Generic Theses on Spontaneous Wave Function Collapse

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Theses on spontaneous collapse models

Spontaneous Localization is not testable

DP/CSL look like "homodyne" measurement

CSL/DP: non-selective TC Measurement

Joint definition of CSL and DP

What is measured spontaneously about a bulk?

Heating - curse or blessing

Summary

Theses on spontaneous collapse models

- Spontanoues collapse models: GRW, QMUPL, DP, CSL
- SN was not claimed to be collapse model (1984).
- Collapse models are standard monitoring theories (1989).
- The only difference: the detectors are hidden (2013).
- Spontaneous decoherence is testable, collapse isn't (1989)
- ME for $\hat{\rho}$ is relevant, SSE for Ψ is redundant (1989).
- Both DP and CSL are monitoring the mass density $\hat{f}(\mathbf{r}, t)$.
- Both increase temperature of mechanical oscillators by $\Delta T_{sp} \sim$ring-down time[s]$\times(10^{-5} - 10^{-6})[\mathrm{K}]$ (2014).
- DP resolves atomic structure of $\hat{f}(\mathbf{r}, t)$, CSL does not.
- DP collapses acoustic modes; CSL: but surfaces (2013).
- DP shows up for large acoustic modes, CSL can't (2013).
- Post-D(P) speculation: collapse causes gravity (2009).

Spontaneous Localization is not testable

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 (SSE): *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 (ME): *Relevant, sufficient*

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

DP/CSL *look like* "homodyne" measurement

CSL's Stochastic Schrödinger Equation (SSE):

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

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

Looks exactly like SSE of 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, ... 1988-1990-...)
TCM implies the classical outcome signal (D. 88):

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

CSL has been eagerly seeking interpretation of $\xi_t(x)$.
In CSL as TCM of $\hat{f}_\sigma(x)$, the CSL noise $\xi_t(x)$ *is* the noise of the measured signal $f(x,t)$ (times $\sqrt{2/\Gamma}$).

CSL/DP: 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* DP/CSL for us.

A crucial component of TCM is missing from CSL. The measurement outcome $f(x,t)=\langle\hat f_\sigma(x)\rangle_t+\sqrt{2/\Gamma}\xi_t(x)$ is not even interpreted in CSL. (In DP it is.)

DP/CSL are equivalent with spontaneous *non-selective* TCM of the mass distribution $\hat f_\sigma(x)$. Remember, we call a measurement *non-selective* if outcomes are not accessible. Non-selectivity leaves Spontaneous Localization of Ψ_t completely untestable: SSE is redundant. The only testable effect is Spontaneous Decoherence, fully captured by $\hat\rho$ and its master equation (ME).

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

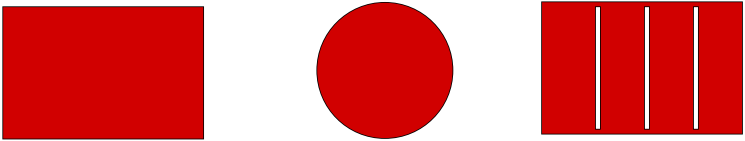
Constant heating (TCM heats!)

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

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

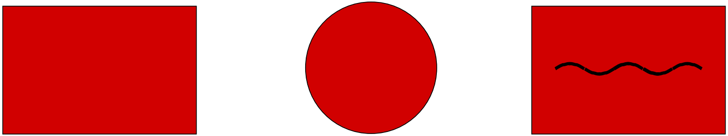
What is measured spontaneously about a bulk?

CSL: location of surfaces and nothing else



position, angle | position, ~~angle~~ | horizontal position 4x stronger

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



position, angle | position, angle | 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.):

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

Spontaneous heating in massive damped oscillators (D 15):

$$\Delta T_{sp} \sim \frac{\text{ring-down time}}{sec} \times (10^{-5} - 10^{-6})[\mathrm{K}]$$

Ground state cooling is hard against CSL/DP heating.
Blessing: easy test of CSL/DP (Bahrami et al. 14, D 15).

Summary

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

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

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