Postquantum stochastic semiclassical gravity: world without Schrödinger cats

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Abstract

'Postquantum' stochastic gravity is a proposal to improve semiclassical gravity which violates causality and Born's statistical interpretation. Principles of quantum foundations explain the cause of such fundamental anomalies and show how to get rid of them. The solution might be built on the non-relativistic theory of spontaneous wavefunction collapse, eliminating Schrödinger cat states. Such 'postquantum' theory is captivating conceptionally, exists formally, but its relativistic covariance could hit a wall.
Accordingly, I explain the principles of 'postquantum' gravity in the nonrelativistic limit and discuss the obstacles of relativistic extension. 'Postquantum' proposal has three equivalent formalisms: i) coupled stochastic processes for the classical geometry and Ψ of quantized matter, ii) hybrid classical-quantum master equation, iii) path integrals. Here I use the most instructive formalism i).

Gradual Extension of QM from MI icro to Macro

- photons (Planck)
- atoms (Bohr)
- micro-world (Schrödinger , Heisenberg)
- condensed matter
- electrodynamics
- nuclei
- elementary particles ↑PERFECT↑

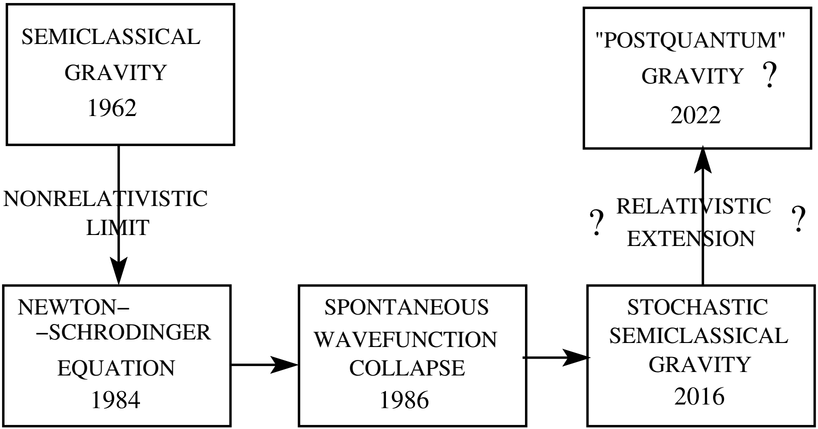
- big masses, gravitation ? ↓NO EVIDENCE↓
- cosmology ?
- biology ?
- consciousness ?

QuantumMechanics was invented for the microscopic world.

IS QM VALID FROM PARTICLE PHYSICS TO COSMOLOGY?

What if space-time remains classical, not quantized?

Encounter of gravity with Schrödinger Cats



Standard Semiclassical Gravity

Powerful effective hybrid dynamics for $(\mathrm{g}_{ab}, |\Psi\rangle)$:

$$\begin{aligned} \frac{d|\Psi\rangle}{dt} &= -\frac{i}{\hbar}\hat{H}[\mathrm{g}]|\Psi\rangle \qquad \textit{action (nonlinear)} \\ \mathrm{G}_{ab} &= \frac{8\pi G}{c^4}\langle\Psi|\hat{\mathrm{T}}_{ab}|\Psi\rangle \quad \textit{backaction} \end{aligned}$$

Breakdown of causality and Born statistical interpretation!
unrelated to relativity (and gravitation, btw)
but to fundamentals of quantum mechanics

Hence we discuss the nonrelativistic limit first.
And we (try to) go back to general relativity after it.

Nonrelativistic limit (Schrödinger-Newton Eq.)

$\hat{\mu} = \hat{\mathrm{T}}_{00}/c^2 =$ quantized field of nonrelativistic mass density

$$\begin{aligned} \frac{d|\Psi\rangle}{dt} &= -\frac{i}{\hbar}\left(\hat{H}_0 + \int \hat{\mu}\Phi dV\right)|\Psi\rangle \quad \textit{action (nonlinear)} \\ \nabla^2\Phi &= -4\pi G\langle\Psi|\hat{\mu}|\Psi\rangle \quad \textit{backaction} \end{aligned}$$

Breakdown of causality and Born statistical interpretation is caused by the nonlinear term in the Schrödinger equation, semiclassicality of coupling $\langle\Psi|\hat{\mu}|\Psi\rangle$ should be blamed.

Surprize: Quantumgravity is thought to be relevant at extreme large energies or curvatures. But SNE shows that both gravity and quantumness can become relevant together nonrelativistically for large masses, already for nanogram's.
Doors open: 'Newtonian Qauntumgravity' for theorists,
'Quantumgravity in the Lab' for experimentalists.

Hybrid Classical-Quantum Coupling — Foundations

Action of C on Q can be trivial (parametric)
Backaction of Q on C is a major issue.

About a quantum system, quantum measurement is the only mean to consistently define classical variables.

About an individual quantum system:
classical numbers like $\langle\Psi|\hat{\mu}|\Psi\rangle$ are not classical variables but the random measurement outcomes are.

Action of quantized matter on classical gravity is only possible via the random outcomes of quantum measurement on $\hat{\mu}$ (instead of $\langle\Psi|\hat{\mu}|\Psi\rangle$) which contains a stochastic term:

$$\mu^{signal} = \langle\Psi|\hat{\mu}|\Psi\rangle + \delta\mu^{noise}$$

Consistent hybrid classical-quantum coupling is irreversible.
Now, who is measuring $\hat{\mu}$?

Spontaneous collapse of Schrödinger Cats (D.,Penrose)

$$|CAT\rangle = \frac{|\text{LEFT}\rangle + |\text{RIGHT}\rangle}{\sqrt{2}} \to \begin{cases} |\text{LEFT}\rangle \\ \text{or} \\ |\text{RIGHT}\rangle \end{cases}$$

SPONTANEOUS COLLAPSE RATE:

$$\frac{1}{\tau} = \frac{V_G^i - V_G^f}{\hbar}$$

V_G^i, V_G^f: gravitational self-energy before/after collapse
Negligible effect for small, dominant for large masses:
$\tau_{1fg} \sim 10^6 s$ but $\tau_{1mg} \sim \mu s$.

DP Gravity-Related Spontaneous Collapse (D.)

Generalizaing spontaneous collapse of Schrödinger Cats

Time-continuous spontaneous collapse of massive macrosopic superpositions

Concept: spontaneous monitoring of $\hat{\mu}$

$$\begin{aligned} \frac{d|\Psi\rangle}{dt} &= -\frac{i}{\hbar}\hat{H}_0|\Psi\rangle \\ &\quad + \textit{stochastic terms of monitoring } \hat{\mu} \\ \mu^{signal} &= \langle\Psi|\hat{\mu}|\Psi\rangle + \delta\mu^{noise} \end{aligned}$$

$\mu^{signal}(\mathbf{r}, t)$ is diffusing around $\langle\Psi(t)|\hat{\mu}(\mathbf{r})|\Psi(t)\rangle$.

$$\textit{Diffusion matrix}: D_\mu(\mathbf{r}, \mathbf{s}) = -4\pi\frac{\hbar}{G}\nabla^2\delta(\mathbf{r}-\mathbf{s})$$

EXPLAINS HOW QM GOES CLASSICAL IN THE MACRO-WORLD "WITHOUT SCH CATS"

On spontaneous measurement

Spontaneous/objective measurement/collapse/reduction
acts on $|\Psi\rangle$ and yields measurement outcome
just like standard quantum measurement does
but without assuming the presence of measurement device.
Like standard measurements,
it is stochastic, irreversible, violates conservation rules,
non-relativistic, resists to relativistic extension
Spontaneous monitoring (time-continuous generalization)
acts on $|\Psi\rangle$ and yields measurement outcome (signal),
just like standard quantum monitoring does
but without assuming the presence of lab devices.

Postquantum stochastic semiclassical gravity

Causality and Born statistical interpretation restored

Reversibility lost

$$\frac{d|\Psi\rangle}{dt} = -\frac{i}{\hbar}\left(\hat{H}_0 + \int \hat{\mu}\Phi dV\right)|\Psi\rangle + \textit{stochastic terms of monitoring } \hat{\mu}$$

$$\nabla^2\Phi = -4\pi G\left(\langle\Psi|\hat{\mu}|\Psi\rangle + \delta\mu^{noise}\right)$$

Feedback of solution Φ in the Hamiltonian yields

$$\frac{d|\Psi\rangle}{dt} = -\frac{i}{\hbar}\left(\hat{H}_0 - G\int\int \frac{\hat{\mu}(\mathbf{r})\hat{\mu}(\mathbf{s})}{|\mathbf{r}-\mathbf{s}|}d\mathbf{r}d\mathbf{s}\right)|\Psi\rangle + \textit{stochastic terms of monitoring } \hat{\mu} + \textit{stochastic terms of feedback of } \Phi$$

Prices to pay:

tiny nonunitarity because $|\Psi\rangle$ collapses

tiny stochasticity of gravity because of $\delta\mu^{noise}$

Relativistic Semiclassical Gravity?

Stochastic Semiclassical Gravity (Tilloy-D.), Postquantum Gravity (Oppenheim et al.), cf. Classical Channel Gravity (Kafri,Taylor,Milburn)

Concept: spontaneous monitoring $\hat{\mathrm{T}}_{ab}$

$$
\begin{aligned}
\frac{d|\Psi\rangle}{dt} &= -\frac{i}{\hbar}\hat{H}[\mathrm{g}]|\Psi\rangle + \\
&\quad + \textit{stochastic contribution of monitoring} \\
\mathrm{G}_{ab} &= \frac{8\pi G}{c^4}\left(\langle\Psi|\hat{\mathrm{T}}_{ab}|\Psi\rangle + \delta\mathrm{T}_{ab}^{noise}\right)
\end{aligned}
$$

Metric g_{ab} is diffusive because T_{ab}^{signal} is diffusive.
Diffusion matrix (kernel) of T_{ab}^{signal}:

$$\left\langle \delta\mathrm{T}_{ab}^{noise}(x)\delta\mathrm{T}_{cd}^{noise}(y)\right\rangle = 2D_{ab|cd}(x)\delta(x,y)$$

NO COVARIANT CHOICE of $D_{ab|cd}$.

Obstacle lies in foundations:

Quantum measurement/collapse is not relativistic.

Quantum monitoring might not have relativistic extension.

Closing remarks

Unified theory of space-time with quantized matter and the physics of quantum measurement were considered unrelated for long time, studied by two separate research communities. Quantum cosmologists used heavy artillery of mathematics. Quantum measurement problem 'solvers', with the speaker among them, used light weapons and sometimes whimsical identification of their problems, e.g. in terms of the Schrödinger cat paradox. The bottle-neck of quantum gravity may be this paradox, not the math difficulties to find a good framework of quantization. An improved but still semiclassical theory might be built on the non-relativistic theory of spontaneous wavefunction collapse, eliminating Schrödinger cat states. Such 'postquantum' theory exists nonrelativistically but its relativistic - even Lorentzian - extension remains a problem.