THE GRAVITY-RELATED DECOHERENCE/COLLAPSE THEORY

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CONTENT:

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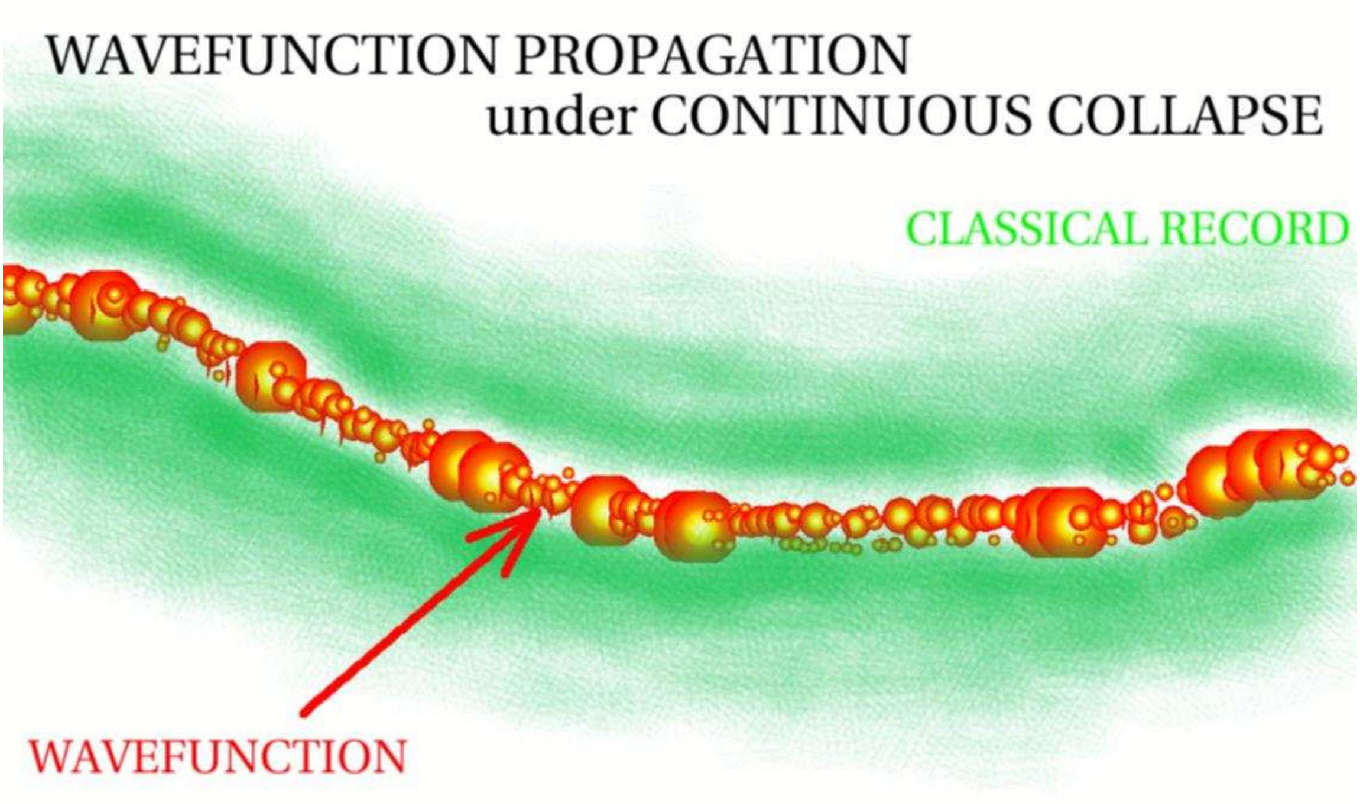
PEOPLE:

- **Concept: Feynman, Károlyházy, Penrose, Diósi**
- **Decoherence time eq: D., Penrose**
- **Time-evolution eq: D.**
- **Related theories: Ghirardi, S.Adler**

Real, Potential, or Fictitious Continuous Collapse



Classicality emerges from Quantum via real, potential, or fictitious often time-continuous measurement [detection, observation, monitoring, ...] of the wavefunction ψ.

- Real: particle track detection, photon-counter detection of decaying atom, homodyne detection of quantum-optical oscillator, ...
- Potential: environmental heat bath, light, radiation, ...
- Fictitious: theories of spontaneous [universal, intrinsic, primary, ...] localization [collapse, reduction, ...].

To date, the mathematics is the same for all classes above! We know almost everything about the mathematical and physical structures if markovian approximation applies. We know much less beyond that approximation.

Why should we suppose a fictitious collapse?

Fictitious Gravity-Related Collapse

Quantum superposition

$$|g\rangle + |g'\rangle$$

of two space geometries g and g' (of mass distributions f and f'). Penrose: If g and g' (i.e.: f and f') are 'very' different from each other then the superposition is conceptionally ill defined. Myself: It can be defined but the proliferating space-time—matter entanglements are practically untractable.

Such superpositions must decohere (decay) at a certain 'gravitational' decoherence time t_G decreasing with the 'distance' ℓ between g and g'. The non-relativistic ansatz:

$$\ell^2[g,g'] \equiv \ell^2[f,f'] =: E_G[f-f']$$

where $E_G[f]$ is the Newton self-energy function. The decoherence time:

$$t_G =: \frac{\hbar}{\ell^2} = \frac{\hbar}{E_G[f-f']}$$

We created borderline between the quantum and the classical universe.

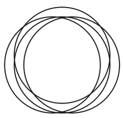
And we saw that this borderline was good.

'Rigid Ball' Schrödinger Cat

- **Distant initial superposition of c.o.m. around x and x′, resp.:**

- **Quick (t_G) decoherence and random collapse leads, e.g., to:**

- **After longer time ($t \gg t_G$), a pointer state of width Δx_G is formed:**



The Micro-macro Borderline

Rigid ball centered at x and x′, in superpostion $|x\rangle + |x'\rangle$.

$$\ell^2 = E_G[f - f'] = U(x - x') - U(0)$$

$$U(x - x') = -G \int \frac{f(r|x)f(r'|x')}{|r' - r|} dr dr'$$

where $f(r|x) = (3M/4\pi R^3)\theta(|r - x| \leq R)$ is the mass density at r; M, R are ball mass and radius, resp. (digr.: GRGWPB s mCSL). The ‘gravitational’ decoherence time becomes:

$$t_G = \frac{\hbar}{U(x - x') - U(0)} \sim \begin{cases} \hbar R/GM^2 & \text{for } |\Delta x| \gg R \\ \hbar R^3/GM^2(\Delta x)^2 & \text{for } |\Delta x| \ll R \end{cases}$$

For atomic masses, t_G is extremely long and the postulated effect is irrelevant. For nano-objects, t_G is shorter and the postulated effect may compete with the inevitable environmental decoherence. For macro-objects t_G is unrealistically short (but environmental decoherence is even faster). What size R is the borderline? Suppose free mass, calculate time-scale of coherent evolution:

$$t_C \sim \frac{\Delta x}{\Delta p/M} \sim \frac{\Delta x}{\hbar/\Delta x M} \sim \frac{M(\Delta x)^2}{\hbar}$$

Decoherence and coherence are balanced if $t_G \sim t_C$, yielding

$$\Delta x_G \sim 10^{-5}\text{cm} \qquad (\text{if } M/R^3 \approx 1\text{g/cm}^3 \text{ is assumed})$$

Good! (Plauzible)

Dynamical Equations: State of Art

Master Eq. that realizes decoherence at scale t_G:

$$\frac{d\rho(\mathrm{x},\mathrm{x}')}{dt} = \text{standard q.m. terms} - \frac{1}{\hbar}[U(\mathrm{x}-\mathrm{x}') - U(0)]\rho(\mathrm{x},\mathrm{x}')$$

Plus stochastic term realizes collapse to pointer states:

$$+\ \frac{1}{\hbar}[W_t(\mathrm{x}) + W_t(\mathrm{x}') - 2\langle W_t\rangle]\rho(\mathrm{x},\mathrm{x}')$$

where W is random field: $\mathrm{M}[W_t(\mathrm{x})W_t(\mathrm{x}')] = -\hbar U(\mathrm{x}-\mathrm{x}')\delta(t-t')$.

For long time, this SME drives any initial state $\rho(\mathrm{x},\mathrm{x}')$ into localized pure state (pointer state) while the SME reduces to the Frictional Schrödinger-Newton Eq.:

$$\frac{d\psi(\mathrm{x})}{dt} = \text{standard q.m. terms} - \frac{1}{\hbar}\int U(\mathrm{x}-\mathrm{x}')|\psi(\mathrm{x}')|^2 d\mathrm{x}'\ \psi(\mathrm{x}) + \frac{1}{\hbar}U_G\psi(\mathrm{x})$$

plus stochastic term:

$$+\ \frac{1}{\hbar}[W_t(\mathrm{x}) - \langle W_t\rangle]\psi(\mathrm{x})$$

Exact solution for free particle, in the $\Delta_G\mathrm{x} \ll R$ limit, in co-moving system:

$$\psi(\mathrm{x}) = \mathcal{N} exp\left(-\sqrt{-2i}\frac{\mathrm{x}^2}{4\Delta x_G^2}\right), \qquad \Delta\mathrm{x}_G^2 = \sqrt{2}\left(\frac{\hbar^2}{GM^3}\right)^{1/4} R^{3/4}$$

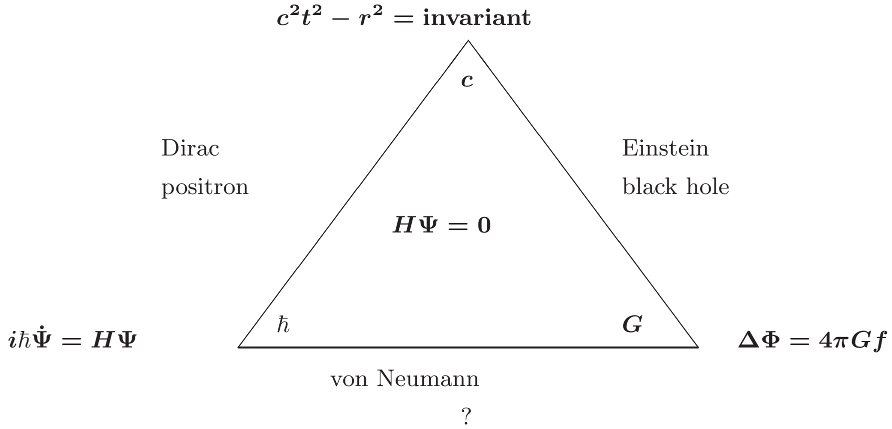
- The SME predicts the pointer states correctly even for $R = 0$.
- But: The process of collapse necessitates a cutoff.

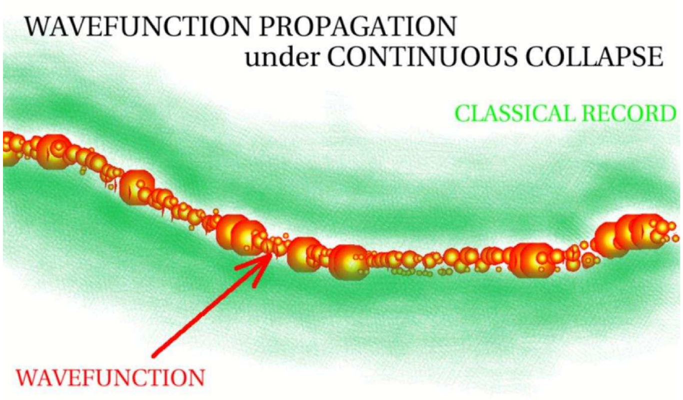
Penrose: pointer states from SNE, no dynamical eq. yet!

Difficulties and Perspectives

- **Heating**
- **Divergence Problem: for pointlike massive ball ($R = 0$) as well as for any object containing pointlike massive constituents $U(0)$ is ∞ therefore t_G would be zero!**
- **Pointer states are ok, but process of collapse necessitates a cutoff.**
- **Relativity?**
- **Experiments: suppress environment**

Two perspectives: experimental progress or radical theoretical development?





We modelled how gravity might cause collapse:

$$\frac{d\hat{\rho}}{dt} = -\frac{i}{\hbar}[\widehat{H}, \hat{\rho}] - \frac{G}{2\hbar}\int\int \frac{d\mathbf{r}d\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|}[\hat{f}(\mathbf{r}), [\hat{f}(\mathbf{r}'), \hat{\rho}]\ ]$$

What if collapse causes gravity?