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

Lajos Diósi

Wigner Center, Budapest

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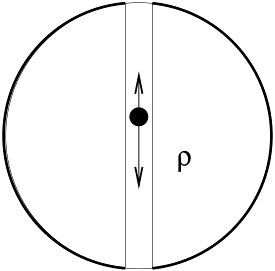
Quantum and gravity are expected to interfere in relativistic cosmic phenomena only. Alternative speculations suggest that quantum and gravity meet in a new way already at nanoscales. The gravity-related model of wave function collapse, a longtime hypothesis, has started to fuel a growing number of nano-experiments to test the quantum mechanical motion of massive objects. The talk extends the hypothesis of gravity-related collapse and assumes that wave function collapse is responsible for the emergence of Newton interaction. Superfluid helium would then show significant and testable gravitational anomalies.

Preparation: 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

Hypotheses of G-related collapse

- Macroscopic superpositions are apparently missing from Nature.
- Consistent quantum-gravity is apparently missing from Science.
- Nature itself might mimic von Neumann measurements.

Suppose mass density $f(\mathbf{r})$ and Newton constant G matter.

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

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

$$\text{collapse rate } \frac{\ell^2(f,f')}{\hbar}$$

Choice of ℓ: no decay (extreme slow rate) for atomic 'cats', immediate decay (fast rate) for 'macroscopic' Cats.

The DP model

Choice of 'catness':

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

Recall: collapse rate is $\ell_G^2(f,f')/\hbar$, i.e., cat's lifetime is $\hbar/\ell_G^2(f,f')$.

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

- 'Macroscopic' resolution ($\sigma \gtrsim 10^{-8} cm$)
  Collapse takes hours.
- 'Microscopic' resolution ($\sigma \lesssim 10^{-12} cm$)
  Collapse takes ms's.

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

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

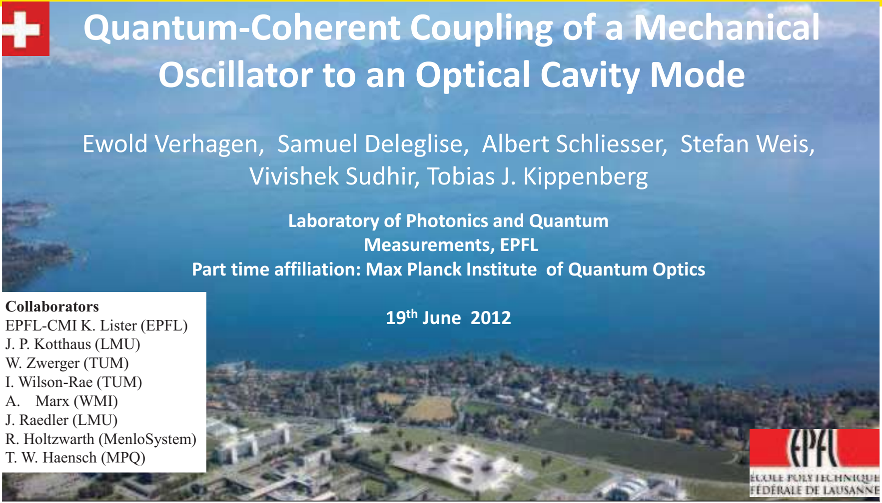
$\omega_G = \sqrt{G\rho} \sim 10^{-4} s^{-1}$ (cf. Newton oscillator)

- '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!

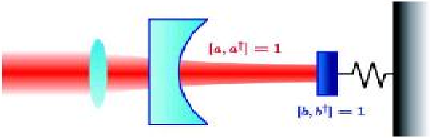
Optomechanics, state of art June 2012

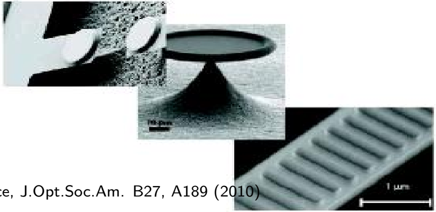


Marie Curie ITN

Monitoring the Cat: Experiments

- Vibrating micro-mirror (Leiden)
- Levitating micro-dielectrics (Vienna-Garching)
- ... on space satellite (Vienna-Garching-Pasadena)
- Silica micro-resonator (Garching-Pasadena)





Aspelmeyer et al.: Quantum Optomechnanics - Throwing a Glance, J.Opt.Soc.Am. B27, A189 (2010)

Currently: 10^{-12}g-1g, kHz-GHz, mK — but μK needed!

Mass resolution: grave issue

$M = 1 - 100ng$ 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 collapse can become relevant for any motional degree of freedom at scales e.g. $10^{-3} cm$, in any condensed matter object.

Exception: He-superfluid - its mass density is coarse-grained by QM, it looks homogeneous. The 'equilibrium' collapse rate in He-superfluid is 10^{6} times lower!

If G-related collapse is the cause of gravity?

- 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 (proportional) to the wave function 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.
Equilibrium collapse rate is $\omega_G \sim 10^{-4}/s$ for He superfluid.

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." No upper limit for He-superfluid!

If

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

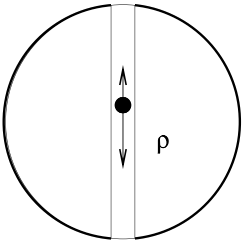
then gravity follows the accelerated source with a delay:

- $\sim 1/10^6\omega_G \sim 1ms$ (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 directly in reachable exprmts."

Summary

Newton oscillator



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* * *

G–related (DP) model predicts collapse rate

ω_G in He superfluid

ω_G^{nucl} in condensed matter

Proposal beyond DP–model: 1) Newton gravity is caused by DP–collapse.
2) Gravity's emergence rate is the collapse rate.

Consequence: Newton field of a moving condensed source is delayed by ms's.
Newton field of a moving He tank would be delayed by about 1h.

Next: What components (short/long range) are delayed?
Minimum model of emergence is needed for the experimental proposal.

Theoretical stress: violation of equivilance principle, momentum conservation, etc.