{O}\rho\mathscr{O} - \{\mathscr{O}^2, \rho\}$

$\mathcal{H}[\mathscr{O}](\rho) = \mathscr{O}\rho + \rho\mathscr{O} - 2\,\mathrm{tr}(\mathscr{O}\rho)\rho$

$\hat{\Phi}(x) = -G \int \mathrm{d}y\, \frac{\hat{M}_\sigma(y)}{|x-y|}$

Results

1 No faster than light signalling

2 The Born rule holds

3 No one-particle self-interaction

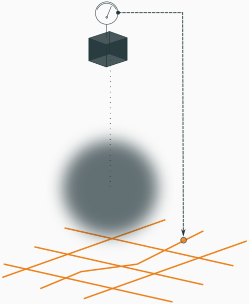
4 Gravitational decoherence **inversely** proportional to intrinsic decoherence $\rightarrow$ falsifiable ($\forall$ param.)

Remaining difficulties

1. Still a regularization scale freedom σ
2. Relativistic extension not so trivial!

Why does it work?

Formally: local mass density measurement and standard quantum feedback



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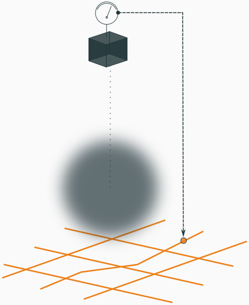
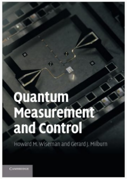
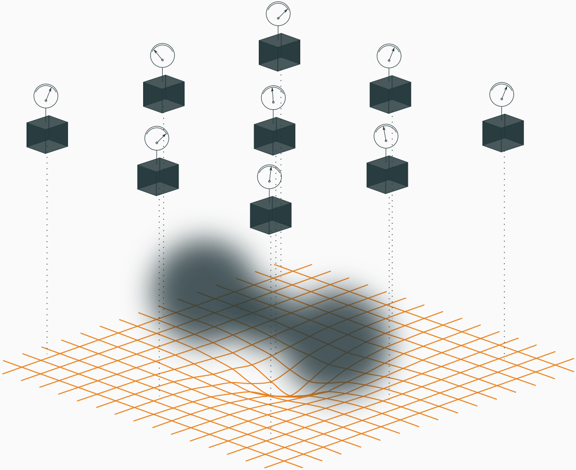


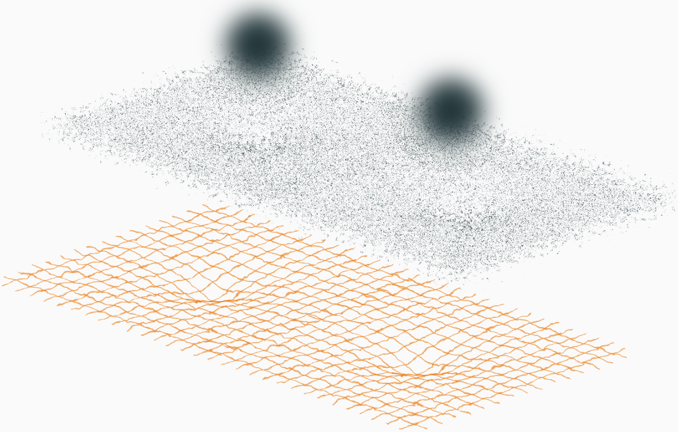
⇒



Formal/mathematical picture



“Reality” picture



Summary

Sourcing the gravitational field from the mass density signal (or "flashes") of a dynamical reduction model provides a paradox free theory of Newtonian quantum gravity.

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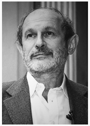
The results presented here are the fruits of a joint work with Lajos Diósi



References:

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M. Derakhshani, `arXiv:1609.01711`