How to teach and think about spontaneous wave function collapse theories: not like before

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Self-quotation 1989

It is natural to ask why people prefer the complicated nonlinear SDE instead of the linear and deterministic master equation. [...] The only objective reason that may support the SDE formalism is a guess that a (still unknown) physical mechanism will modify the set of measurable quantities [...]. [*Phys. Rev.* **A40**, 1165 (1989)]

Self-quotation 2000

We are being captured in the old castle of standard quantum mechanics. Sometimes we think that we have walked into a new wing. It belongs to the old one, however. [*Lect. Notes Phys.* **583**, 243 (2000)]

Self-quotation 2018

A simple and natural introduction to the concept and formalism of spontaneous wave function collapse can and should be based on textbook knowledge of standard quantum state collapse and monitoring. This approach explains the origin of noise driving the paradigmatic stochastic Schrodinger equations of spontaneous localization of the wave function. It reveals, on the other hand, that these equations are empirically redundant and the master equations of the noise-averaged state $\widehat{\rho}$ are the only empirically testable dynamics in current spontaneous collapse theories. [in: *Collapse of the Wave Function*, ed.: S. Gao Cambridge University Press, Cambridge, 2018]

When standard collapse is testable, when it is not

Ideal measurement

$$|1\rangle, |2\rangle, \dots \text{ (BASIS)}$$

$$|\Psi\rangle \longrightarrow \text{DEVICE} \longrightarrow |n\rangle \text{ (COLLAPSE)}$$

$$n \text{ (OUTCOME)}$$

$$p_n = |\langle n|\Psi\rangle|^2 \text{ (OUTCOME PROBABILITY)}$$

Average over n:

$$|\Psi\rangle \longrightarrow \text{DEVICE} \longrightarrow \widehat{\rho} = \sum p_n |n\rangle\langle n| \text{ (DECOHERENCE)}$$

COLLAPSE, i.e.: the post-measurement statevector, is testable if the OUTCOME is known. Otherwise it is not testable. Only the DECOHERENCE, i.e.: the post-measurement density matrix is testable.

Standard Von Neumann position measurement

$\Psi(x) \longrightarrow$ DEVICE $\longrightarrow \Psi_{\bar{x}}(x)$ localized randomly at $\bar{x}$ ($\bar{x}$: OUTCOME)

SELECTIVE measurement ($\bar{x}$ available): Ψ COLLAPSES

COLLAPSE mathematics, stochastic

$$\Psi(x) \longrightarrow \Psi_{\bar{x}}(x) = \frac{1}{\sqrt{p(\bar{x})}} \exp\left(-\frac{(x-\bar{x})^2}{4\sigma^2}\right)\Psi(x)$$

NONSELECTIVE measurement ($\bar{x}$ avaraged out): Ψ only DECOHERES

DECOHERENCE mathematics, deterministic

$$\Psi(x)\Psi^*(y) \longrightarrow \exp\left(-\frac{(x-y)^2}{8\sigma^2}\right)\Psi(x)\Psi^*(y)$$

SELECTIVE contains NONSELECTIVE but not the other way around.

Spontaneous position measurement

$\Psi(x) \longrightarrow$ ~~DEVICE~~ $\longrightarrow \Psi_{\bar{x}}(x)$ localized randomly at $\bar{x}$ ($\bar{x}$: OUTCOME)

SELECTIVE measurement ($\bar{x}$ available): Ψ COLLAPSES

COLLAPSE mathematics, stochastic

$$\Psi(x) \longrightarrow \Psi_{\bar{x}}(x) = \frac{1}{\sqrt{p(\bar{x})}} \exp\left(-\frac{(x-\bar{x})^2}{4\sigma^2}\right)\Psi(x)$$

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$$\Psi(x)\Psi^*(y) \longrightarrow \exp\left(-\frac{(x-y)^2}{8\sigma^2}\right)\Psi(x)\Psi^*(y)$$

SELECTIVE contains NONSELECTIVE but not the other way around.

GRW: universal spontaneous position measurement

GRW postulate: spontaneous independent selective position measurements on each microscopic constituent (of the Universe):

$$\Psi(x_1, x_2, \dots) \longrightarrow \text{~~DEVICE~~} \longrightarrow \Psi_{\bar{x}_1\bar{x}_2\dots}(x_1, x_2, \dots)$$

repeated at average rate $\lambda = 10^{-17}/s$ at constant precision $\sigma = 10^{-5}cm$.

Physics: Ignorable on individual constituents. But: $\sim 10^6$ independent measurements/sec, each of precision $10^{-5}cm$ w.r.t. the c.o.m. of a $1g$ composite object, meaning $10^{-8}cm$ c.o.m. localization in every second!

STANDARD PHYSICS	GRW NEW PHYSICS
device	no device
measurement	hit
outcomes	flashes

Selective or nonselective?

SELECTIVE (if outcomes $\bar{x}_1, \bar{x}_2 \ldots$ are accessible): Wavefunction $\Psi(x_1, x_2, \ldots)$ is testable, evolves stochastically, COLLAPSE mechanism (localization) is encoded and testable.

NONSELECTIVE (if outcomes $\bar{x}_1, \bar{x}_2 \ldots$ are not accessible): Only the density matrix $\rho(x_1, x_2, \ldots; y_1, y_2, \ldots)$ is testable, evolves by deterministic master (LIndblad) equation, DECOHERENCE is encoded and testable. COLLAPSE is not encoded and not testable.

GRW has no DEVICE, spontaneous measurements leave the measurement OUTCOMES (flashes $\bar{x}_1, \bar{x}_2, \ldots$) UNACCESSIBLE.

Universal spontaneous collapse models GRW, CSL, DP

Overmighty G. arranges GRW (CSL, DP) mechanism within standard quantum mechanics via repeated standard position (mass configuration) measurements on each constituents of the Universe, while keeping Her/His DEVICEs hidden from our eyes and physics. Also His/Her measurement OUTCOMES are unaccesible for us. We can test the ensemble average density matrix instead of the stochastic wavefunction. We can test DECOHERENCE, not COLLAPSE.

Stochastic state vector equations of GRW/CSL/DP models are redundant because the state vectors are not testable. All testable effects are perfectly encoded by the GRW/CSL/DP master equations of density matrices.

In case of doubts: Suggest an effect and its test! (Thoughtexperiments are welcome.)

More details: p3-11 in *Collapse of the Wave Function*, ed.: S. Gao Cambridge University Press, Cambridge, 2018; arXiv:1710.02814