MAQRO - Testing the foundations of quantum physics in space

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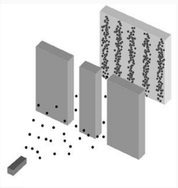
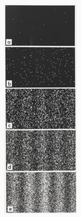
Superposition

Double-Slit Experiment





Did particle go left or right?

Quantum Theory:

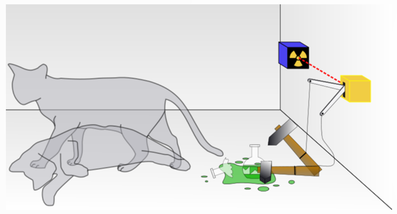
$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|\mathrm{left}\rangle + \mathrm{e}^{\mathrm{i}\,\chi}|\mathrm{right}\rangle\right)$$

$$p = \tfrac{1}{2}\left(1 + \cos\chi\right)$$

Schrödinger's Cat

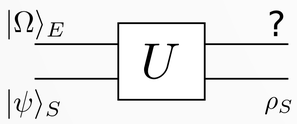
Entanglement of microscopic with macroscopic system

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|\mathrm{g}\rangle|\mathrm{dead}\rangle + |\mathrm{e}\rangle|\mathrm{alive}\rangle\right)$$



Quantum Decoherence

Quantum decoherence - coupling to environment



$$\rho_S = \mathrm{tr}_E\left[U\left(|\psi\rangle\langle\psi|_S \otimes |\Omega\rangle\langle\Omega|_E\right)U^\dagger\right]$$

Interactions with environment include scattering, absorption & emissions of:

- phonons (via mechanical support)
- molecules (background gas, outgassing)
- photons (blackbody radiation)

long-wavelength limit: $\frac{\partial\rho(\mathbf{x},\mathbf{y},t)}{\partial t} = -\Lambda(\mathbf{y}-\mathbf{x})^2\rho(\mathbf{x},\mathbf{y},t)$

Macrorealistic Theories

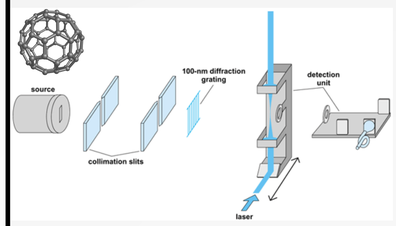
Physical mechanism leads to "localization" of wavefunction

- **Ghirardi-Rimini-Weber, Pearle, Gisin**:
  continuous spontaneous localization (CSL)
- **Ellis, Mohanty, Mavromatos, Nanopoulos**:
  collapse due to quantum gravity (space-time foam)
- **Diosi, Penrose**:
  collapse due to "self-gravitation" of wavepacket (Diosi)
  spontaneous decay of superposed spacetimes (Penrose)
- **Karolyhazy**:
  grav. collapse due to metric fluctuations

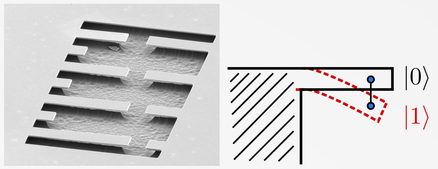
Can we test that experimentally?

Have to make "Schrödinger Cats": massive objects in quantum superposition then observe interference

Buckyball interference

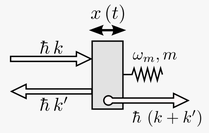


Mechanical oscillators

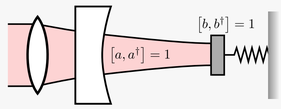


Quantum Optomechanics

Radiation pressure couples light to mechanical oscillator



with single photons?
-> increase coupling via cavity



Optomechanical Hamiltonian

$$H = \hbar\omega a^\dagger a + \tfrac{1}{2}\hbar\omega_m\left(p^2+q^2\right) - \hbar g_0 a^\dagger a q + \mathrm{i}\,\hbar E\left(a^\dagger \mathrm{e}^{-\mathrm{i}\,\omega_0 t} - a\mathrm{e}^{\mathrm{i}\,\omega_0 t}\right)$$

Current Status of Optomechanics

2009: strong coupling & 30 thermal quanta
2010: ground-state by cooling environment
2011: ground-state by back-action cooling

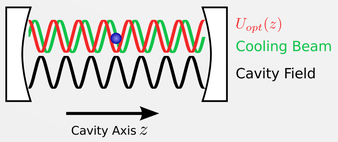
limitations: noise & mechanical quality factor

Optically Levitated Spheres

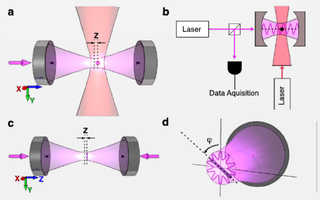
classical: A. Ashkin PRL 24, 156 (1970)

quantum:

D. E. Chang et al. (2009)

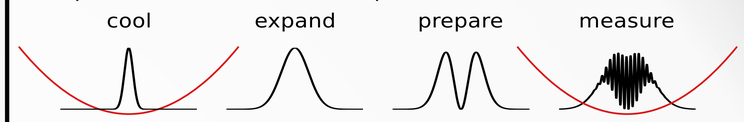


O. Romero-Isart et al. (2010)

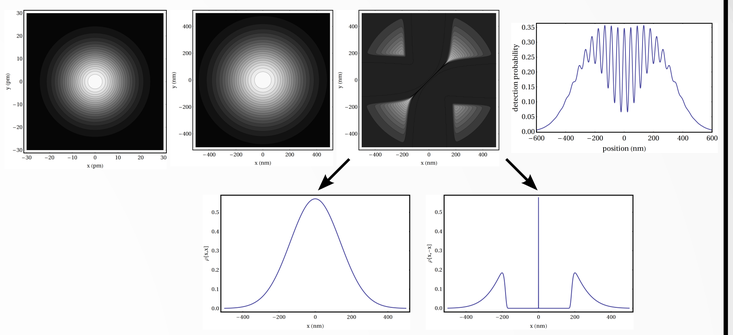


DECIDE - **Dec**oherence **i**n a **d**ouble-slit **e**xperiment

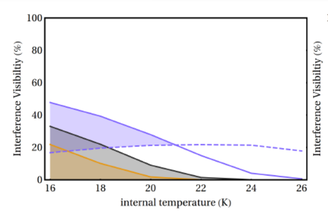
Proposal for a medium-sized space mission



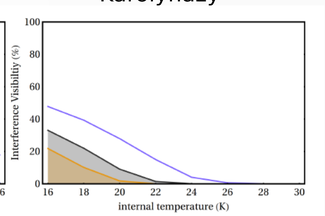
Novel type of DS preparation - via decoherence



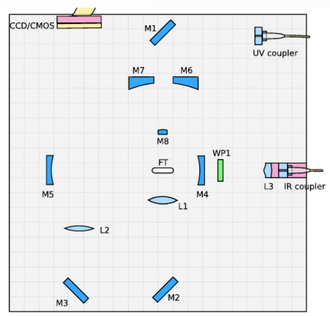
Diósi-Penrose



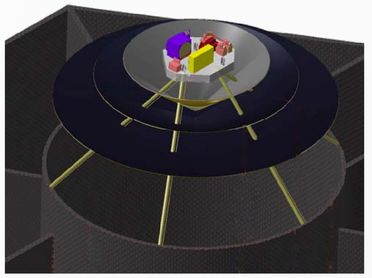
Károlyházy



Proposed setup



External Platform + Heat Shield mounted on Lisa-Pathfinder-type spacecraft



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