Gravity-related wave function collapse: Is superfluid He exceptional?

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October 3, 2012

Acknowledgements go to:
Hungarian Scientific Research Fund under Grant No. 75129
EU COST Action MP1006 'Fundamental Problems in Quantum Physics'

Hypotheses of G-related decoherence/collapse

- Macroscopic superpositions are apparently missing from Nature.
- Consistent quantum-gravity is apparently missing from Science.
- Wouldn't Nature mimic von Neumann measurements?

Suppose mass density $f(\mathbf{r})$ matters.

$$|Cat\rangle = |f\rangle + |f'\rangle$$

f and f' are 'macroscopically' different.
'Catness' will be measured by distance $\ell(f,f')$, $[\ell^2]$=energy.
Nature makes $|Cat\rangle$ decay at

$$\text{rate } \frac{\ell^2(f,f')}{\hbar}, \quad \text{lifetime } \tau = \frac{\hbar}{\ell^2(f,f')}.$$

Choice of ℓ: no decay (extreme large τ) for atomic 'cats', immediate decay (small τ) for 'macroscopic' Cats.

1 G-related (and 2 G-unrelated) examples

Coarse-grain f at length scale σ, otherwise ℓ diverges.

- Gravity related, Diosi (1987), Penrose (1996), σ=?

$$\ell_G^2(f,f') = G\int\int [f(\mathbf{r})-f'(\mathbf{r})][f(\mathbf{s})-f'(\mathbf{s})]\frac{d\mathbf{r}d\mathbf{s}}{|\mathbf{r}-\mathbf{s}|}$$
$$= 2U(f,f') - U(f,f) - U(f',f')$$

- Gravity-unrelated, Ghirardi et al. (1990-...), σ=$10^{-5}cm$

$$\ell_{GRW}^2(f,f') = \sum_k \frac{\hbar\lambda}{m_k}\int\left[\sqrt{f_k(\mathbf{r})}-\sqrt{f_k'(\mathbf{r})}\right]^2 d\mathbf{r}$$
$$\ell_{CSL}^2(f,f') = \frac{\hbar\lambda\sigma^3}{m_{proton}^2}\int [f(\mathbf{r})-f'(\mathbf{r})]^2 d\mathbf{r}$$

λ=$10^{-17}/s$, σ=$10^{-5}cm$, f_k=f of k'th constituent of mass m_k.

Resolution of mass density $f(\mathbf{r})$ matters

Mechanical Schrödinger Cat: mass M, radius R, density $\rho \sim 1g/cm^3$

$$|Cat\rangle = |x\rangle + |x'\rangle$$

$$\ell_G^2(x,x') = 2U(x,x') - U(x,x) - U(x',x') \propto (x-x')^2 \equiv (\Delta x)^2; \quad (\Delta x \ll R)$$

- Macroscopic resolution ($\sigma \gtrsim 10^{-8} cm$)

$$\ell_G^2(x,x') \sim \frac{GM^2}{R}\frac{(\Delta x)^2}{R^2} \sim GM\rho(\Delta x)^2 = M\omega_G^2(\Delta x)^2$$

$\omega_G = \sqrt{G\rho} \sim 10^{-4}s^{-1}$ (cf. Newton oscillator)

- Microscopic resolution ($\sigma \lesssim 10^{-12} cm$)

$$\ell_G^2(x,x') \sim \frac{M}{m_{nucl}}\frac{Gm_{nucl}^2}{r_{nucl}}\frac{(\Delta x)^2}{r_{nucl}^2} \sim GM\rho_{nucl}(\Delta x)^2 = M(10^6 \times \omega_G)^2(\Delta x)^2$$

With 'nuclear' resolution, 'catness' ℓ_G becomes 10^6 times bigger!

Mass resolution: grave issue

Running and planned experiments to test Cat's decay.
$M = 1 - 100ng$ Cat in optical interferometer (Bouwmeester, Leiden):

- $\sigma \gtrsim 10^{-8}\,cm \Longrightarrow \tau$ is astronomic long, irrelevant
- $\sigma \sim 10^{-11} cm \Longrightarrow \tau \sim 10^6 - 10^4 s$, exp. unreachable
- $\sigma \lesssim 10^{-12} cm \Longrightarrow \tau \sim 10^{-2} - 10^{-4} s$, exp. reachable!

If Nature does respect nuclear size resolution of mass density, then G-related decoherence can become relevant for any motional degrees of freedom at scales e.g. $10^{-3} cm$, in any condensed matter objects. Exception: He-superfluid - its mass density is coarse-grained by QM.

If G-related collapse is the cause of gravity?

(D. at DICE2008)

- Collapse confines the wave packet:
  as if there were a field pointing inward.
- Collapse violates momentum conservation:
  Newton field might restore it.

If so, then the emergence rate of Newton gravity is related to the collapse rate of the sources.
Collapse rate competes with Hamiltonian kinetic rate. In balance:

$$\frac{M(10^6\omega_G)^2(\Delta x)^2}{\hbar} \sim \frac{\hbar}{M(\Delta x)^2}$$

Equilibrium collapse rate is $10^6\omega_G \sim 10^2/s$ for condensed matter, $\omega_G \sim 10^{-4}/s$ for He.

Testing gravity's laziness: Is He exceptional?

'Kick-off Note on Possible Emergence Time of Newton Gravity' arXiv:1209.2110

"... both astronomic and laboratory evidences have poor time resolution regarding how immediate the creation of Newton field of accelerating mass sources is. The current upper limit is perhaps not stronger than 1s." [Shame!]

If

- G-related collapse is real,
- its spatial cutoff σ is lower than the nuclear size,
- gravity is caused by collapse,

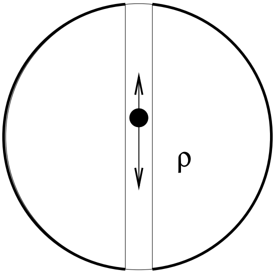
then gravity follows the accelerated source with a delay:

- $\sim 1/10^6\omega_G \sim 1ms$ (condensed matter)
- $\sim 1/\omega_G \sim 1h$ (He-superfluid)

"Although the concrete theoretical model of gravity's 'laziness' is missing, the concept might be tested dierctly in reachable exprmts."

Appendix: Newton oscillator

Newton oscillator



$\rho \sim 1 \mathrm{g/cm}^3$

$\omega_G = \sqrt{G\rho} \sim 10^{-4}/\mathrm{s}$

period ~1h

$\rho_{nucl} \sim 10^{12} \mathrm{g/cm}^3$

$\omega_G^{nucl} = \sqrt{G\rho_{nucl}} \sim 10^{2}/\mathrm{s}$

period ~1ms