Can we understand if gravity is quantum?

Trieste Junior Quantum Days

11th May 2018

Matteo Carlesso (University of Trieste & INFN)

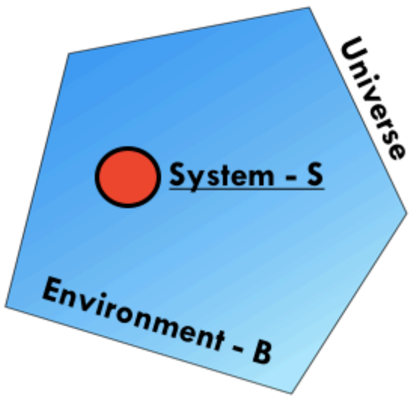
Who am I?

Former student (Bachelor, Master and PhD) and now PostDoc @ University of Trieste

Research Activities

Open Quantum Systems

- Decoherence models
- Collapse models



- MC and A. Bassi.
  Physics Review A, 95, 052119 (2017).
- MC and A. Bassi.
  Physics Letters A, 380, 31–32, pp. 2354 – 2358 (2016).
- S. McMillen, M. Brunelli, MC, A. Bassi,
  H. Ulbricht, M.G. Paris and M. Paternostro.
  Physical Review A, 95, 012132 (2017).
- MC, A. Bassi, P. Falferi, and A. Vinante.
  Physical Review D, 94, 124036 (2016).
- A. Vinante, R. Mezzena, P. Falferi, MC and A. Bassi.
  Physics Review Letters, 119, 110401 (2017).
- MC, M. Paternostro, H. Ulbricht, A. Vinante and A. Bassi.
  ArXiv 1708.04812 (2017)

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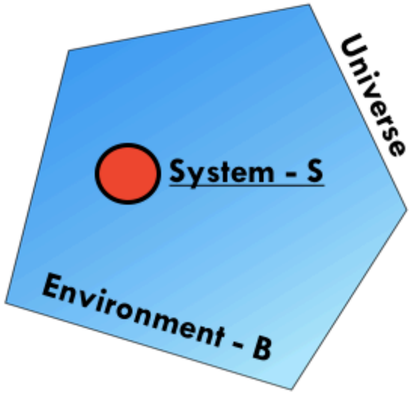


- MC, M. Paternostro, H. Ulbricht and A. Bassi. *ArXiv 1710.08695* (2017)

Gravitational Decoherence
Bassi, Grossardt, Ulbricht,
Class. Quantum Grav. **34**, 193002 (2017)

Review on theoretical and experimental gravity-related works

Several other works, see next slides

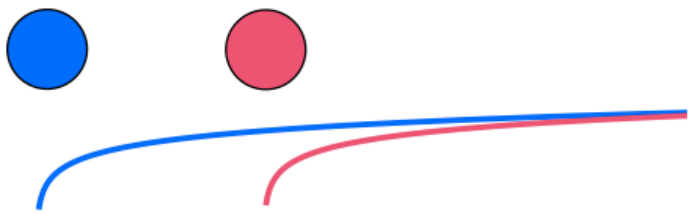
Can we understand if gravity is quantum?

Feynman **The Role of Gravitation in Physics**

Report from the 1957 Chapel Hill Conference

What is the gravitational field generated by a massive quantum superposition?

- Is it the superposition of the two gravitational fields generated by the two terms of the superposition?
- Is it the sum of the two gravitational fields, as predicted by the Schroedinger–Newton equation and perhaps by any theory, which keeps gravity fundamentally classical?



$$i\hbar\frac{\partial\psi(\boldsymbol{r},t)}{\partial t} = \left(-\frac{\hbar^2}{2m}\nabla^2 - Gm^2\int \mathrm{d}\boldsymbol{r}'\,\frac{|\psi(\boldsymbol{r}',t)|^2}{|\boldsymbol{r}'-\boldsymbol{r}|}\right)\psi(\boldsymbol{r},t)$$

Diosi L 1984 Phys. Lett. A 105

Penrose R 1996 Gen. Relativ. Gravit. 28 581–600

Can we understand if gravity is quantum?

- Is it the superposition of the two gravitational fields generated by the two terms of the superposition?

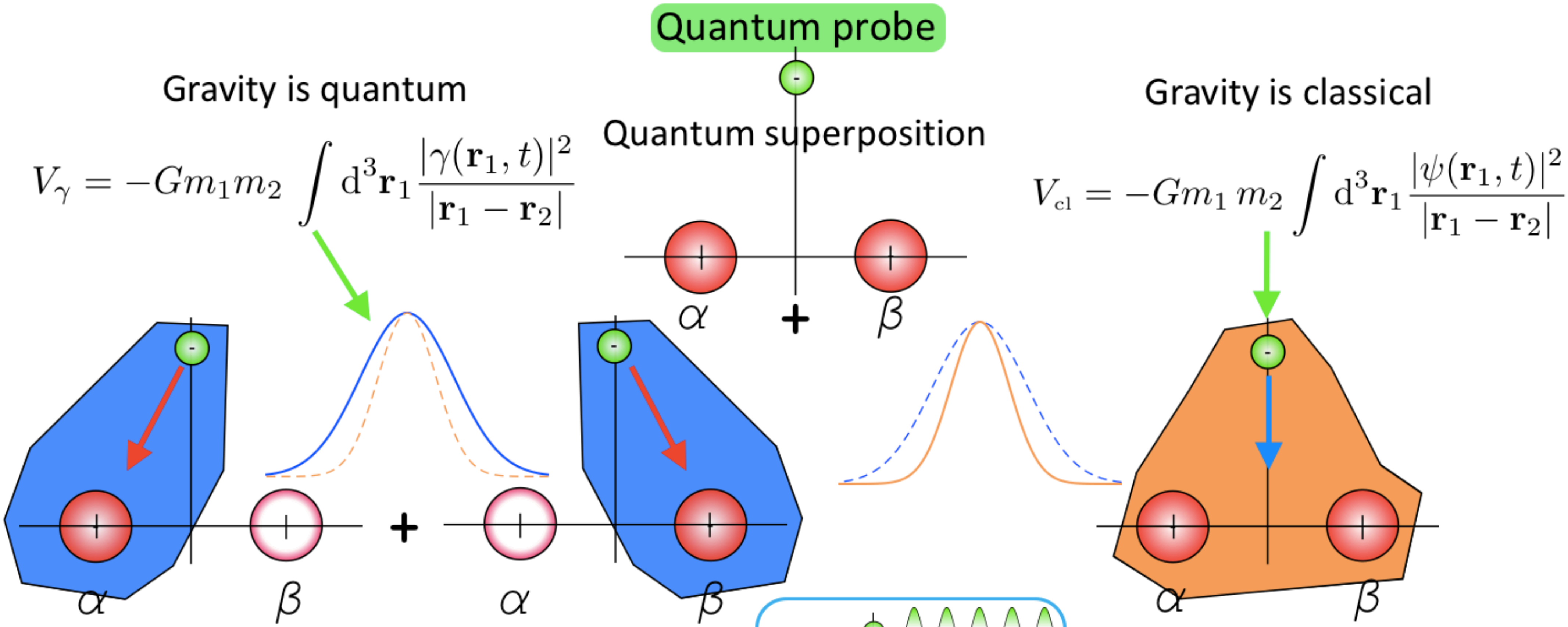
  → Gravitational field is in a superposition;
  Quantum scenario

- Is it the sum of the two gravitational fields, as predicted by the Schroedinger–Newton equation and perhaps by any theory, which keeps gravity fundamentally classical?

  → 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

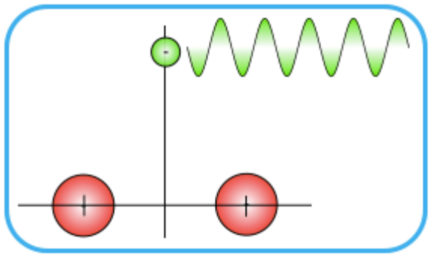
Previous experimental proposals



Is Gravity Quantum?

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

ArXiv 1507.05733 (2015)



The gravitational effect is too small to be detected

Previous experimental proposals

The Role of Gravitation in Physics

Report from the 1957 Chapel Hill Conference Feynman

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]

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,¶]

Is Gravity Quantum? 2015

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

ArXiv 1507.05733 (2015)

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]

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 119, 240401 (2017) PHYSICAL REVIEW LETTERS week ending 15 DECEMBER 2017

Spin Entanglement Witness for Quantum Gravity

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

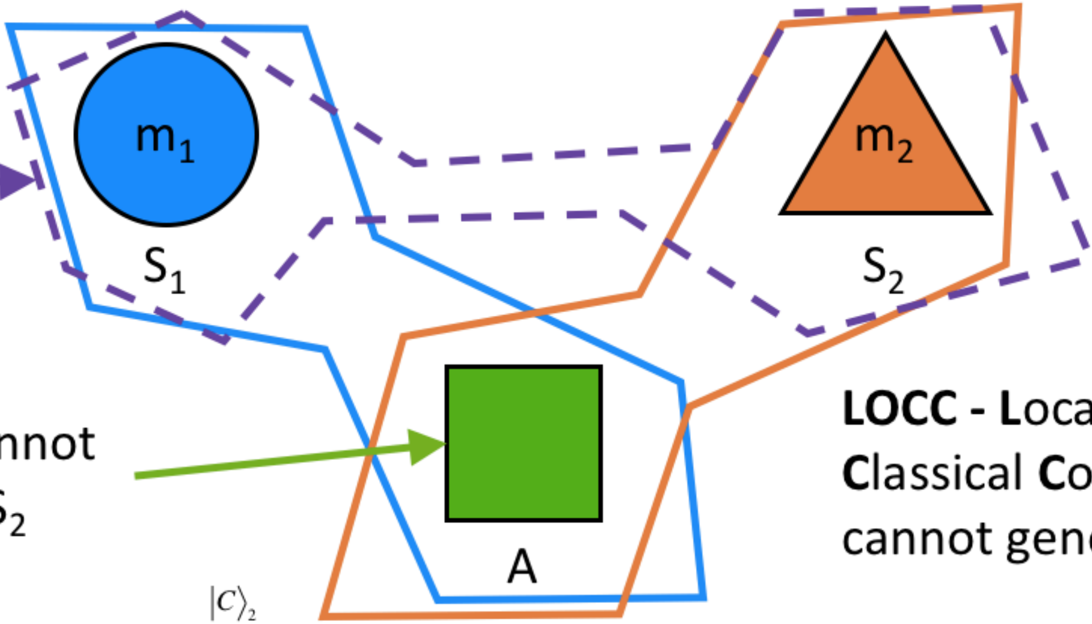
PRL 119, 240402 (2017) PHYSICAL REVIEW LETTERS week ending 15 DECEMBER 2017

Gravitationally Induced Entanglement between Two Massive Particles is Sufficient Evidence of Quantum Effects in Gravity

C. Marletto[1] and V. Vedral[1,2]

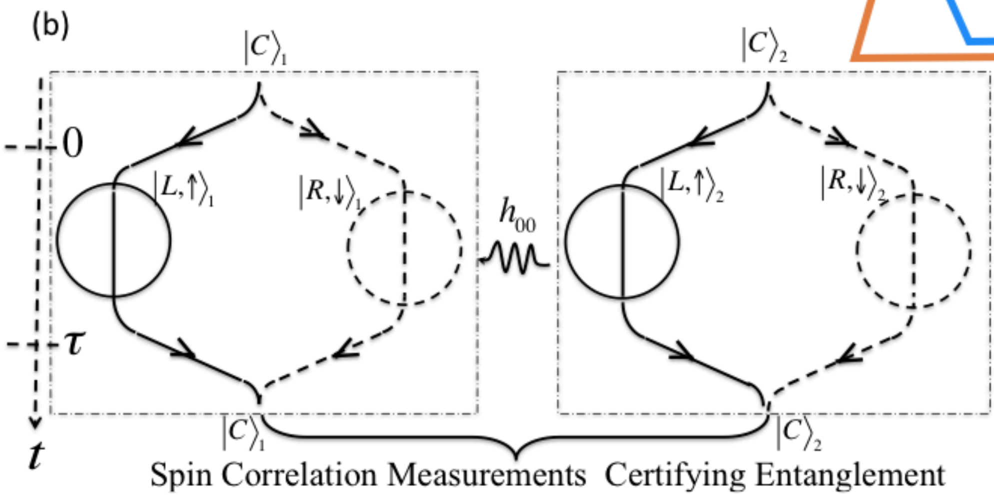
Gravity entangles masses

If entanglement is measured, gravity is quantum



A classical ancilla cannot entangle S_1 and S_2

LOCC - Local **O**peration and **C**lassical **C**ommunication cannot generate <u>Entanglement</u>



PRL **119,** 240401 (2017) PHYSICAL REVIEW LETTERS week ending 15 DECEMBER 2017

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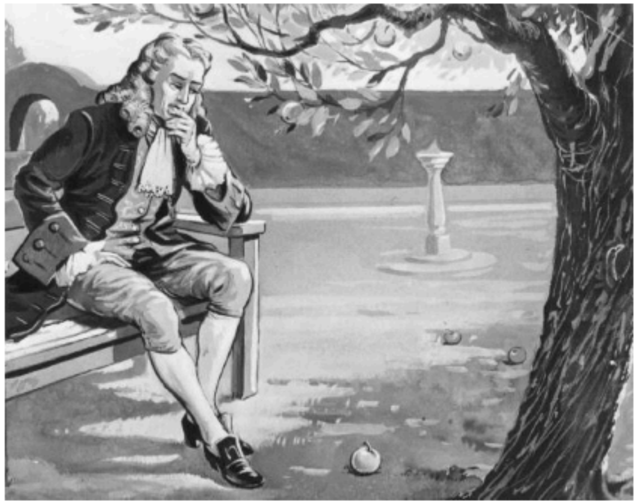
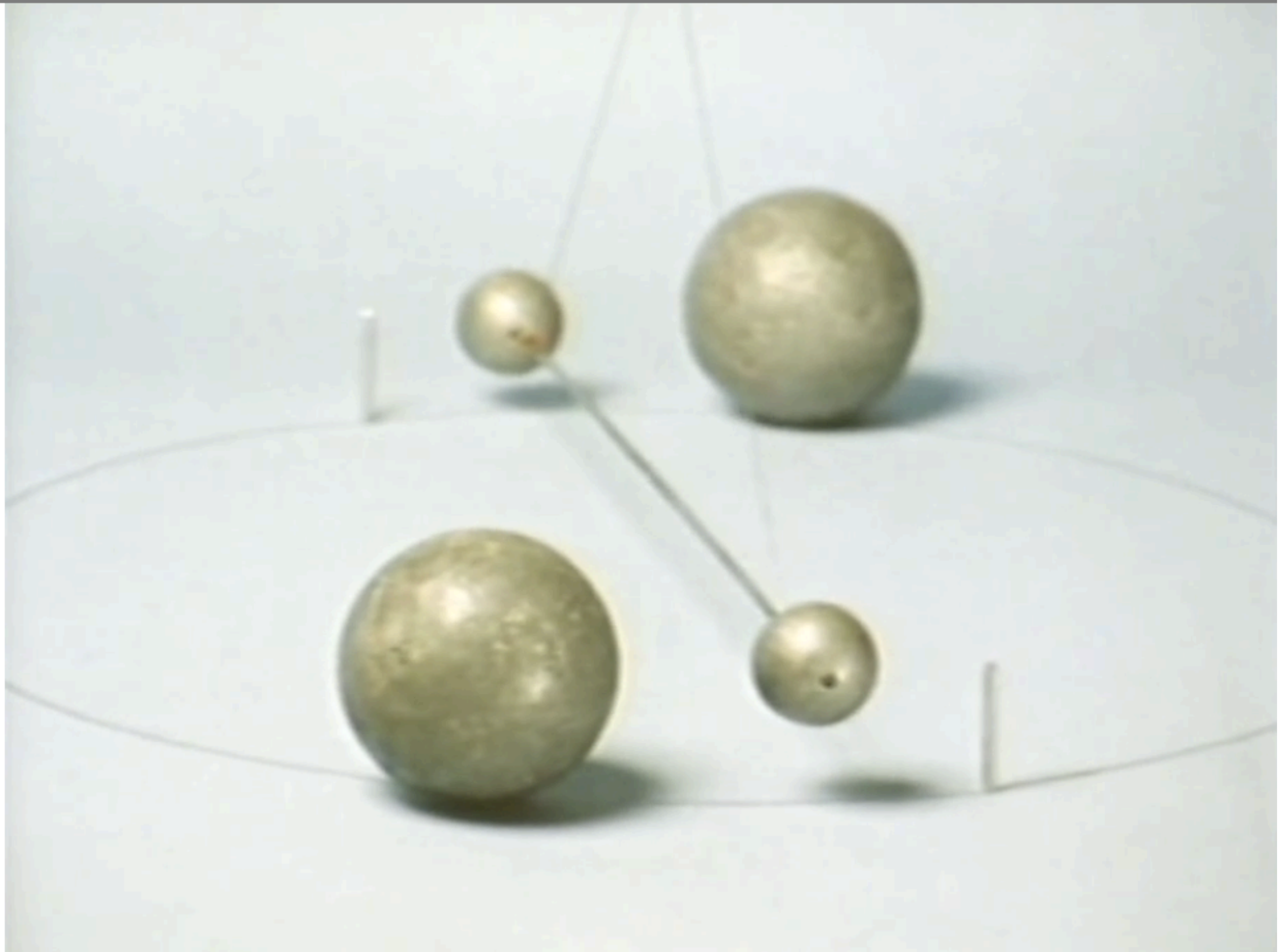
C. Marletto[1] and V. Vedral[1,2]

1798 – Cavendish probes Newton's law





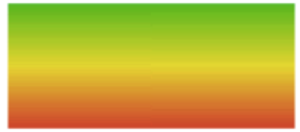
2018 – Cavendish probes Feynman???

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]

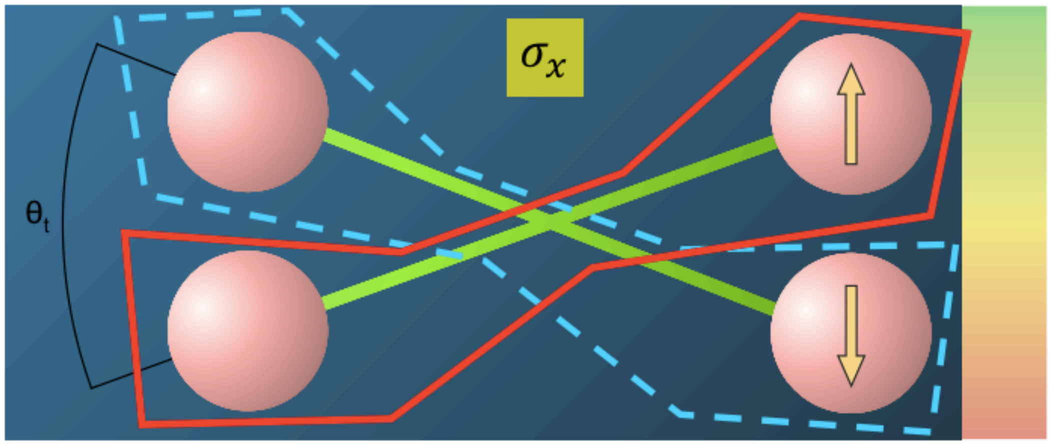
ArXiv 1710.08695 (2017)

1) Cooling at low Temperature and Pressure



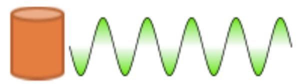
3) Angular superposition 4) Decoupling spin-angular dof Spin 1 Nitrogen Vacancy

Nanorod



2) MW π/2 pulse
Spin superposition

Magnetic gradient



5) Detection

Quantum scenario

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

→ No effect, the superposition holds

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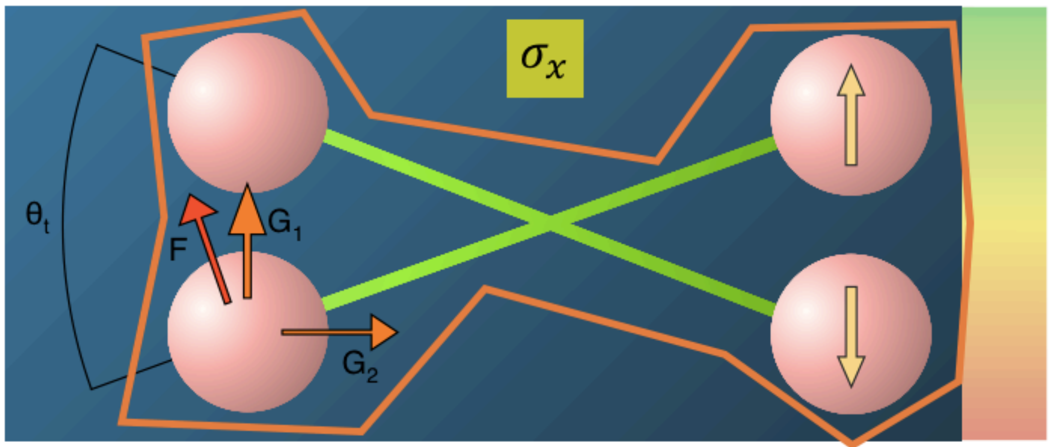

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Spin superposition

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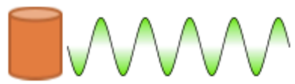


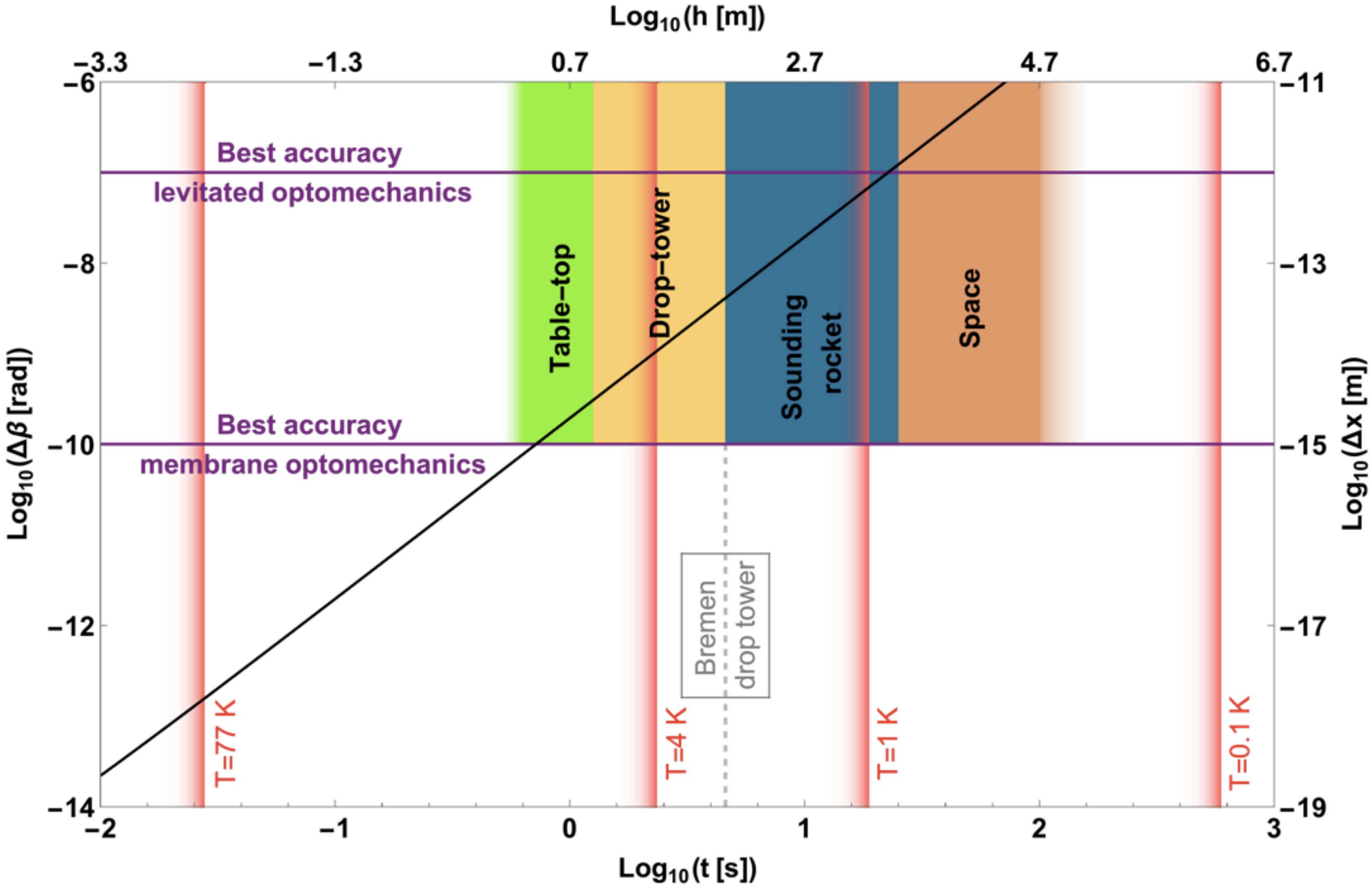
5) Detection

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

Bassi A *et al.*, Class. Quantum Grav. 34, 193002 (2017)

TEQ

European Commission
HORIZON 2020

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