When Cavendish meets Feynman: A quantum torsion balance for testing the quantumness of gravity

Workshop Quantum Foundations. New frontiers in testing quantum mechanics from underground to space

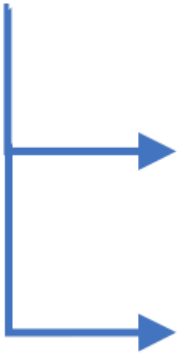
Laboratori Nazionali di **Frascati**

29th November - 1st December 2017

Matteo Carlesso (University of Trieste & INFN)

Can we test if gravity is quantum?

How is shaped the gravitational field resulting from a massive superposition?



Gravitational field is in a superposition;
Quantum scenario

Gravitational field is equally distributed on the superposition;
Classical scenario

We propose an experimental scheme to provide evidences in favour or against the quantumness of gravity

- Single self-probing system
- Superposition of torsional degrees of freedom

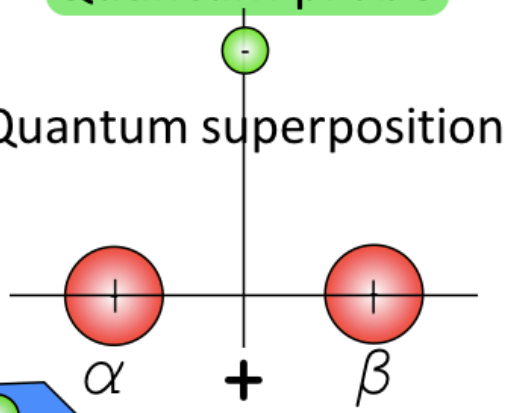
Can we test if gravity is quantum?

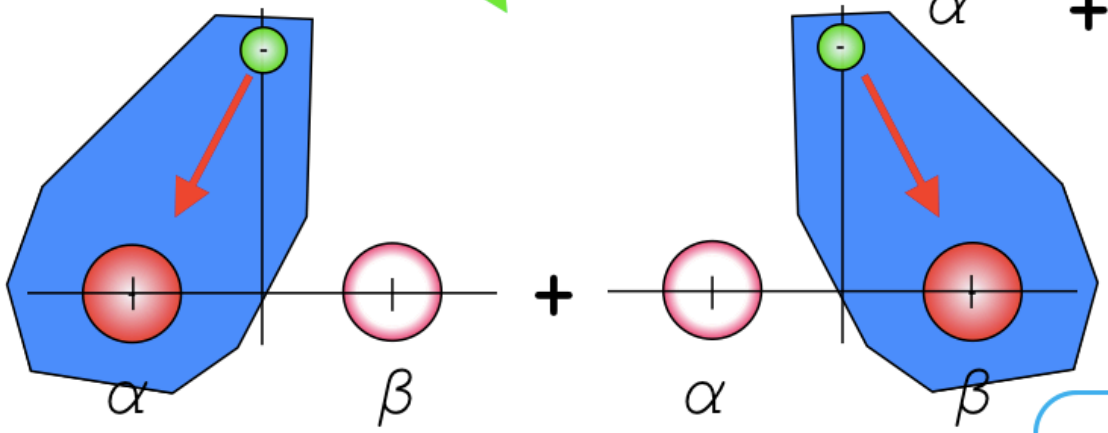
Quantum probe

Gravity is quantum

$$V_\gamma = -Gm_1m_2 \int \mathrm{d}^3\mathbf{r}_1 \frac{|\gamma(\mathbf{r}_1,t)|^2}{|\mathbf{r}_1-\mathbf{r}_2|}$$

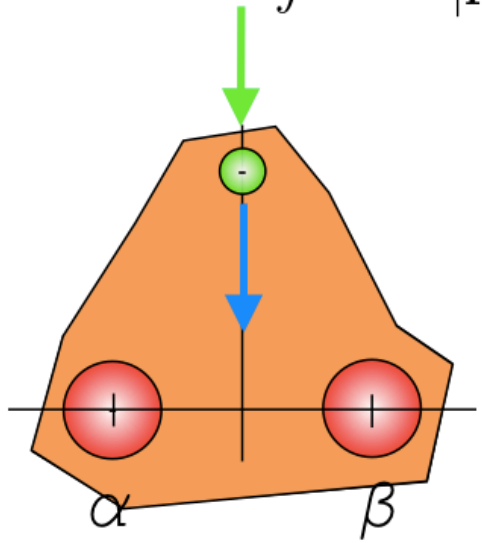
Quantum superposition





Gravity is classical

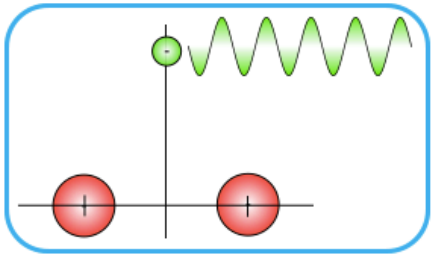
$$V_{\mathrm{cl}} = -Gm_1\,m_2 \int \mathrm{d}^3\mathbf{r}_1 \frac{|\psi(\mathbf{r}_1,t)|^2}{|\mathbf{r}_1-\mathbf{r}_2|}$$



Is Gravity Quantum?

M. Bahrami,[1,2] A. Bassi,[1,2] S. McMillen,[3] M. Paternostro,[3] and H. Ulbricht[4]

Optomechanical measurement of the quantum probe



The gravitational effect is too small to be detected

Can we test if gravity is quantum?

The Role of Gravitation in Physics

Report from the 1957 Chapel Hill Conference Feynman

PRL **119,** 120402 (2017) PHYSICAL REVIEW LETTERS week ending 22 SEPTEMBER 2017

Revealing Nonclassicality of Inaccessible Objects

Tanjung Krisnanda,[1] Margherita Zuppardo,[1,2] Mauro Paternostro,[3] and Tomasz Paterek[1,4,5]

IOP Publishing Classical and Quantum Gravity
Class. Quantum Grav. **32** (2015) 165022 (24pp) doi:10.1088/0264-9381/32/16/165022

Probing a gravitational cat state

C Anastopoulos[1,3] and B L Hu[2]

Witness gravity's quantum side in the lab 2017

Physicists should rethink interference experiments to reveal whether or not general relativity follows classical theory, argue **Chiara Marletto** and **Vlatko Vedral**.

PRL **116,** 161303 (2016) PHYSICAL REVIEW LETTERS week ending 22 APRIL 2016

Testing Quantum Gravity Induced Nonlocality via Optomechanical Quantum Oscillators

Alessio Belenchia,[1,*] Dionigi M. T. Benincasa,[1,†] Stefano Liberati,[1,‡] Francesco Marin,[2,3,§] Francesco Marino,[4,‖] and Antonello Ortolan[5,¶]

A Spin Entanglement Witness for Quantum Gravity 2017

Sougato Bose,[1] Anupam Mazumdar,[2] Gavin W. Morley,[3] Hendrik Ulbricht,[4] Marko Toroš,[4] Mauro Paternostro,[5] Andrew Geraci,[6] Peter Barker,[1] M. S. Kim,[7] and Gerard Milburn[7,8]

Is Gravity Quantum? 2015

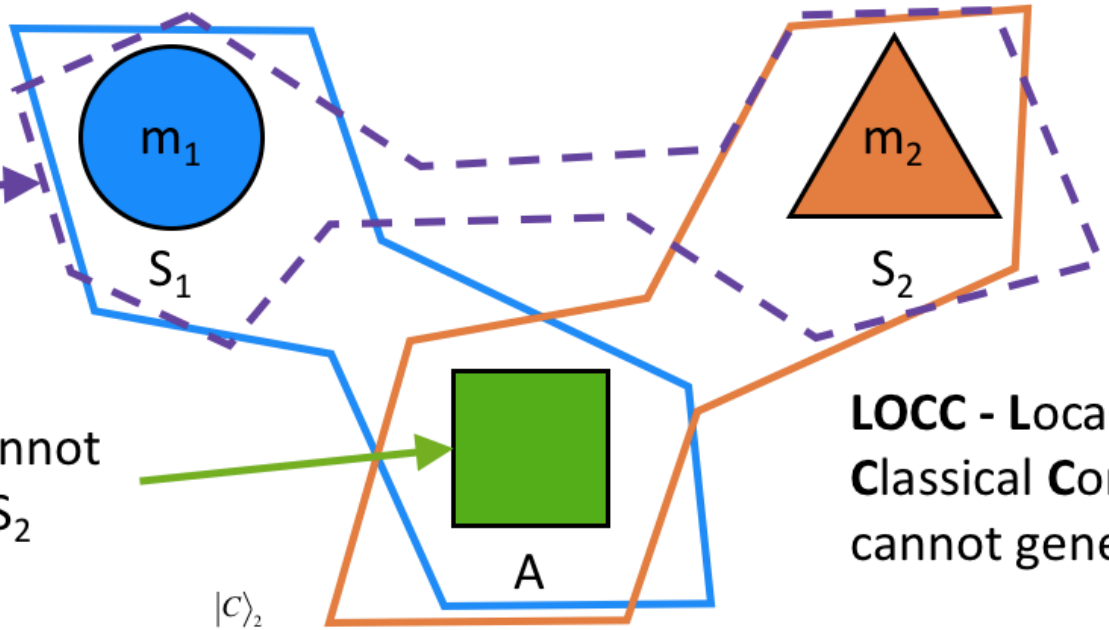
M. Bahrami,[1,2] A. Bassi,[1,2] S. McMillen,[3] M. Paternostro,[3] and H. Ulbricht[4]

An entanglement-based test of quantum gravity using two massive particles

C. Marletto[a] and V. Vedral [a,b] 2017

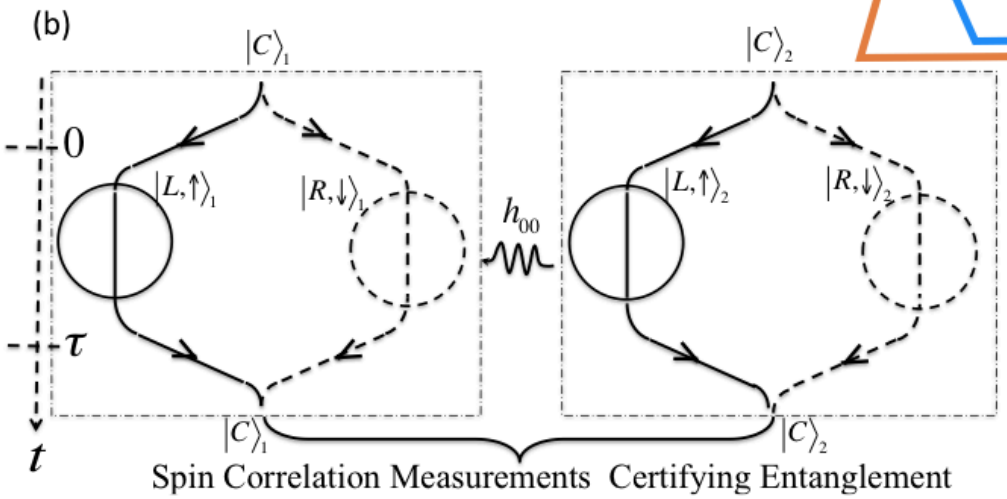
Gravity entangles masses

If entanglement is measured, gravity is quantum



A classical ancilla cannot entangle S_1 and S_2

LOCC - Local Operation and Classical Communication cannot generate Entanglement



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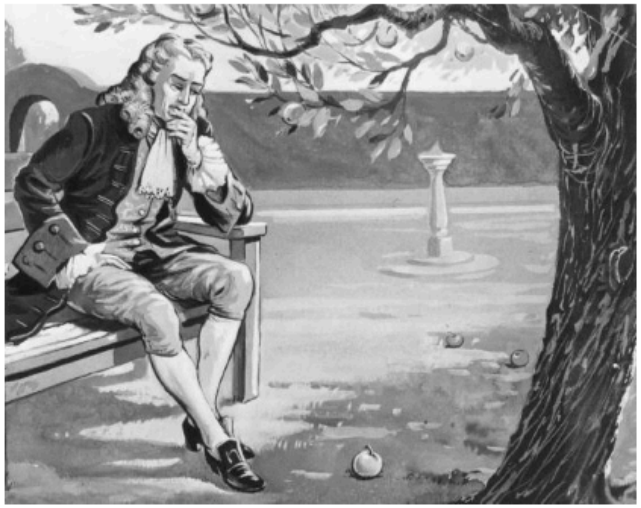
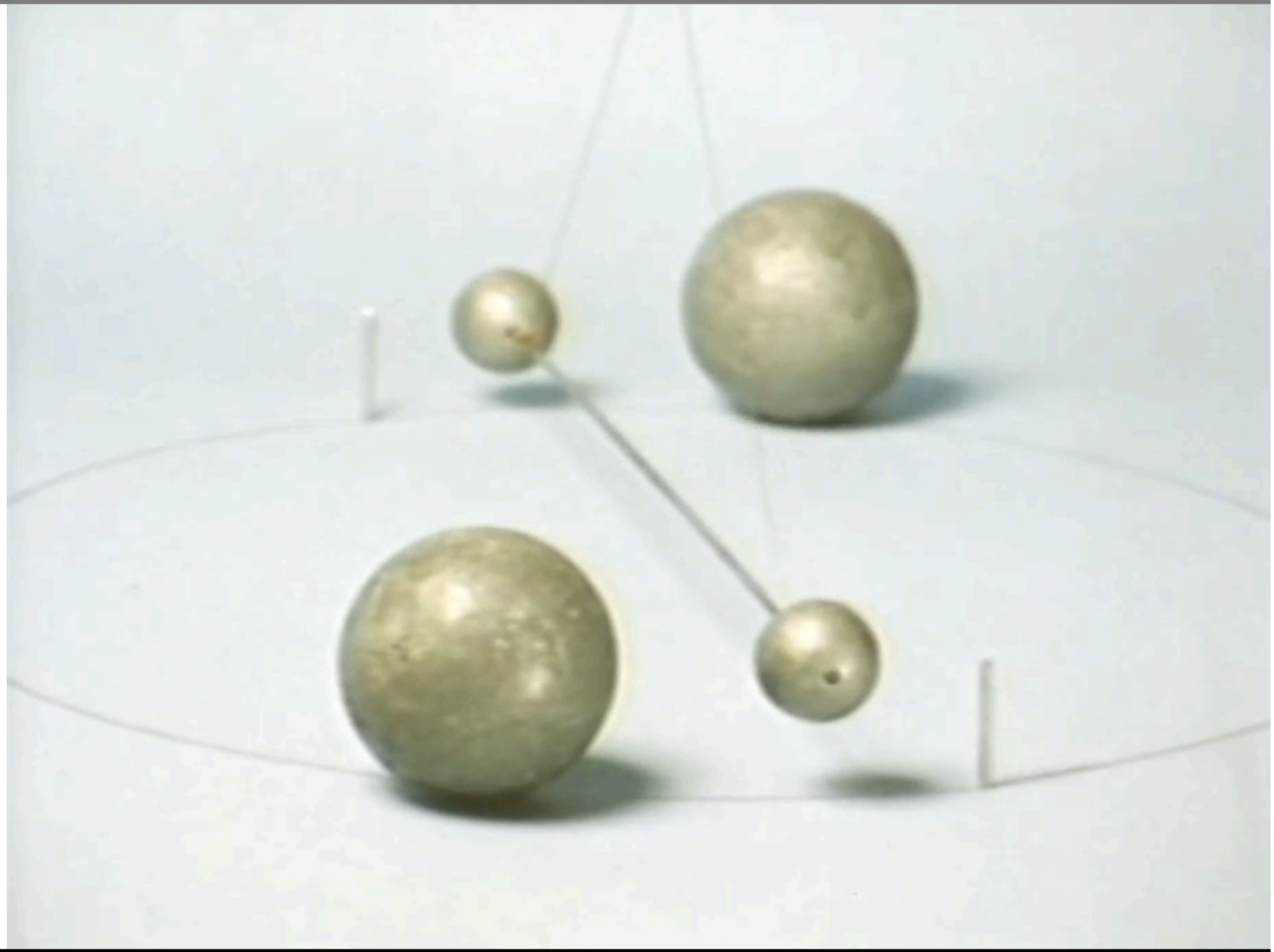
An entanglement-based test of quantum gravity using two massive particles

C. Marletto[a] and V. Vedral [a,b]

1797 – Cavendish probes Newton's law



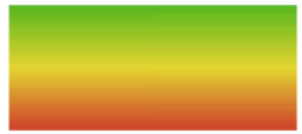


2017 – Cavendish probes Feynman???

When Cavendish meets Feynman: A quantum torsion balance for testing the quantumness of gravity

Matteo Carlesso,[1,2,*] Mauro Paternostro,[3,4] Hendrik Ulbricht,[5] and Angelo Bassi[1,2]

1) Cooling at low Temperature and Pressure

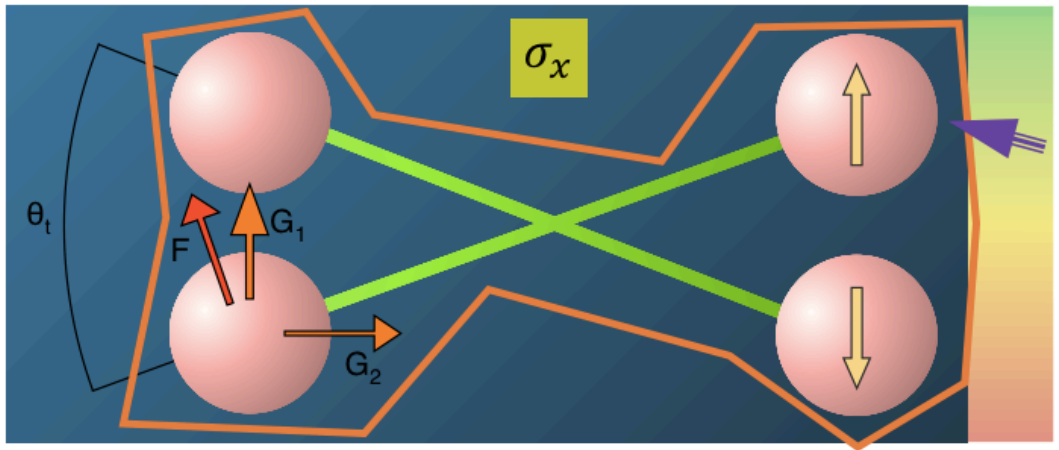


3) Angular superposition

4) Decoupling spin-angular dof

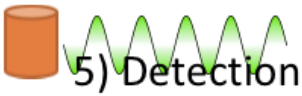
Spin 1 Nitrogen Vacancy

Nanorod



2) MW π/2 pulse
Spin superposition

Magnetic gradient



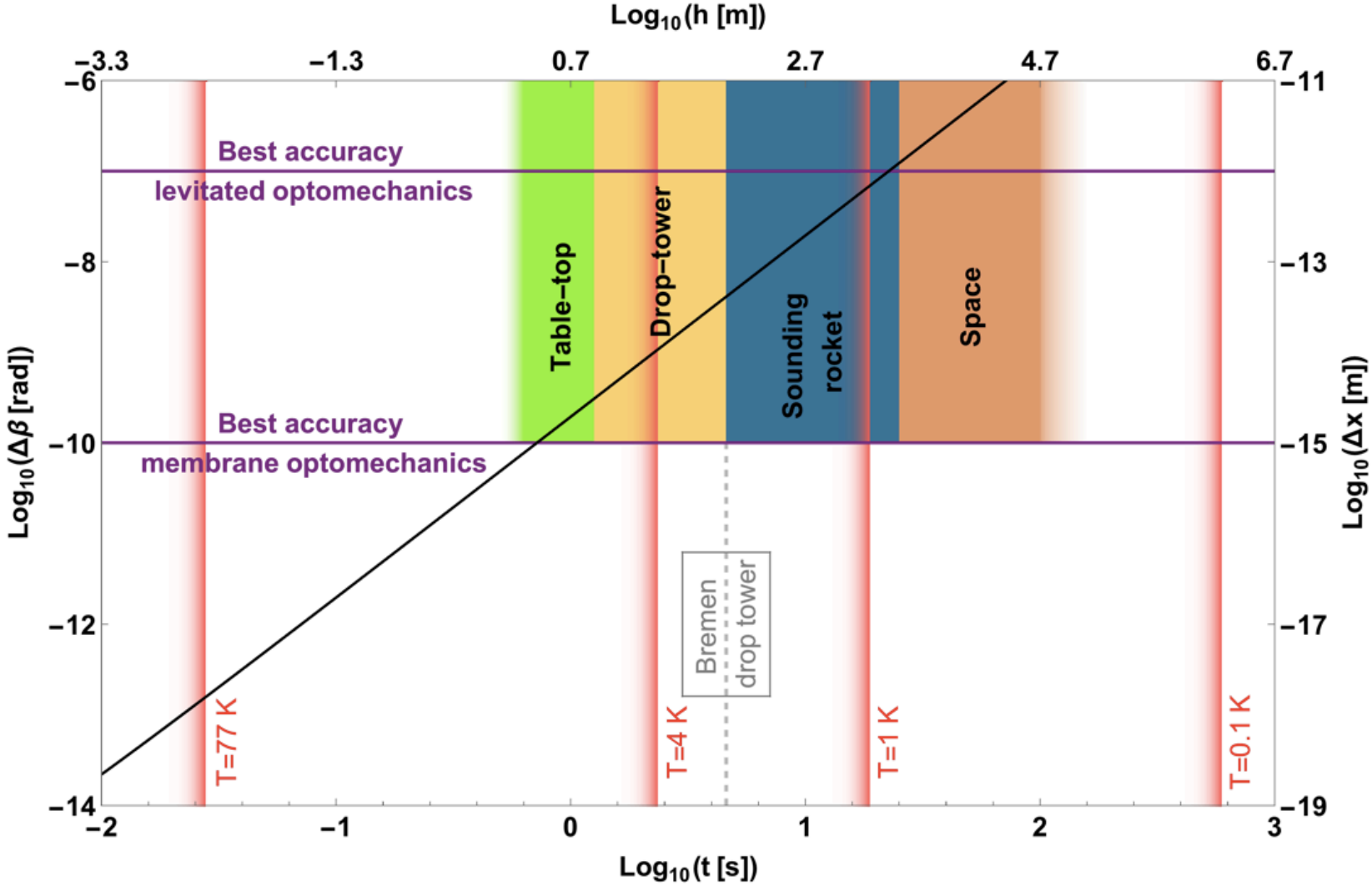
5) Detection

Classical scenario

$$V_{\rm cl} = -G m_1 m_2 \int \mathrm{d}^3\mathbf{r}_1 \frac{|\psi(\mathbf{r}_1,t)|^2}{|\mathbf{r}_1-\mathbf{r}_2|}$$

→ Attraction between the two parts of the superposition

Decoherence vs Gravitational effect



Diamond
r=7.92 nm
L=20 um

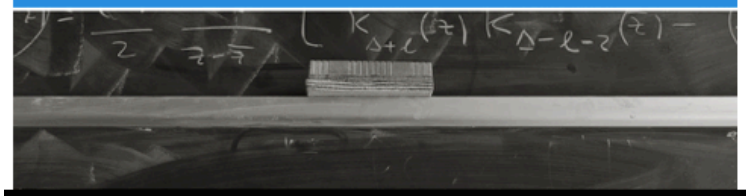
Conclusions

A test of quantumness of gravity within reach of state-of-the-art technology

- Single self-probing system
  - No limitations in distances
  - Gravitational interaction can be directly observed
- Superposition of torsional degrees of freedom
  - Enhanced measurement precision

UNIVERSITÀ DEGLI STUDI DI TRIESTE

Bassi Group University of Trieste QUANTUM MECHANICS



INFN Istituto Nazionale di Fisica Nucleare

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

QTSPACE