

# The Forgotten Present

## A Quest for a Richer Concept of Time

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*“The problem of instantaneous quantum collapses  
in a relativistic framework”*

# Textbook Quantum Mechanics

1. **Kinematics:** States and state space

$$|\psi_t\rangle \in \mathcal{H}$$

2. **Dynamics:** Schrödinger equation

$$i\hbar \frac{d}{dt} |\psi_t\rangle = H |\psi_t\rangle$$

3. **Interpretation:** Probabilities in measurements

$$\mathbb{P}[o_n] = |\langle o_n | \psi_t \rangle|^2$$

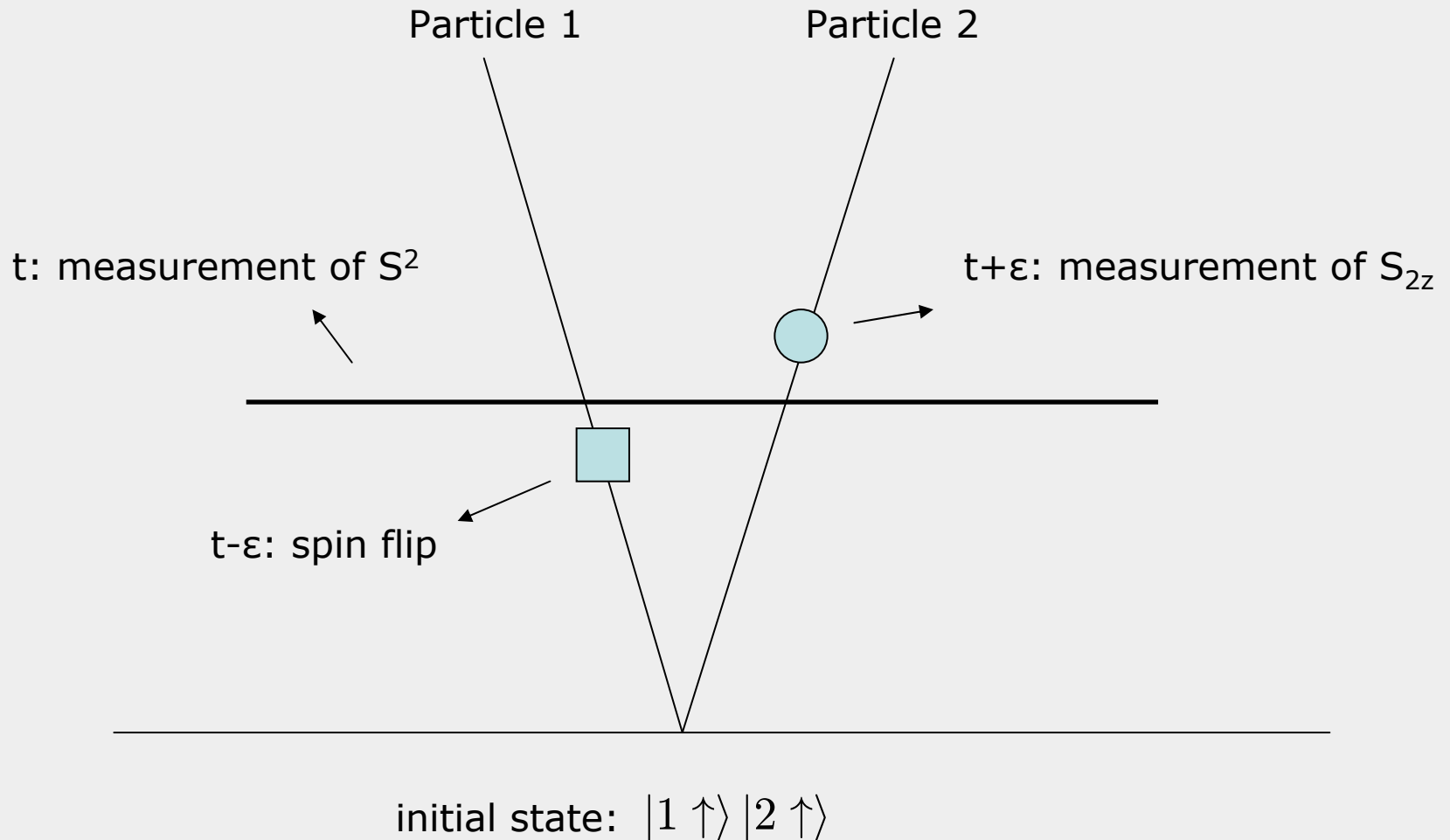
4. **Collapse:** effect of measurements

$$|\psi_t\rangle \rightarrow |o_n\rangle$$



Ok with relativity

# 1. Non-local measurements



# Faster-than-light signaling

## No spin flip:

initial state:  $|1 \uparrow\rangle |2 \uparrow\rangle$

Measurement of  $S^2$ :  $|1 \uparrow\rangle |2 \uparrow\rangle$

Measurement of  $S_{2z}$ : **Always up**

## Spin flip:

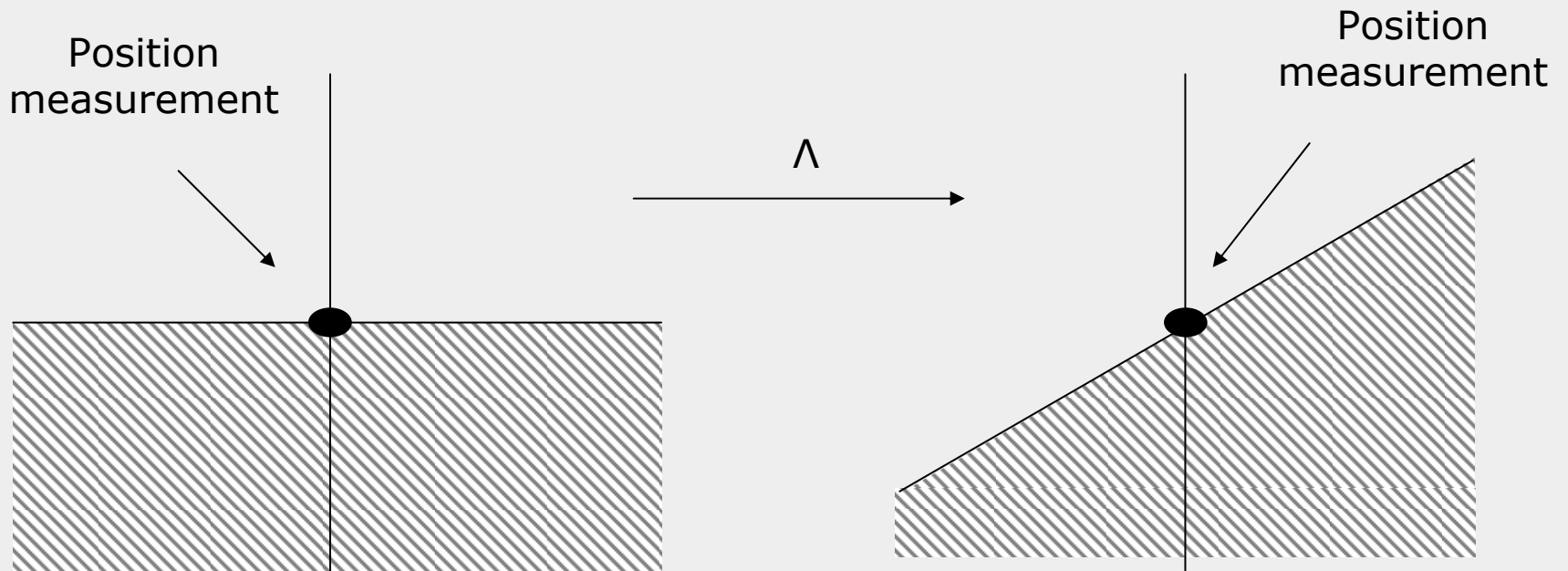
initial state:  $|1 \uparrow\rangle |2 \uparrow\rangle$

Spin flip:  $|1 \downarrow\rangle |2 \uparrow\rangle$

Measurement of  $S^2$ :  $\frac{1}{\sqrt{2}} [ |1 \downarrow\rangle |2 \uparrow\rangle \pm |1 \uparrow\rangle |2 \downarrow\rangle ]$  50% each

Measurement of  $S_{2z}$ : **50% up, 50% down**

# 2. Non covariance of collapse



The measurement can be described in a covariant way, the collapse no

# Solutions

- **Solution to problem 1**

Landau & Peierls (1931): non-local quantities are not observables

→ Momentum is not observable:  $\Delta p \Delta t \geq \hbar/c$

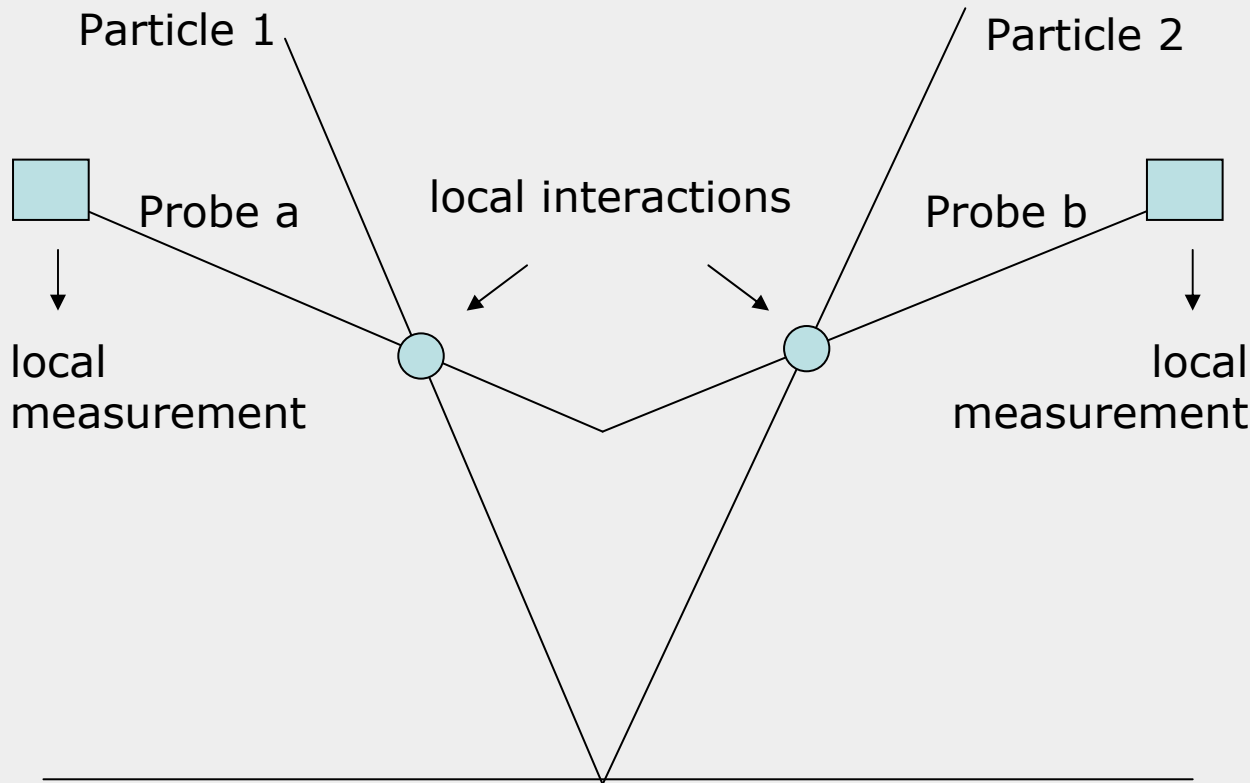
- **Solution of problem 2:**

Hellwig & Kraus (1970): collapse along the past light-cone

→ It gives the correct prescription for all local measurements

# Non-local measurements are possible

Aharonov & Albert (1980): some non-local quantities can be measured through **local measurements and local interactions**



**Initial state of probes**

$$q_a(0) - q_b(0) = 0$$

$$p_a(0) + p_b(0) = 0$$

**Interaction**

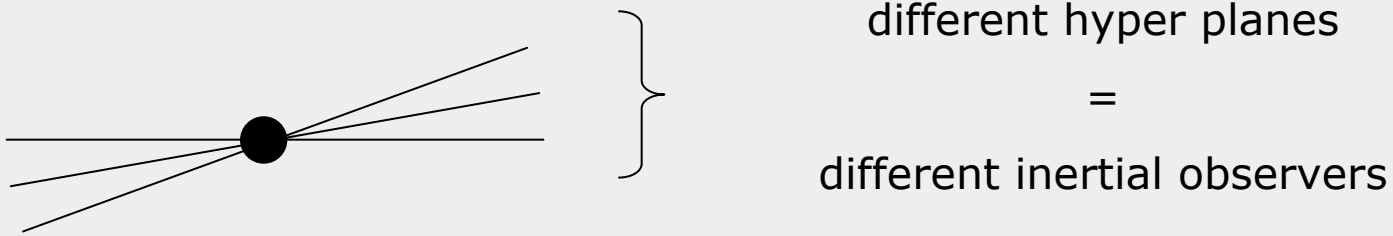
$$H_I = g_t [q_a S_{1z} + q_b S_{2z}]$$

**Measurement**

$$S_z = -\frac{p(t > \bar{t})}{\int_0^{\bar{t}} g_t dt}$$

# A way out

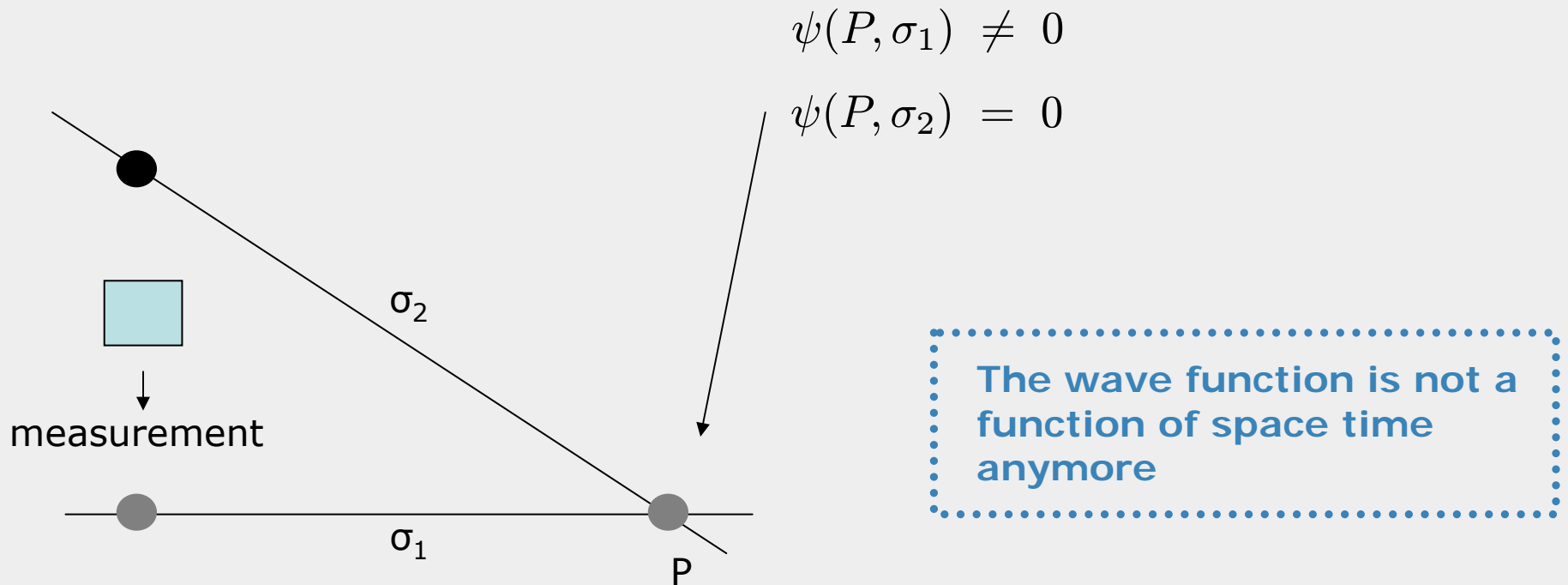
Aharonov & Albert (1984): **the collapse occurs instantaneously for every inertial observer**



- **It is a covariant prescription:** all axioms of QFT are covariant now
- **All observers agree on the outcomes and their statistics**

# Consequences

Aharonov & Albert (1984): **the collapse occurs instantaneously for every inertial observer**



# Comments

1. **Reasonable?** Only consistent proposal, so far.
2. **Alternative 1:** Remove the instantaneous character of the collapses
  - Problem 1: Find “local equations” for the collapses
  - Problem 2: The process must be superluminal (Bell’s correlations)  
→ anyhow problems with special relativity
3. **Alternative 2:** Question Lorentz invariance

# The CSL Model

G.C. Ghirardi, P. Pearle and A. Rimini, *Phys. Rev. A* 42, 78 (1990).

$$d|\psi_t\rangle = \left[ -\frac{i}{\hbar} H dt + \sqrt{\lambda} \int d^3x (N(\mathbf{x}) - \langle N(\mathbf{x}) \rangle_t) dW_t(\mathbf{x}) - \frac{\lambda}{2} \int d^3x (N(\mathbf{x}) - \langle N(\mathbf{x}) \rangle_t)^2 dt \right] |\psi_t\rangle$$

Quantum Hamiltonian

COLLAPSE TERMS

$$N(\mathbf{x}) = a^\dagger(\mathbf{x})a(\mathbf{x}), \quad \langle N(\mathbf{x}) \rangle_t = \langle \psi_t | N(\mathbf{x}) | \psi_t \rangle$$

➡ nonlinearity

$$\mathbb{E}[W_t(\mathbf{x})] = 0,$$

$$\mathbb{E}[W_t(\mathbf{x})W_s(\mathbf{y})] = \delta(t-s)e^{-(\alpha/4)(\mathbf{x}-\mathbf{y})^2}$$

➡ stochasticity



Not Lorentz invariant

# Relativistic CSL Model

1. **White in time**  $\longrightarrow$  **white in space**: The equation formally exist and do the job.

Infinite divergences popping out from the vacuum

2. **Gaussian in space**  $\longrightarrow$  **Gaussian in time**: Non Markovian model

Non local coupling among quantum fields. The equations do not make sense

# A possible way out

Noise = physical cosmological random field, filling space



It selects a cosmological reference frame (like the CMBR), where it takes the simplest form

The equations are invariant. Initial conditions break the invariance

- **Problem 1:** Find the equations for the noise
- **Problem 2:** Justify the nonlinear coupling with quantum matter (gravity?)
- **Problem 3:** Discuss the initial conditions


# Preliminary question

Can a physically reasonable cosmological field induce an efficient collapse of the wave function, as the CSL model does?

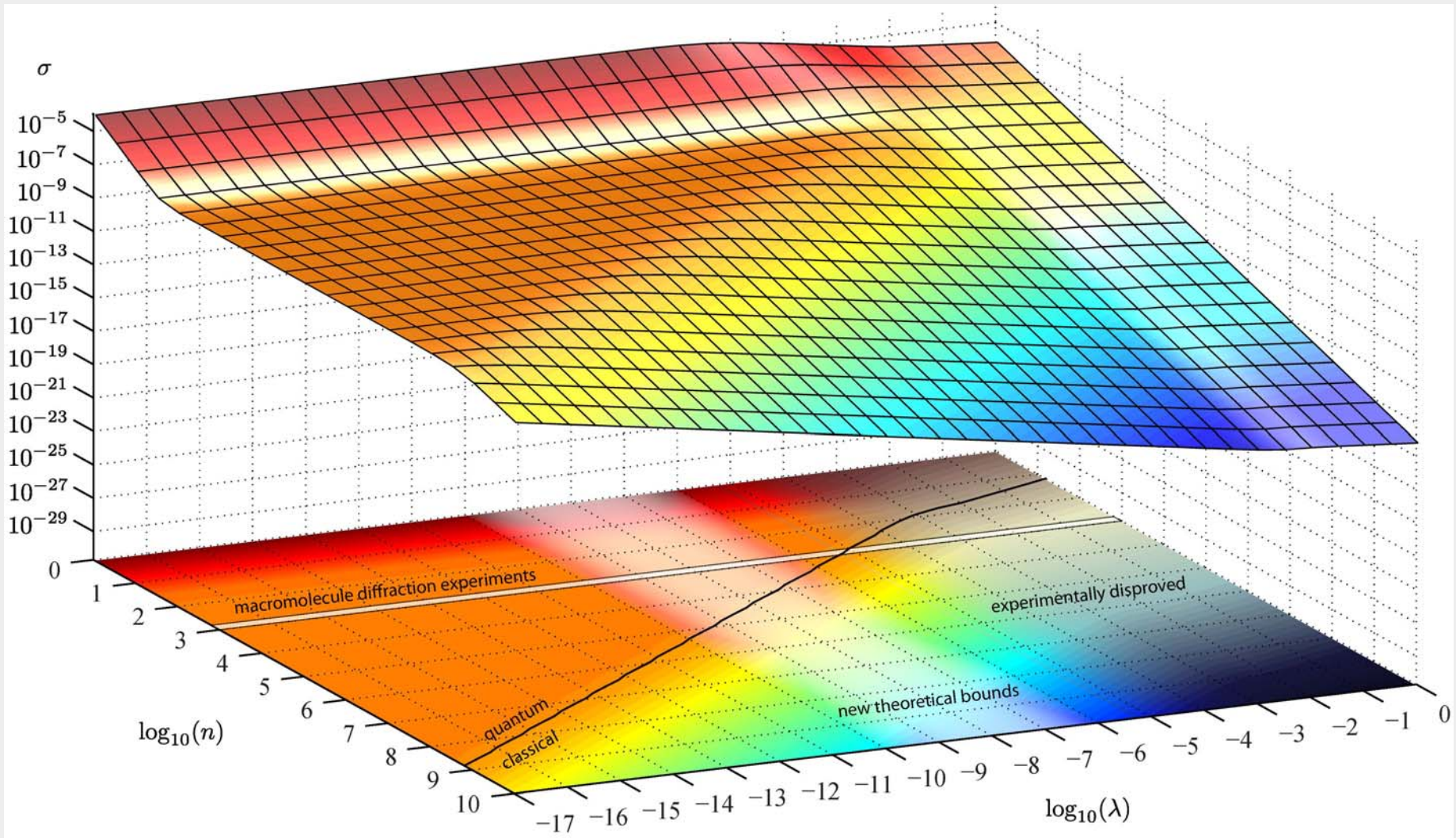
The noise field of the CSL model is not physically realistic:

- It corresponds to a infinite-temperature field
- It is white (no frequency cut-off)

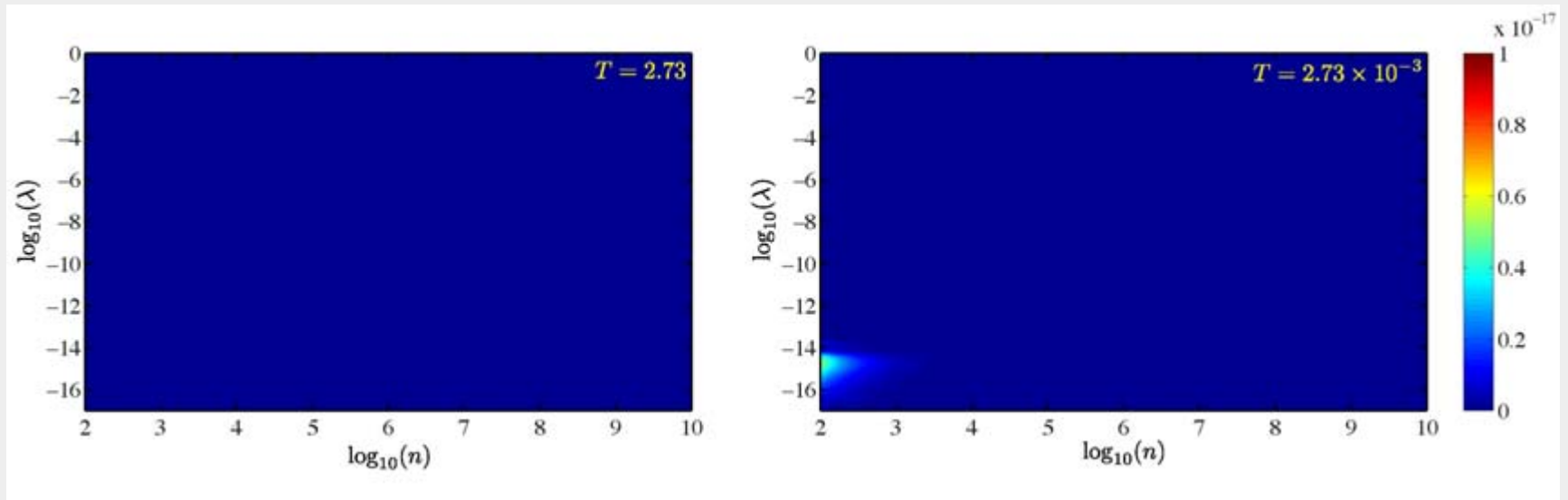
# A cosmological noise field?

	<b>White noise models</b>	<b>Colored noise models</b>
	All frequencies appear with the same weight	The noise can have an arbitrary spectrum
<b>Infinite temperature models</b>  Only the noise acts on the wave function	<b>GRW / CSL</b>  <b>QMUPL</b>  L. Diosi, <i>Phys. Rev. A</i> <u>40</u> , 1165 (1989).	<b>Non-Markovian CSL</b> P. Pearle, in <i>Perspective in Quantum Reality</i> (1996) S.L. Adler and A. Bassi, <i>Journ. Phys. A</i> <u>41</u> , 395308 (2008). arXiv: 0807.2846  <b>Non-Markovian QMUPL</b> A. Bassi and L. Ferialdi, <i>arXiv: 0901.1254</i>
<b>Finite temperature models</b>  Noise and wave function act on each other	<b>Dissipative QMUPL model</b> A. Bassi, E. Ippoliti and B. Vacchini, <i>J. Phys. A</i> <u>38</u> , 8017 (2005). ArXiv: quant-ph/0506083	  The "true" model?

# Collapse of the wave function



# Finite-temperature field

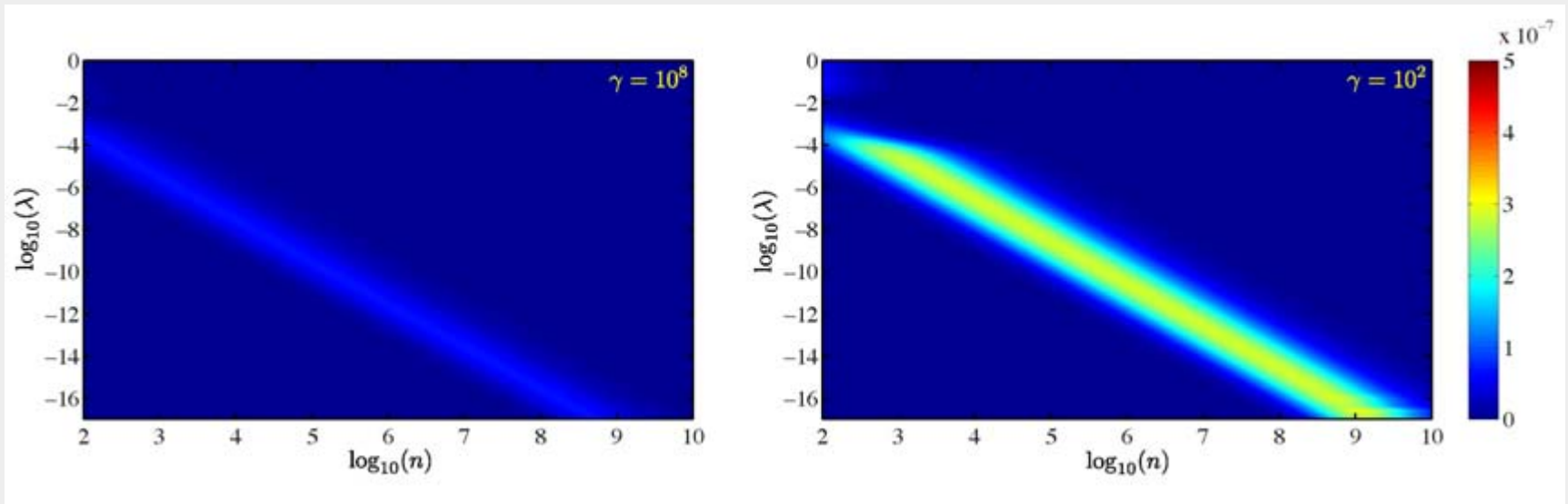


Difference of the time of the spread in position of the wave function, as given by the infinite temperature model and by the finite temperature model



A noise field with a typical cosmological temperature can induce an efficient collapse of the wave function

# Noise with frequency cut off



Difference of the time of the spread in position of the wave function, as given by the white-noise model and by the colored-noise model



A noise field with a typical cosmological cut-off can induce an efficient collapse of the wave function

# Conclusion

Two messages:

## 1. The noise field could break Lorentz invariant

This is because of initial conditions. The equations would still be invariant

Different inertial observers see the collapse differently. Experimental verification?

## 2. A random cosmological field with “typical” features for temperature and spectrum can induce an efficient collapse of the wave function

The collapse as a physical process, caused a background cosmological field

Underlying deeper level theory?