The case of Quantum Gravity with Spontaneous Collapse

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Abstract 2014

Gravity related spontaneous decoherence: from Wheeler-Bekenstein-Hawking to optomechanics (Erice 2015)

The inception of a universal gravity-related irreversibility took place originally in quantum cosmology but it turned out soon that a universal non-unitary dynamics is problematic itself. Independent investigations of the quantum measurement postulate clarified that a non-unitary dynamics is of interest already in the non-relativistic context. An intricate relationship between Newton gravity and quantized bulk matter might result in universal non-relativistic violation of unitarity - also called spontaneous decoherence. The corresponding gravity-related spontaneous decoherence model is now on the verge of detectability in optomechanical experiments. It is also a toy-model of cosmic quantum-gravitational non-unitarity, illuminating that the bottle-neck of quantum-gravity is the quantum measurement postulate instead of quantum cosmology.

Abstract 2022

When about half a century ago the concept of universal spontaneous collapse of the wave function was concieved it was an attempt to alter standard non-relativistic quantum physics. As such, it was largely ignored by relativistic field theory and quantum-gravity communities. A central motivation of spontaneous collapse community has been to replace the standard collapse-by-measurement that annoyed many. For long time it did not annoy the field theory and quantum-gravity communities. Concept of quantum field theory with certain universal irreversibilities had been initiated very long ago by Wheeler, Hawking and a few others independently from the concept of spontaneous collapse. Over the decades the two concepts have come close and support each other.

Fundamental irreversibility? — Two Communities

QUANTUM COSMOLOGISTS	SCHRODINGER-CAT KILLERS*
field-string-membrane theorists,	quantum foundation experts,
for full relativistic	for non-relativistic
quantum gravity	spontaneous wavefunction collapse
of the Universe	of macroscopic bodies
within standard unitary (rev.) QM	with modified non-unitary (irrev.) QM

FUNDAMENTAL IRREVERSIBILITY?

POSSIBLE MECHANISM	MANDATORY ASSUMPTION
cf. black hole information loss	wave function collapse

* Measurement Problem Solvers.

Irrev Quantum Gravity/Cosmology at Planck Scale

Heuristic Arguments **within** Standard Physics

- Wheeler (1955): foamy space-time at Planckian scale
  no compact dynamical eq.
- Bekenstein (1972): black-holes behave termodynamically

$$S_{BH} = \frac{k_B}{4}\frac{A_{BH}}{A_{Pl}}$$

  ... and even radiate thermally, Hawking (1973)
- Hawking (1983): unitarity is lost due to instantons

$$\widehat{\rho} \to \$\widehat{\rho} \neq \widehat{S}\widehat{\rho}\widehat{S}^{\dagger}$$

- Banks-Susskind-Peskin (1984): violation of conservations laws

$$\dot{\widehat{\rho}} = -i[\widehat{H}, \widehat{\rho}] - \int\int [\widehat{Q}(x), [\widehat{Q}(y), \widehat{\rho}\,]]h(x-y)d^3xd^3y$$

  $\widehat{Q}$ is relativistic quantum field, h is positive kernel.

Irrev Quantum Mechanics for Massive Objects

Heuristic **modifications** of Standard Physics

Purpose: massive Schrodinger Cats $|f_1\rangle + |f_2\rangle$ decay spontaneously

- Karolyhazy (1966): fluctuations of space-time at Planckian scale
  G-related qualitative eqs.
- GRW (1986): rare spontaneous localizations of constituents
  G-unrelated exact eqs.
- D. (1986): fluctuations of Newtonian gravitational field

$$\dot{\widehat{\rho}} = -\frac{i}{\hbar}[\widehat{H}, \widehat{\rho}] - \frac{G}{2\hbar}\int\int [\widehat{f}(x), [\widehat{f}(y), \widehat{\rho}\,]]\frac{1}{|x-y|}d^3x d^3y$$

  $\widehat{f}$ is non-relativistic quantized mass density field
- Penrose (1996): uncertainty of time-flow

$$\frac{1}{\tau_{decay}} = \frac{G}{\hbar}\int\int [f_1(x) - f_2(x)][f_1(y) - f_2(y)]\frac{1}{|x-y|}d^3x d^3y$$

  f_1, f_2 mass densities of Cat state

G-related spontaneous decoherence

Particular purpose: $|f_1\rangle + |f_2\rangle$ decay into mixture of $|f_1\rangle$ and $|f_2\rangle$.

Construction of G-related spontaneous decoherence
(with one eye on G-related spontaneous collapse):

- formal von Neumann measurements of local mass densities $f(x)$
- detectors are hidden this time!
- nobody reads out the measurement outcomes

Resulting Master Equation of G-related spontaneous decoherence:

$$\dot{\widehat{\rho}} = -\frac{i}{\hbar}[\widehat{H}, \widehat{\rho}] - \frac{G}{2\hbar}\int [\widehat{f}(x), [\widehat{f}(y), \widehat{\rho}\,]]\frac{1}{|x-y|}d^3x d^3y$$

$\widehat{f}$ is non-relativistic quantized mass density field: $\widehat{f}(x) = \sum_n m_n g_\sigma(x - \widehat{q}_n)$.
Note: same structure as BSP eq., interpretation is very different.

Fundamental irreversibility? — Parallel Histories

	QUANTUM COSMOLOGISTS	SCHRODINGER-CAT KILLERS
1936	Bronstein: ambiguity δg_{ab}	
1950	Wheeler: space-time foam	
1966		Károlyházi: δg_{ab} collapses Ψ
1972	Bekenstein: black hole entropy	
1973	Hawking: black hole radiates	
1976		[Pearle: Ψ's formal collapse eqs.]
1983	Hawking: $\rho_f = \$\rho_i \neq S\rho S^\dagger$	
1984	BanksSusskindPeskin: $T^{ab}{}_{,b} \neq 0$	[Gisin: Ψ's prototype collapse eq.]
1986		D.: δg_{ab} collapses Ψ, master eq.
		[GRW: toy model of Ψ-collapse]
1990		[GRWP: CSL model of Ψ-collapse]
1996	Penrose: δg_{ab} collapses Ψ	
2008	Hogan: holographic noise	

SchCatKillers: Pearle, D., Bassi's, Tumulka, Tilloy, Bedingham, Laloe, ...

COSMOLOGISTS may profit from results of SchCAT KILLERS.

Some already do: BL Hu, TP Singh, Sudarsky, Oppenheim, ...

David Poulin — On Information Loss

Conclusion

- Models of information loss that
  - do not violently break well established principles;
  - are well formulated mathematically; and
  - agree with experiments;

  have not been ruled out.
- The secret sauce in our model is violation of causality at microscopic scales.
- Fundamental non-unitary evolution opens up new possibilities for quantum-classical evolution:
  - Further justifies non-unitary evolution since dissipative terms can be controlled by classical gravitational variables: turn on only in extreme conditions.
- To do:
  - Explicitly write rate equation for gravitational field.
  - Work out model details to provide experimental test to refute.

David Poulin — A relativistic Lindblad Eq.

A free field model

A model

- Start with a free scalar theory $H = \frac{1}{2}\int \frac{d^3p}{(2\pi)^3}(\pi^2 + m^2\phi^2 + (\nabla\phi)^2)$.
- Consider positive frequency component of field operators $\pi^+(x)$.
- Use them as jump operators

$$\dot{\rho} = -i[H,\rho] + \gamma \int d^3x \left[2\pi^-\rho\pi^+ - \{\pi^+\pi^-,\rho\}\right]$$

- In momentum space,

$$\dot{\rho} = \int \frac{d^3p}{(2\pi)^3}\omega_p\left(\gamma a_p\rho a_p^\dagger - \frac{\gamma}{2}\{a_p^\dagger a_p,\rho\} - i[a_p^\dagger a_p,\rho]\right)$$

- By virtue of $U_\Lambda\sqrt{\omega_p}a_pU_\Lambda^\dagger = \sqrt{\omega_{\Lambda p}}a_{\Lambda p}$, the model is Lorentz covariant.

Relativistic GKLS master equation? — No!

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Abstract

... ... A closer look uncovers a smartly hidden defect which leaves us without Lorentz invariant Markovian master equations. They, in view of the present author, should not exist.

Summary

- Quantum-gravity 1950's- **departure from unitarity**
  - Standard Quantum Theory
  - Quantum measurement, collapse: not discussed
  - **Today: struggle to understand non-unitary dynamics learning results of non-relativistic Cat Killers**
- Quantum Mechanics 1960's - **departure from unitarity**
  - Modified Quantum Theory, to kill Cats
  - Intrinsic link between G and quantum measurement, collapse
  - **Today: struggle to understand relativistic dynamics learning schemes of mainstream quantum-gravity**

— *Gravity & Quantum Mechanics for Each Other: The measurement problem culminates in quantum cosmology (D. 1992)*
— *The bottle-neck of quantum-gravity is the quantum measurement postulate instead of quantum cosmology* (D. at DICE 2008, Erice 2015)
— *Gravitization of quantum mechanics instead of quantization of gravity (Penrose, 2014)*