Postquantum stochastic semiclassical gravity: world without Schrödinger cats

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Encounter of gravity with Schrödinger Cats

Standard Semiclassical Gravity

Nonrelativistic limit (Schrödinger-Newton Eq.)

Spontaneous collapse of Schrödinger Cats (D.,Penrose)

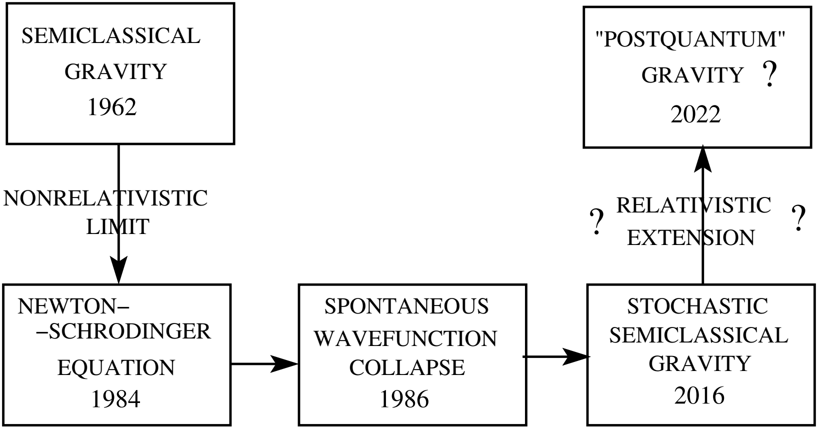
On spontaneous measurement

Postquantum stochastic semiclassical gravity

Relativistic Semiclassical Gravity?

Closing remarks

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

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

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.

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 $\tau_{1mg} \sim \mu s$.

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

$$
\begin{aligned}
\frac{d|\Psi\rangle}{dt} &= -\frac{i}{\hbar}\left(\hat{H}_0 + \int \hat{\mu}\Phi dV\right)|\Psi\rangle \\
&\quad + \mathit{stochastic\ terms\ of\ monitoring}\ \hat{\mu} \\
\nabla^2\Phi &= -4\pi G\left(\langle\Psi|\hat{\mu}|\Psi\rangle + \delta\mu^{noise}\right)
\end{aligned}
$$

Feedback of solution Φ in the Hamiltonian yields

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

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.