Possibilities for a fundamentally semi-classical theory of gravity

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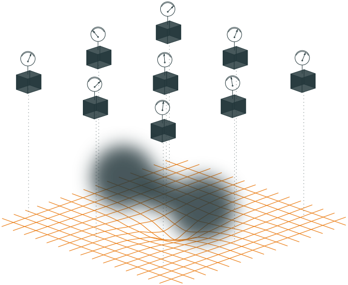

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"Space, Time, and Matter"
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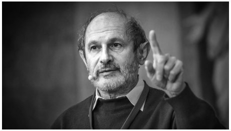
Alexander von Humboldt
Stiftung/Foundation

MPQ

Collaboration with Lajos Diósi



My first "foundational" work, now with new developments: `arXiv:1706.01856`

No experimental evidence for the quantization of gravity
but
romantic and counterintuitive consequences.

Introduction

No experimental evidence for the quantization of gravity
but
romantic and counterintuitive consequences.

Is semi-classical gravity really impossible?
Is romanticism really inevitable?

Outline

1. The arguments for quantized gravity
2. "Standard" semi-classical gravity
3. A (better?) alternative
4. Conclusion

The shaky case for quantization

3 classes of arguments for **quantized** gravity:

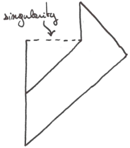
- to cure existing theories
- because of aesthetics of unification
- because semi-classical theories are inconsistent

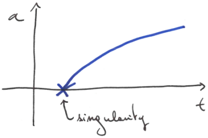
The **third** is the strongest $\rightarrow$ the one that really needs to be addressed

The shaky case for quantization I: smoothing out nastiness

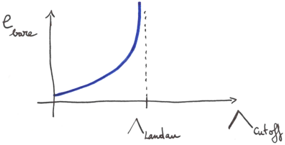
Problematic divergences in known theories:

- Singularities in **GR** (black-holes, Big-Bang) $R \longrightarrow +\infty$





- Landau Pole in $U(1)$ sector of the **SM** $\Lambda_{\text{cutoff}} \leq \Lambda_{\text{Landau}}$



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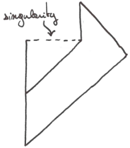

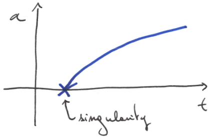

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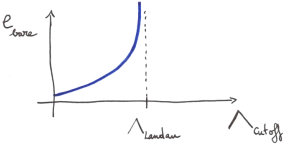


"Quantizing" gravity will save the day!

BUT: Quantization is not snake oil

- quantization did not save EM
- not even clear what singularities **mean** in QG
- many other ways to solve these problems
- pure wishful thinking?

The shaky case for quantization II: aesthetics

Quantum theory as a **meta theory**, as a procedure to transform the "old fashioned" into the "modern":

- "Everything should be quantized"
- "Gravity is just like the other forces"
- "People tried to have the EM field classical and it turned out they were wrong"

Unifying means **quantizing**

$$\{,\} \to [,] \;\; ; \;\; [x, p] = i$$

BUT: Quantization is not a sausage machine

- gravity is **not** just a spin 2 Gauge field
- unification $\neq$ quantization.
- approaches that look universal are sometimes not:
  - geometrization of electrodynamics via Kaluza-Klein theories failed
  - $SU(5)$ and other GUT failed
- maybe gravity is just different

The shaky case for quantization III: impossibles chimera

"Semi-classical theories are mathematically impossible."

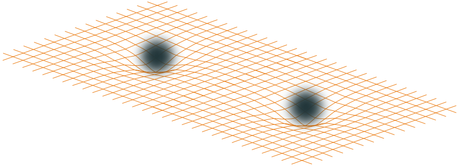
Chimera

If true, crippling argument $\Longrightarrow$ gravity needs to be quantized (or emerge from some purely quantum theory)

“Standard” semi-classical gravity

A semi-classical theory of gravity tells 2 stories:

1. Quantum matter moves in a curved classical space-time
2. The classical space time is curved by quantum matter



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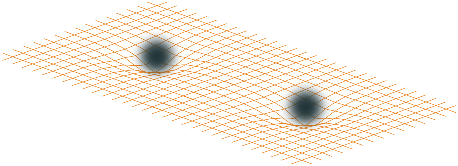

1 is known (QFTCST), **2** is not

The crucial question of semi-classical gravity is to know how quantum matter should source curvature.

Møller-Rosenfeld semi-classical gravity

The **CHOICE** of Møller and Rosenfeld it to take:

$$R_{\mu\nu} - \frac{1}{2} R \, g_{\mu\nu} = 8\pi G \, \langle \hat{T}_{\mu\nu} \rangle$$

$\rightarrow$ source gravity via expectation values


Christian Møller


Leon Rosenfeld

There are:

- **technical relativistic** difficulties [renormalization of $\langle T_{\mu,\nu} \rangle$]
- **conceptual non-relativistic** difficulties [Born rule, $\cdots$].

Schrödinger-Newton

1. Non-relativistic limit of the "sourcing" equation:

$$\nabla^2 \Phi(\mathbf{x}, t) = 4\pi G \langle \psi_t | \hat{M}(\mathbf{x}) | \psi_t \rangle$$

2. Non-relativistic limit of QFTCST (just external field)

$$\frac{\mathrm{d}}{\mathrm{d}t} |\psi\rangle = -i \left(H_0 + \int \mathrm{d}\mathbf{x}\, \Phi(\mathbf{x}, t) \hat{M}(\mathbf{x}) \right) |\psi_t\rangle,$$

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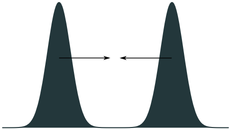
Putting the two together:

$$\frac{\mathrm{d}}{\mathrm{d}t} |\psi_t\rangle = -iH_0 |\psi_t\rangle + i\, G \int \mathrm{d}\mathbf{x}\, \mathrm{d}\mathbf{y}\, \frac{\langle \psi_t | \hat{M}(\mathbf{x}) | \psi_t \rangle\, \hat{M}(\mathbf{y})}{|\mathbf{x} - \mathbf{y}|} |\psi_t\rangle.$$

The problems with Schrödinger-Newton

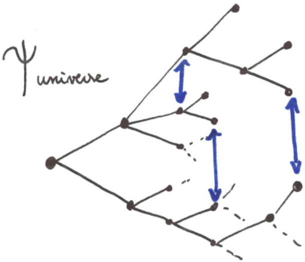


The SN equation is problematic for a fundamental theory because of its **deterministic non-linearity** (Gisin, Diósi, Polchinski)

- If there is **no fundamental collapse** [Many Worlds, Bohm, $\cdots$], super weird world unlike our own
- If there is **fundamental collapse** [Copenhaguen, Collapse models]: break down of the statistical interpretation of states & instantaneous signaling

The problems with Schrödinger-Newton

Without collapse upon measurement (Bohm, Many Worlds, $\cdots$)



Decohered branches interact with each other $\rightarrow$ **totally ridiculous**

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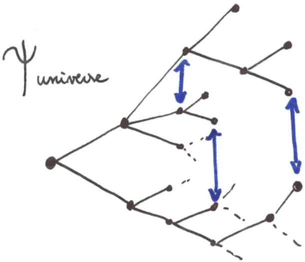

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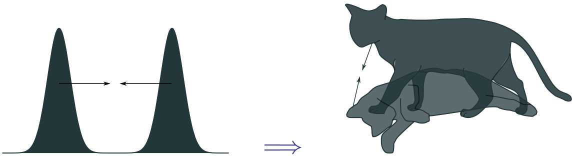


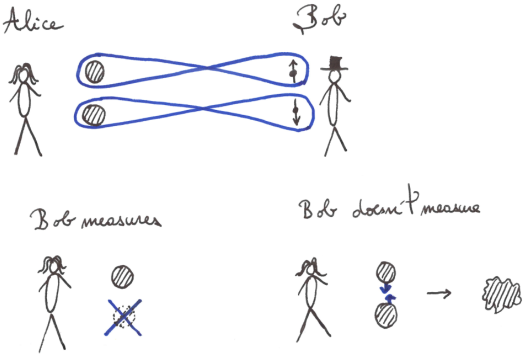
The problems with Schrödinger-Newton

With collapse upon measurement (either from pure Copenhaguen or collapse models).

Consider a mass entangled with a spin far away:

$$|\Psi\rangle \propto |\text{left}\rangle^{\text{Alice}} \otimes |\uparrow\rangle^{\text{Bob}} + |\text{right}\rangle^{\text{Alice}} \otimes |\downarrow\rangle^{\text{Bob}}.$$

Bob can decide to whether or not he measures his spin:



Two first steps

- Via Bohmian mechanics
  Couple with **the particle trajectories** $\rightarrow$ Struyve 2015-2017
- Via Collapse models
  Add an objective collapse $\rightarrow$ Derakhshani 2014

In both cases, destroy the statistical interpretation of the state vector $\rightarrow$ extract predictions only via the **primitive ontology**.

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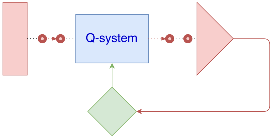
Maybe there is no way out and gravity has to break the statistical interpretation of states. But **if possible, it would be better not to screw everything**.

Measurement + feedback

Actually, in orthodox quantum theory, trivial way to do quantum-classical coupling: **measurement** & **feedback** [Diósi & Halliwell]



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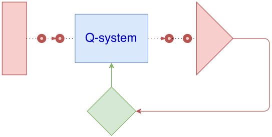
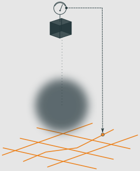


The state of the controler is the classical variable

Idea:

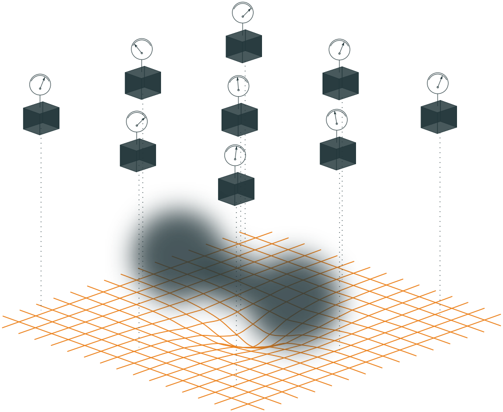
Source gravity by measuring the mass density:

$$\nabla^2 \Phi(\mathbf{x}) = 4\pi G \mathscr{S}_{\hat{M}}(\mathbf{x})$$



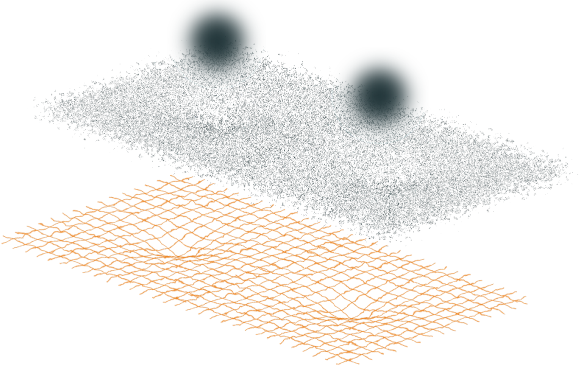
[Kafri, Taylor & Milburn 2014]
[Diósi & T 2015]

Formal / “intuition pump” picture



“There are detectors in space-time measuring the mass density continuously and curving space-time accordingly.” $\rightarrow$ this is why it works

Ontological picture



“The gravitational interaction is mediated by a stochastic field, which is the **primitive ontology** of the theory” $\rightarrow$ this is how it should be understood physically

Consistent semi-classical gravity

After textbook computations one gets:

$$\ldots$$

$$\ldots$$

Predictions

- Recover the expected Newtonian pair potential $\mathscr{V}(x, y)$
- Additional decoherence $\mathscr{D}(x, y)$
- No Schrödinger cat states of large mass
- As expected, a linear master equation and no inconsistency
- Not falsified (yet) but falsifiable (Derakhshani 2016)

Link with collapse models I

Continuous measurement of the mass density

$\equiv$

Continuous collapse models

(modulo interpretation)

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Collapse translation

Our theory consists in sourcing gravity by the continuous equivalent of the GRW flashes.
We are just sourcing gravity with a natural primitive ontology of collapse models.

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$$\equiv$$

Continuous collapse models
(modulo interpretation)

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Slight difference with collapse models

The gravitational feedback adds decoherence inversely proportional to “intrinsic” decoherence:

$$\mathscr{D}_{\text{total}} = \gamma\, \mathscr{D}_{\text{intrinsic}} + \frac{1}{\gamma}\, \mathscr{D}_{\text{gravitational}}$$

$\Longrightarrow$ all values of the collapse parameter are **experimentally** falsifiable.

Link with collapse models II

1. We have as much freedom in the theory as there are collapse models.
$\rightarrow$ What collapse model can we single out?

- Insist that gravity does not entangle different regions of space-time $\rightarrow$ CSL model
- Insist that gravity introduces the smallest possible amount of noise $\rightarrow$ DP model (thus the most constraining model)

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2. Same short distance cut-off problem
Gravity needs to me smoothed at short distances otherwise decoherence explodes

Conclusions

1. **About this model**
   - Two birds one shot: solve the measurement problem and semi-classical gravity with the same tool, pay the price once
   - Makes collapse models falsifiable in all their parameter diagram
   - Singles out the Diósi-Penrose model as the least restrictive

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   - Schrödinger-Newton is a straw-man, easy to do better
   - No real objection to semi-classical gravity
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3. **About physics in general**
   - Discussion of primitive ontology is not just philosophical BS