Spontaneous quantum measurement of mass distribution: DP and CSL models

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Two models in single nutshell

Spontaneous Localization is not testable

CSL (DP, too) look like "homodyne" measurement

CSL (DP, too): non-selective TC Measurement

Joint definition of CSL and DP

What is measured spontaneously about a bulk?

Heating - curse or blessing

Summary

Two models in single nutshell

ContinuousSpontaneousLocalization (Ghirardi-Pearle-Rimini 90)
DP gravity-related spontaneous collapse (D 89, Penrose 96)
Key quantities: mass distribution $\hat{f}_\sigma(x)$ plus white-noise $\xi_t(x)$:

$$\hat{f}_\sigma(x) = \sum_n m_n g_\sigma(x - \hat{x}_n) \qquad \sigma = \begin{cases} \sigma_{CSL} = 10^{-5} cm & CSL \\ \sigma_{DP} = 10^{-12} cm & D(P) \end{cases}$$

$g_\sigma =$ Gaussian, width σ

$$\overline{\xi_t(x)\xi_s(y)} = \Lambda(x,y)\delta(t-s) \qquad \Lambda(x,y) = \begin{cases} \Gamma\delta(x-y); & \Gamma = 10^{16}\frac{cm^3}{g^2 s} \;\; CSL \\ \frac{G}{\hbar}\frac{1}{|x-y|}; & \frac{G}{\hbar} = 10^{19}\frac{cm}{g^2 s} \;\; DP \end{cases}$$

Spontaneous Localization equation:

$$\dot{\Psi} = \frac{-i}{\hbar}\hat{H}\Psi + \int \left[\hat{f}_\sigma(x) - \langle\hat{f}_\sigma(x)\rangle\right]\xi(x)dx\, \Psi - \frac{1}{2}\iint \Lambda(x,y)\left[\hat{f}_\sigma(x) - \langle\hat{f}_\sigma(x)\rangle\right]\left[\hat{f}_\sigma(y) - \langle\hat{f}_\sigma(y)\rangle\right]dxdy\, \Psi$$

Spontaneous Decoherence equation:

$$\dot{\hat{\rho}} = \frac{-i}{\hbar}[\hat{H},\hat{\rho}] - \frac{1}{2}\iint \Lambda(x,y)\left[\hat{f}_\sigma(x),[\hat{f}_\sigma(y),\hat{\rho}]\right]dxdy$$

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Spontaneous Localization equation: REDUNDANT (D. 89)

$$\dot{\Psi} = \frac{-i}{\hbar}\hat{H}\Psi + \int \left[\hat{f}_\sigma(x) - \langle \hat{f}_\sigma(x)\rangle\right] \xi(x) dx \; \Psi - \frac{1}{2}\iint \Lambda(x,y) \left[\hat{f}_\sigma(x) - \langle \hat{f}_\sigma(x)\rangle\right]\left[\hat{f}_\sigma(y) - \langle \hat{f}_\sigma(y)\rangle\right] dxdy \; \Psi$$

Spontaneous Decoherence equation: RELEVANT

$$\dot{\hat{\rho}} = \frac{-i}{\hbar}[\hat{H}, \hat{\rho}] - \frac{1}{2}\iint \Lambda(x,y) \left[\hat{f}_\sigma(x), [\hat{f}_\sigma(y), \hat{\rho}]\right] dxdy$$

CSL (DP, too) *look like* "homodyne" measurement

$$\dot{\Psi} = \frac{-i}{\hbar}\hat{H}\Psi + \int\left[\hat{f}_\sigma(x) - \langle\hat{f}_\sigma(x)\rangle\right]\xi(x)dx\Psi - \frac{\Gamma}{2}\int\left[\hat{f}_\sigma(x) - \langle\hat{f}_\sigma(x)\rangle\right]^2 dx\Psi$$

$$\overline{\xi_t(x)\xi_s(y)} = \delta(x-y)\delta(t-s)$$

Looks like Time-Continuous Measurement (TCM) of mass distribution $\hat{f}_\sigma(x)$ at each location x.
TCM is *standard* quantum theory (Belavkin, Barchielli, D., Carmichael, Wiseman-Milburn, ...)
TCM implies the classical outcome signal (D. 88):

$$f(x,t) = \langle\hat{f}_\sigma(x)\rangle_t + \sqrt{2/\Gamma}\xi_t(x)$$

CSL has been eagerly seeking interpretation of $\xi_t(x)$.
If CSL *were* TCM of $\hat{f}_\sigma(x)$, the CSL noise $\xi_t(x)$ would be just the noise of the measured signal, times $\sqrt{2/\Gamma}$.

CSL (DP, too): non-selective TC Measurement

Suppose G. likes to know mass distribution in the Universe. Installs von Neumann unsharp detectors (1932) at each location of the Universe, switch them on, watches the random signal $f(x,t)$ and calculates Ψ_t. All what G. is doing is TCM and it exactly *looks like* CSL for us.

However, a crucial component of TCM is missing from CSL. The quantity, corresponding to the measurement outcome $f(x,t) = \langle \hat{f}_\sigma(x) \rangle_t + \sqrt{2/\Gamma}\xi_t(x)$ is physically not accessible to the observer, whereas it is being directly observed by G.'s TCM (similarly in laboratory TCMs worldwide). Remember, we call a measurement *non-selective* if outcomes are not accessible.

Hence: CSL is equivalent with spontaneous *non-selective* TCM of the mass distribution $\hat{f}_\sigma(x)$. Non-selectivity leaves Ψ completely untestable. The only testable effect is Spontaneous Decoherence, fully captured by $\hat{\rho}$ and its master equation.

Joint definition of CSL and DP

Non-selective spontaneous TCM of mass distribution $\hat{f}_\sigma(x)$

CSL detectors are uncorrelated, DP's are $1/r$ correlated.

CSL has two parameters σ, Γ; DP has only σ (the other is G).

Major difference is spatial resolution of TCM:

$\sigma_{CSL} = 10^{-5} cm$ almost macroscopic

$\sigma_{DP} = 10^{-12} cm$ 'nuclear' size

Coherent displacements are decohered when:

of the whole bulk (surface matters) — CSL

of the whole bulk or inside it (like acoustic waves) — DP

Significance under natural conditions?

apparently nowhere — CSL

perhaps, e.g. in long wavelenghts acoustics — DP

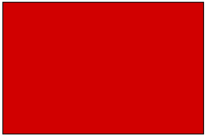
Constant heating (TCM heats!)

extreme low rate: 10^{-36}erg/s/microscopic d.o.f. — CSL

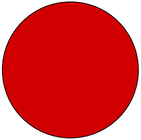
extreme high rate: 10^{-21}erg/s/microscopic d.o.f. — DP

What is measured spontaneously about a bulk?

CSL: location of surfaces and nothing else



position, angle



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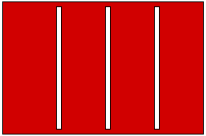
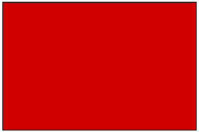
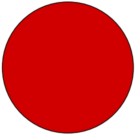


horizontal position
4x stronger

DP: all bulk coordinates, like c.o.m., solid angle, acoustics



position, angle



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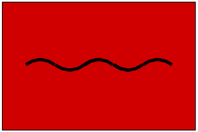

internal macroscopic
modes

Heating - curse or blessing

Options to fight heating:

spontaneous decoherence plus dissipation — CSL, DP?

spontaneous decoherence: only macroscopic d.o.f.—DP(D.13)

Center-of-mass $\hat{x}$ spontaneous decoherence (i.e.: mom. diff.):

$$\dot{\hat{\rho}} = \frac{-i}{\hbar}[\hat{H},\hat{\rho}] - \frac{D}{\hbar^2}\left[\hat{X},[\hat{X},\hat{\rho}]\right]$$

Cantilever $M{=}10ng$; size $d{\times}L{\times}L$; $d{=}1\mu m$, $L{=}100\mu m$ (Bahrami-Paternostro-Bassi-Ulbricht 14):

$$D{=}\begin{Bmatrix}\frac{\hbar^2\Gamma}{\sigma_{CSL}}\frac{M^2}{2\sqrt{\pi}d^2L^2}\\ \frac{\hbar G}{\sigma_{DP}^3}\frac{Mm^{nucl}}{12\sqrt{\pi}}\end{Bmatrix}{\sim}\frac{10^{-29}g^2cm^2}{s^3} \Rightarrow \text{heating:}\frac{D}{M}{\sim}10^{-21}\frac{erg}{s}$$

Vibrating cantilever $\Omega{=}100kHz$, $Q{=}10^5$, damping rate $\Omega/Q{=}1/s$

heating: $\frac{10quanta}{s}$; damping: $\frac{1}{s}$; equilibrium occupation: $10quanta$

Ground state cooling is very hard against CSL/DP heating.

Blessing: easy test of CSL (Bahrami et al. 14) and of DP.

Summary

- CSL, DP = non-selective Time-Continuous Measurement, i.e.: standard quantum mechanics
- Stochastic Schrödinger equation is physically redundant i.e.: not testable
- Spontaneous Decoherence equation captures everything:

$$\dot{\hat{\rho}} = \frac{-i}{\hbar}[\hat{H}, \hat{\rho}] - \frac{1}{2}\iint \begin{Bmatrix} \Gamma\delta(x-y) \\ \frac{G}{\hbar}\frac{1}{|x-y|} \end{Bmatrix} \left[\hat{f}_\sigma(x), [\hat{f}_\sigma(y), \hat{\rho}]\right] dxdy$$

- Heating is fatal for ground state cooling
- Heating is blessed: direct test of CSL/DP