The case of Quantum Gravity with Spontaneous Collapse

Lajos Diósi

Wigner Research Center for Physics, Budapest
Eötvös Loránd University, Budapest

16 June 2022, Växjø

Supports by: FQXi (Grant No. FQXi-RFP-CPW-2008), National Research, Development and Innovation Office for "Frontline" Research Excellence Program (Grant No. KKP133827) and research grant (Grant. No. K12435), John Templeton Foundation (Grant 62099).

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.

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
  $$\widehat{\rho} \rightarrow \$\widehat{\rho} \neq \widehat{S}\widehat{\rho}\widehat{S}^\dagger$$
- Banks-Susskind-Peskin (1984): violation of conservations laws
  $$\dot{\widehat{\rho}} = -i[\widehat{H}, \widehat{\rho}] - \int\int [\widehat{Q}(x), [\widehat{Q}(y), \widehat{\rho}\,]] h(x-y) d^3x d^3y$$
  $\widehat{Q}$ 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

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

  $\widehat{f}$ is non-relativistic quantized mass density field

- Penrose (1996): uncertainty of time-flow

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

  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:

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

$\widehat{f}$ 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 History

	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	
1983	Hawking: $\rho_f = \$\rho_i \neq S\rho S^\dagger$	
1984	BanksSusskindPeskin: $T^{ab}{}_{,b} \neq 0$	
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	

†Researchers of Spontaneous Ψ Collapse.

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

COSMOLOGISTS may profit from results of SchCAT KILLERS.

Some already did, e.g. BL Hu, TP SIngh, Sudarsky, Oppenheim, and ...

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

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

- In momentum space,

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

- 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?

arxiv:2206.05701

Lajos Diósi

Wigner Research Centre for Physics,
H-1525 Budapest 114, P. O. Box 49, Hungary
and
Eötvös Loránd University, H-1117 Budapest,
Pázmány Péter stny. 1/A

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
  - Relativistic approach
  - 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
  - Non-relativistic context
  - Intrinsic link between G and quantum measurement, collapse
  - **Today: struggle to understand relativistic dynamics learning schemes of mainstream quantum-gravity**

'... the bottle-neck of quantum-gravity is the quantum measurement postulate instead of quantum cosmology' (DICE 2008, Erice 2015)