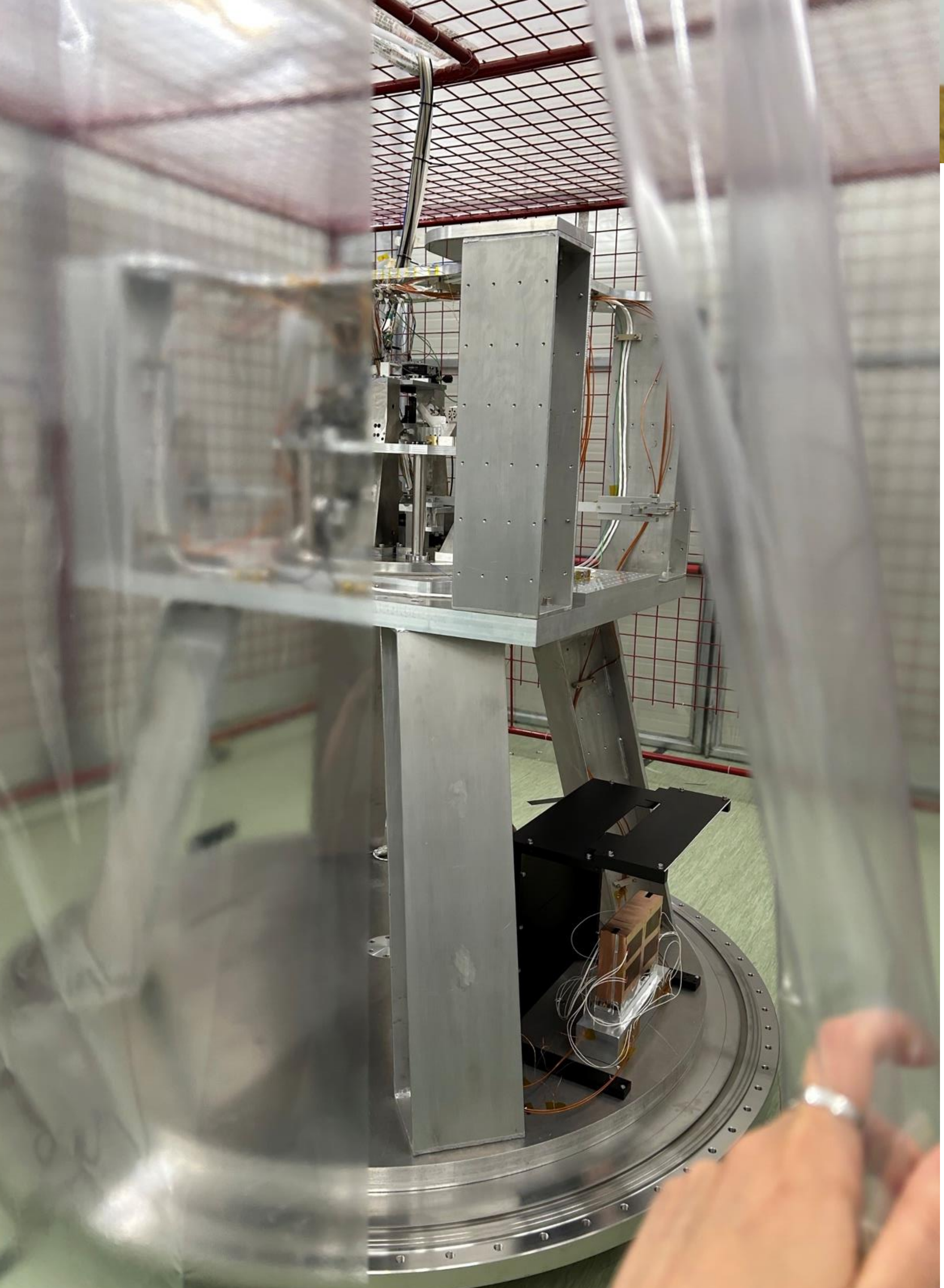


Weighing the Quantum Vacuum:
Latest Progress and Experimental Status of the
Archimedes experiment

Marina Esposito
University of Napoli “Federico II”
INFN - Sezione di Napoli

Jun 5, 2026

OUTLINE

I. Scientific Motivation

Does vacuum energy *weigh*?

II. The Archimedes Modulation Strategy

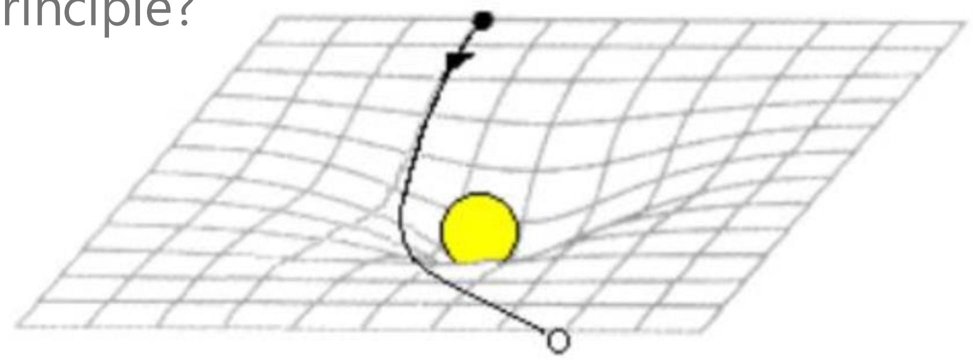
Casimir Energy

High-T_C Superconductors as a Vacuum Switch

III. Current Status of the Experiment

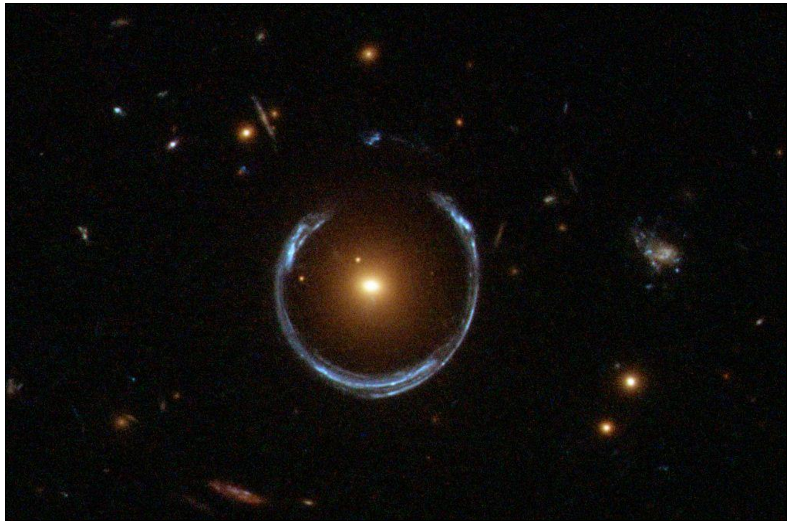
Gravity and EM field coupling

Does the Zero Point Energy (ZPE) satisfy the Equivalence Principle?



- Gravity on massive objects also depends on their stress state

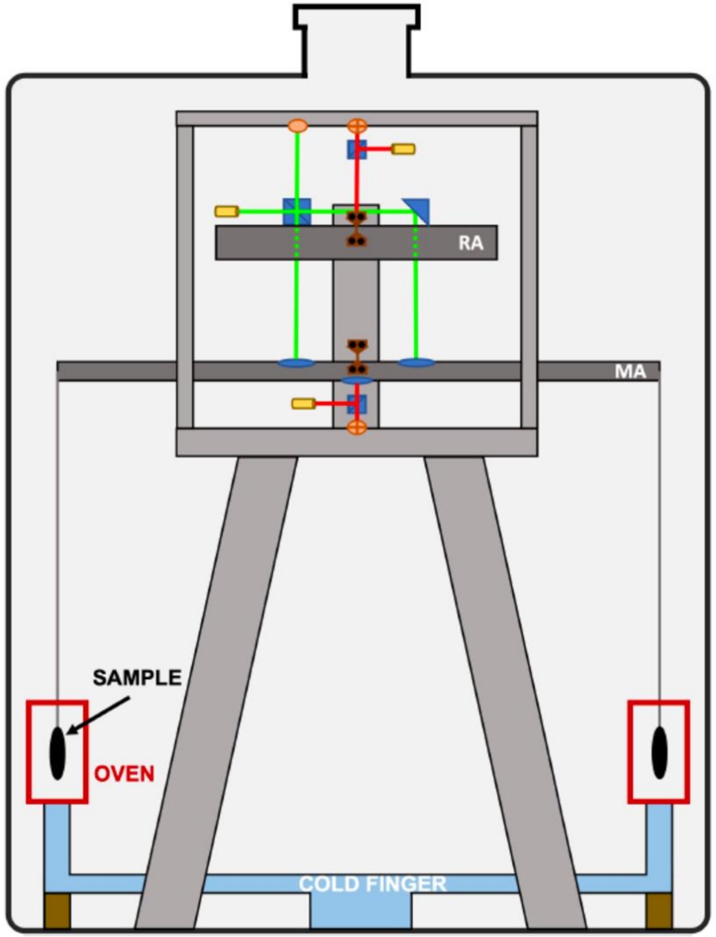
$$G_{\mu\nu} + \Lambda_{eff}\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$



- Gravity also applies to non-massive fields (like the e.m. field)
- While QED in curved spacetimes is established, its coupling with gravity is still topic of debate

  → ***Cosmological Constant Problem*** *[Weinberg, 1989]*

How much does *Nothing* weigh?



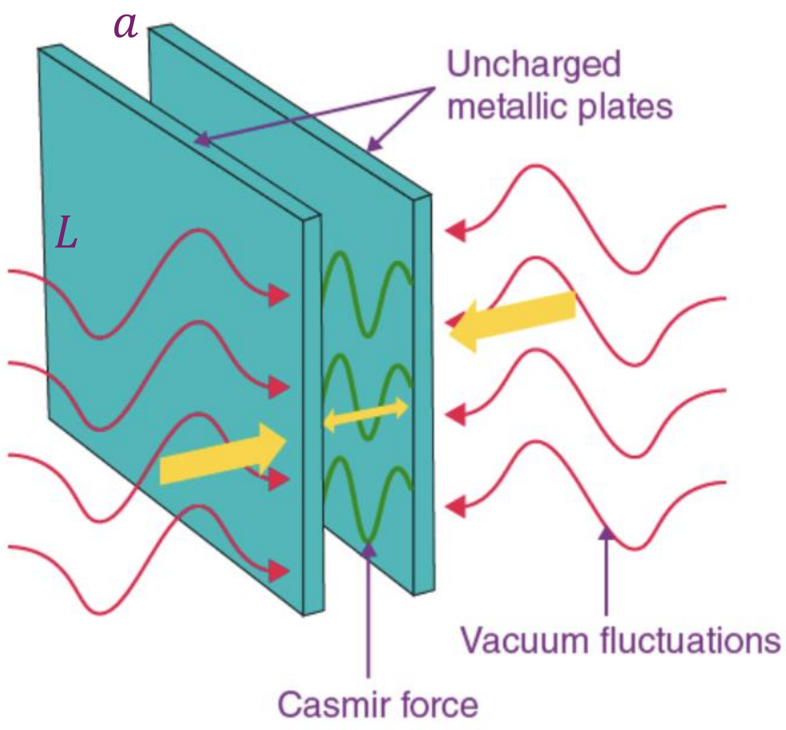
- Macroscopic bulk samples (+ their internal energy) suspended from a **highly sensitive interferometric beam-balance**;
- The samples host a significant amount of quantum **vacuum energy**;
- The internal quantum vacuum energy is periodically **modulated**;

If quantum vacuum couples to gravity, the weight changes and the weight variation is detected in real time with the balance

The Casimir Effect

Archimedes aims to measure the interaction between gravity and the vacuum energy density localized in a Casimir cavity.

Vacuum Energy confined using Casimir Effect (1948), also the most direct proof of vacuum fluctuations



$$E_{reflective\ plates} - E_{empty} \equiv \mathcal{E}_{Cas} = -\frac{\pi^2}{720}\frac{\hbar c}{a^3}L^2$$

negative energy

Vacuum energy inside is less when plates are reflective

$$\frac{1}{L^2}F(a) = -\left(\frac{1}{L^2}\right)\frac{\partial}{\partial a}\mathcal{E}_{Cas}(a) = -\frac{\pi^2 \hbar c}{240 a^4}$$

Casimir Force

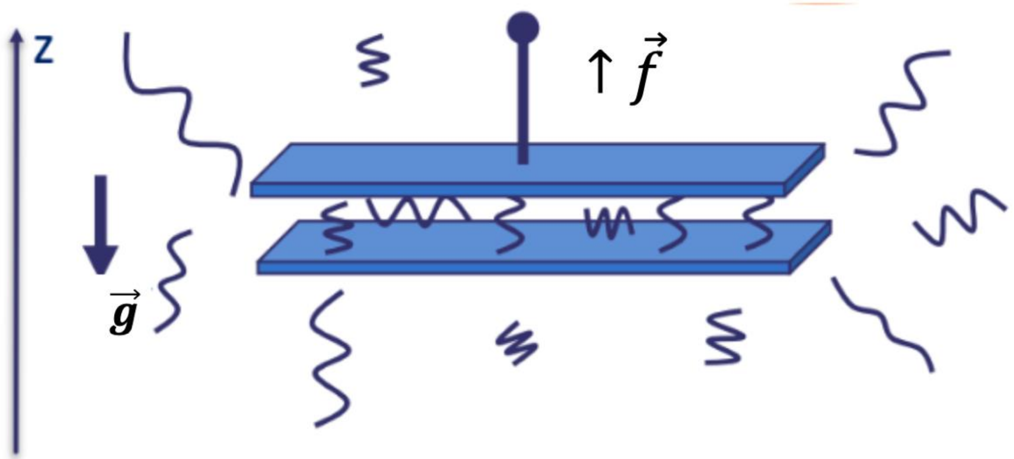
for $a \sim 1\ \mu m,\ \ L \sim 1\ cm \rightarrow\ \mathcal{E}_{Cas} \sim 40\ nJ,\ \ F_{Cas} \sim 10^{-7} N$

First experimental observation: Sparnaay, 1958
2005 Mohideen: force tested with 5‰ accuracy

Casimir Cavity in the Gravitational Field

$$\vec{f} = \frac{|\mathcal{E}_{Cas}|}{c^2} \, g \, \hat{z}$$

$\vec{f}$ is the weight of the cavity in GR framework



For a single Casimir cavity with $S \approx 1 \, \mathrm{dm}^2$ and $a \approx 1 \, \mu\mathrm{m}$, the signal force intensity would be $|\vec{F}| \sim 4 \cdot 10^{-28}$ N

Too small for static detection!

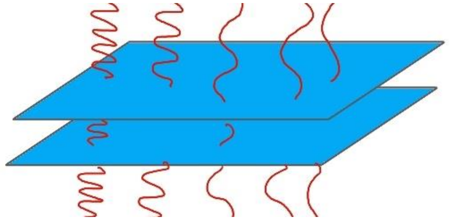
[G.Bimonte, E. Calloni, G. Esposito, L. Rosa - Phys. Rev D 76:025008 (2007)]

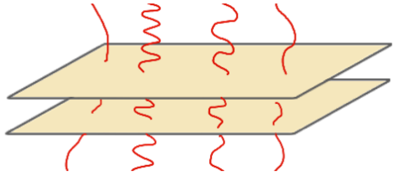
Expelling electromagnetic modes reduces local vacuum energy

Modulating Vacuum Energy

Superconductivity as a switch

Casimir on

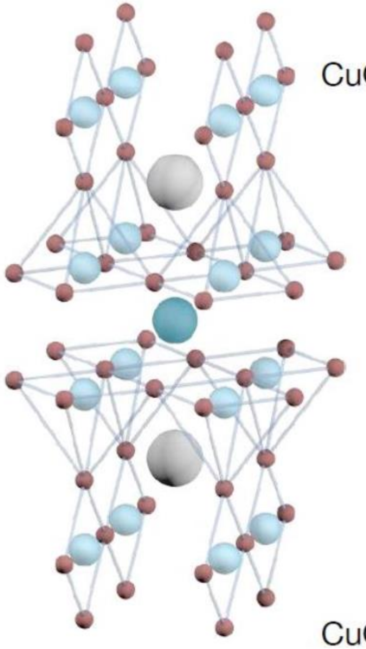




Casimir off

Phase Transition

Transitioning from the normal to superconducting state alters the material's reflectivity ▻ "amount of vacuum" modulated

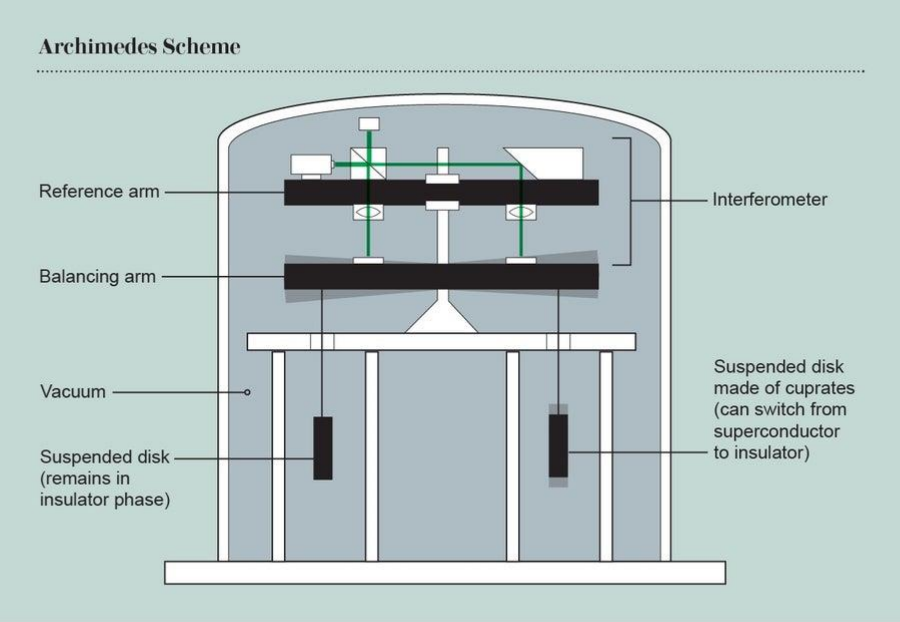


HTS are natural multi-layered Casimir cavities. For a disk-shaped YBCO with R = 5 cm, thickness 5 mm, the force exerted by the gravitational field is:

$$\left|\vec{F}\right| \approx 5 \times 10^{-16}\, N$$

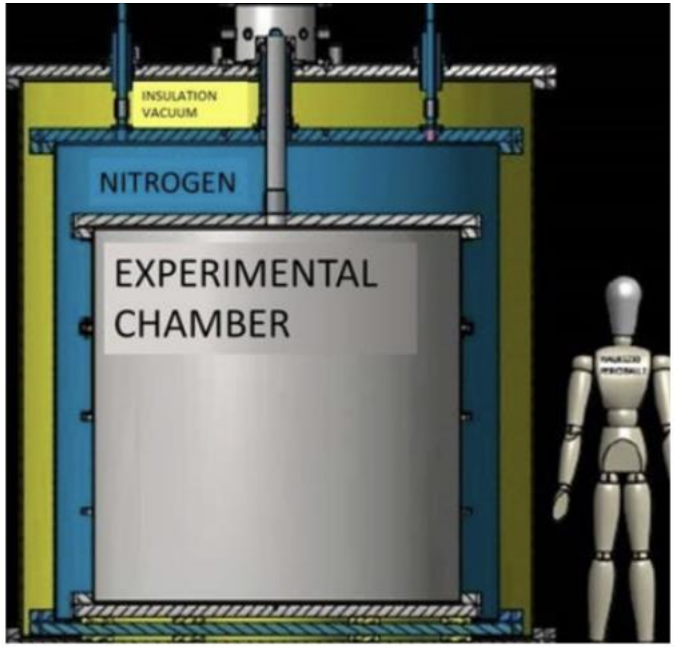
L. Rosa et al, Eur. Phys. J. Plus 137, 826 (2022)
A. Allocca et al., Phys. Rev. B 106, 134502 (2022)

The Archimedes Experiment



- Cryogenic double suspended beam balance
- interferometer readout
- reference arm (upper) insulates the measurement arm (bottom) from the ground disturbances.

Two superconductive samples are suspended to the measurement arm

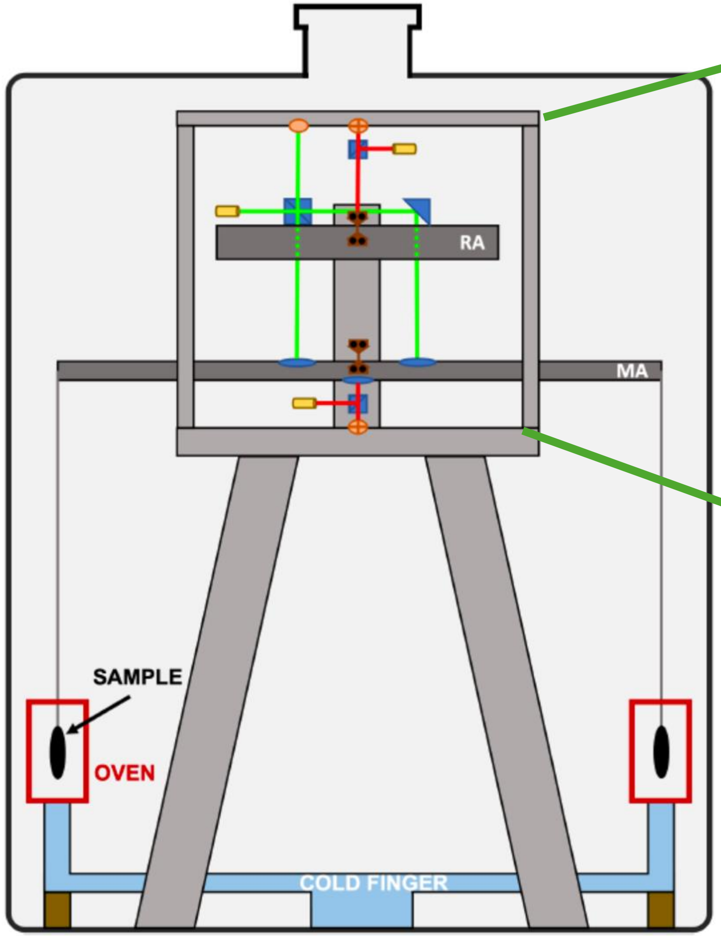


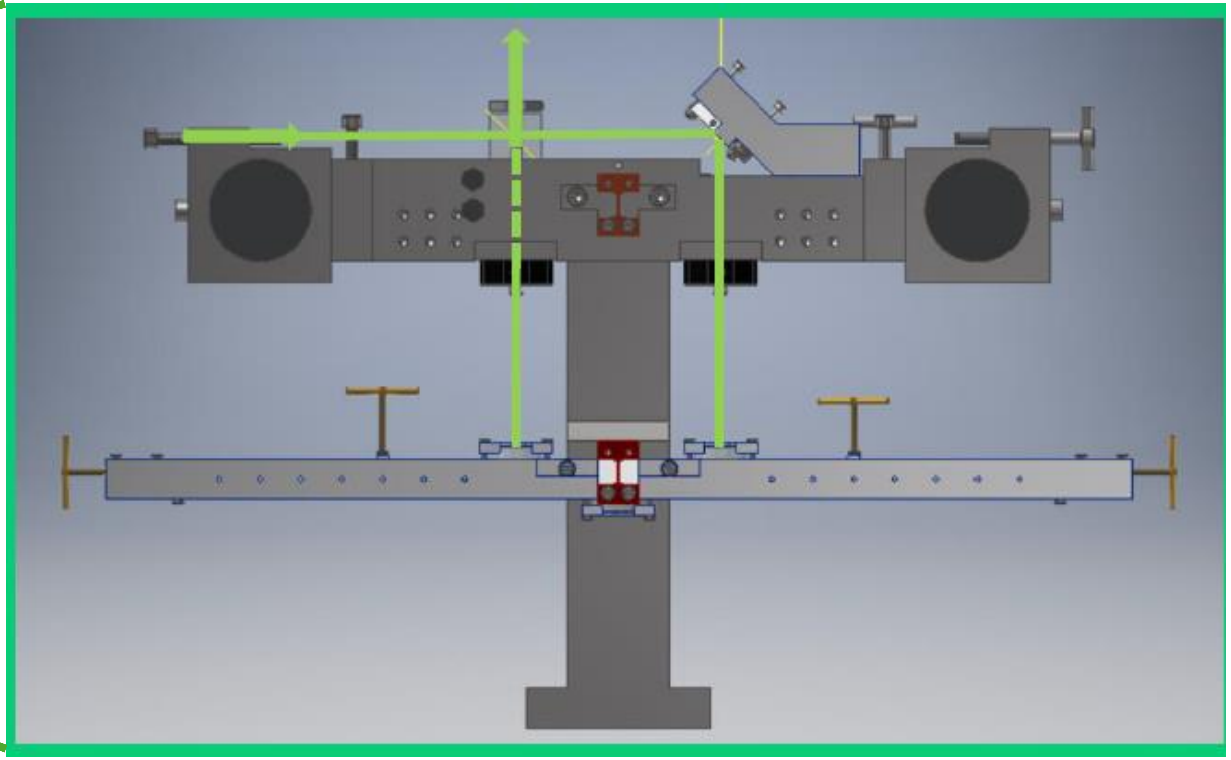
kept at cryogenic temperature of ~90 K thanks to a suitably designed 3-chambers cryostat filled with liquid Nitrogen

Spectral Torque Signal in 2 weeks of integration:

$$\tau_S = 3.5 \times 10^{-13} \frac{N\, m}{\sqrt{Hz}}$$

Status of the experiment





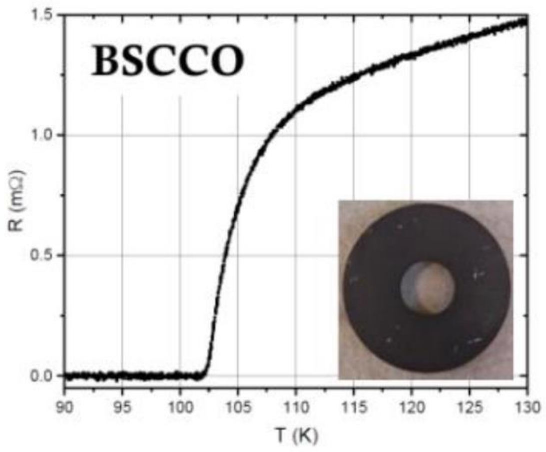
- Suspended with thin flexible joints (Cu-Be, 100 μm x 100 μm)
- Measurement arm very light to lower the moment of inertia

HTS Sample Requirements

(1) Target mass $\sim 200\ g$

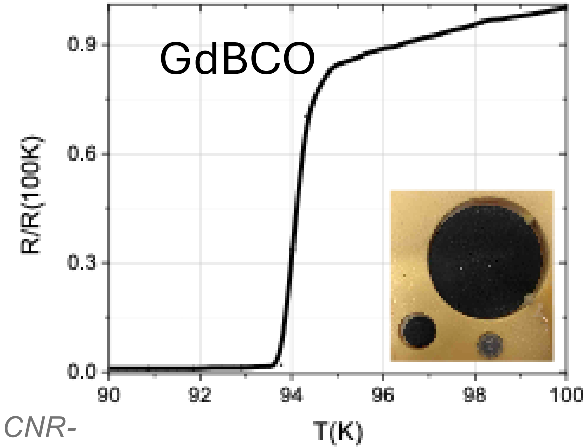
(2) sharp superconducting transition: $\Delta T = T_{onset} - T_{zero} = 1\ K$

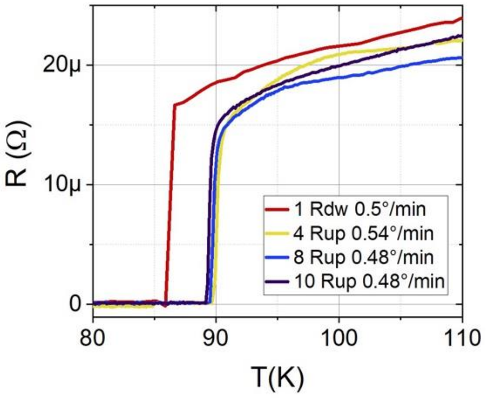
(3) fast heat exchange for quasi-static approach

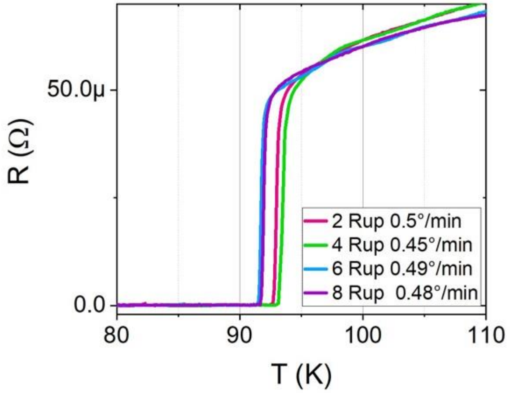


The prime candidate: GdBCO ($GdBa_2Cu_3O_{7-x}$)

- Critical Temperature 93.5 K
- proven feasibility for single-domain scaling and ring shape -> efficient thermal exchange

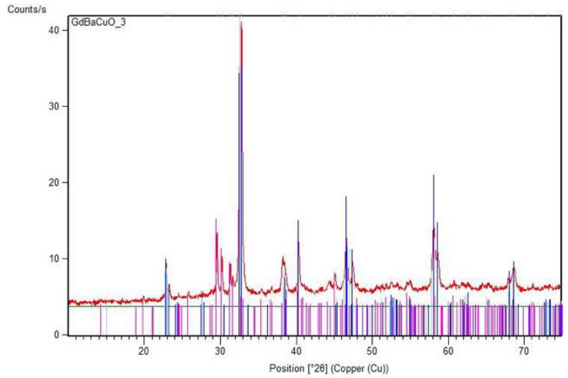






measurements performed by R. Fittipaldi, A. Guarino CNR-SPIN Salerno

Room temperature XRD verified a highly crystalline structure consisting of 77% active superconducting Gd-123 phase

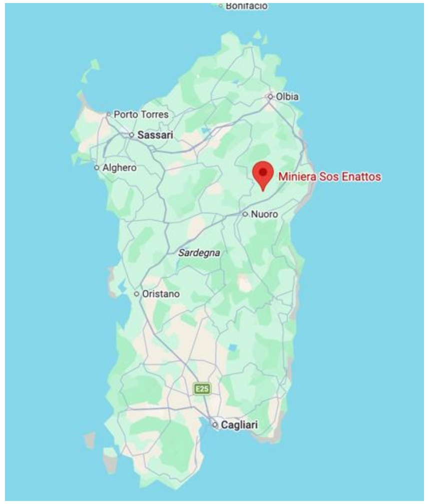


Fase 1:
ICDD 01-079-0466, $GdBa_2Cu_3O_7$
I/Ic = 4,63, Scale factor = 0,853, S-Q = 77%
a = 3,895 Å
b = 3,835 Å
c = 11,699 Å

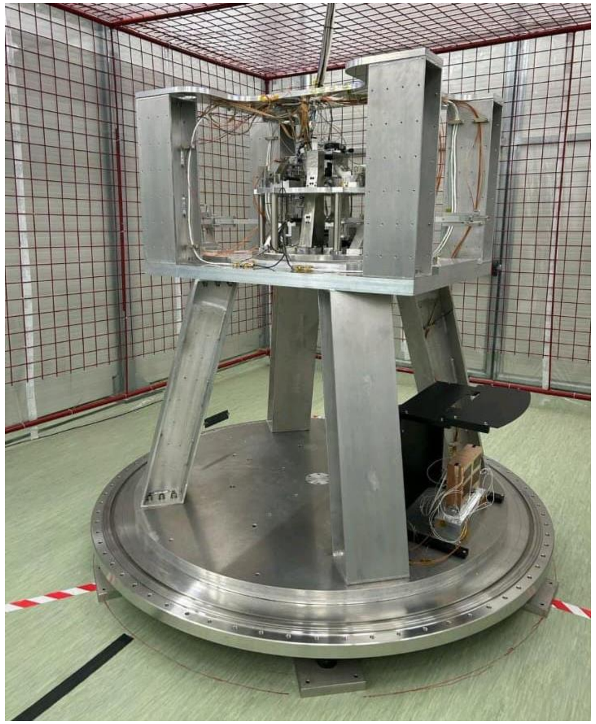
Fase 2:
ICDD 01-075-2427, Gd_2BaCuO_5
I/Ic = 5,65, Scale factor = 0,273, S-Q = 23%
a = 7,226 Å
b = 12,3210 Å
c = 5,7240 Å

Status of the experiment

System installation at room temperature fully completed since April 2025.
First data taking in October 2025.



Installed at the SarGrav surface laboratories in Lula (NU) at Sos Enattos mine, one of the candidate sites for third generation GW interferometer Einstein Telescope.

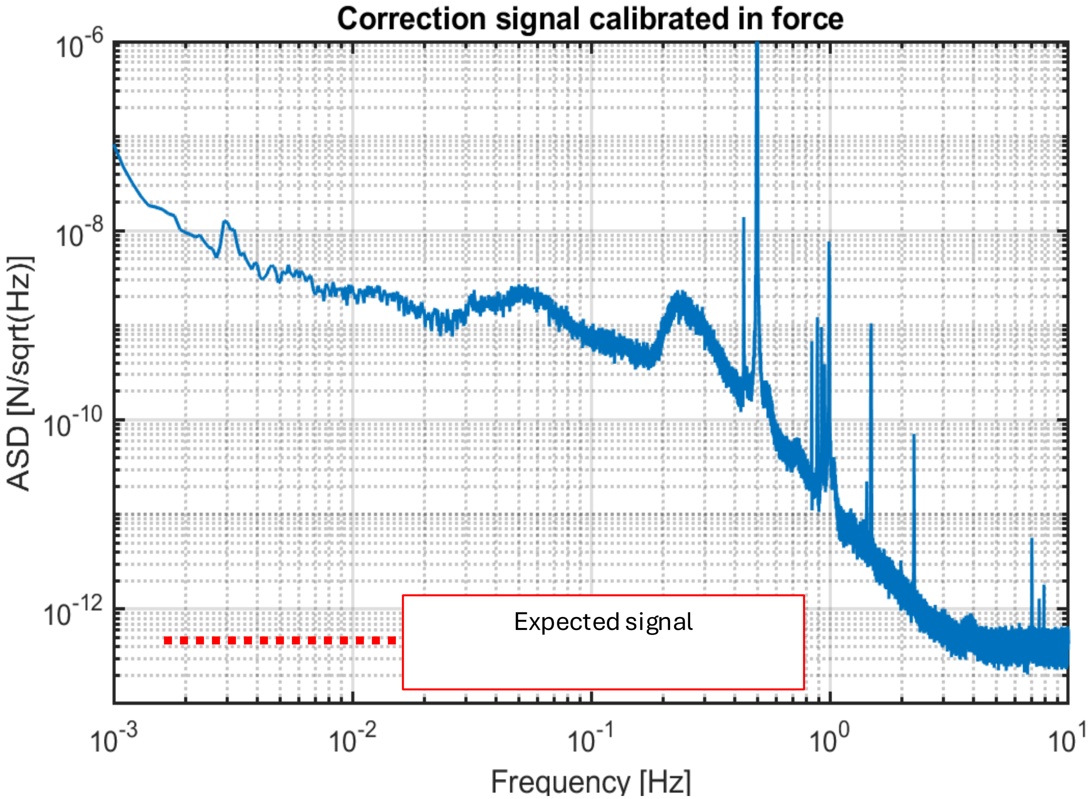


Vacuum level reached 2e-6 mbar
Virgo-like vacuum pump and system

Status of the experiment

System installation at room temperature fully completed since April 2025.
First data taking in October 2025.

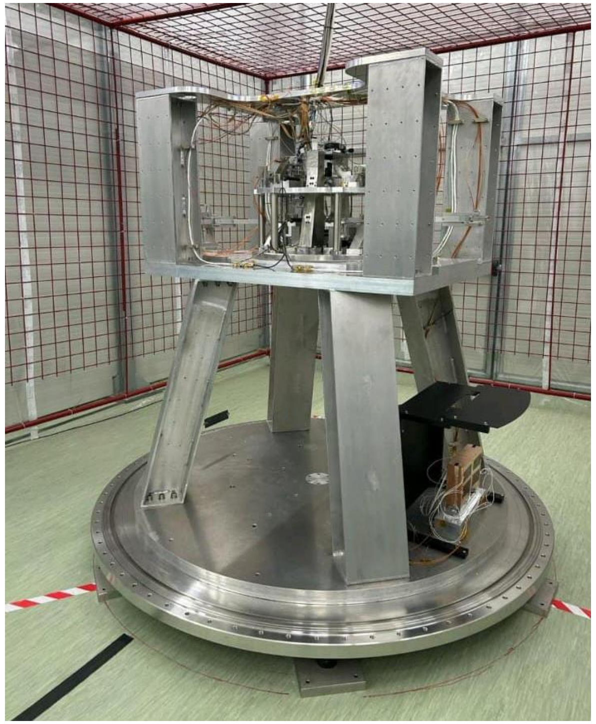
Low frequency noise still high for the experiment purposes (about 3 orders of magnitude), but we are focusing on it in the commissioning

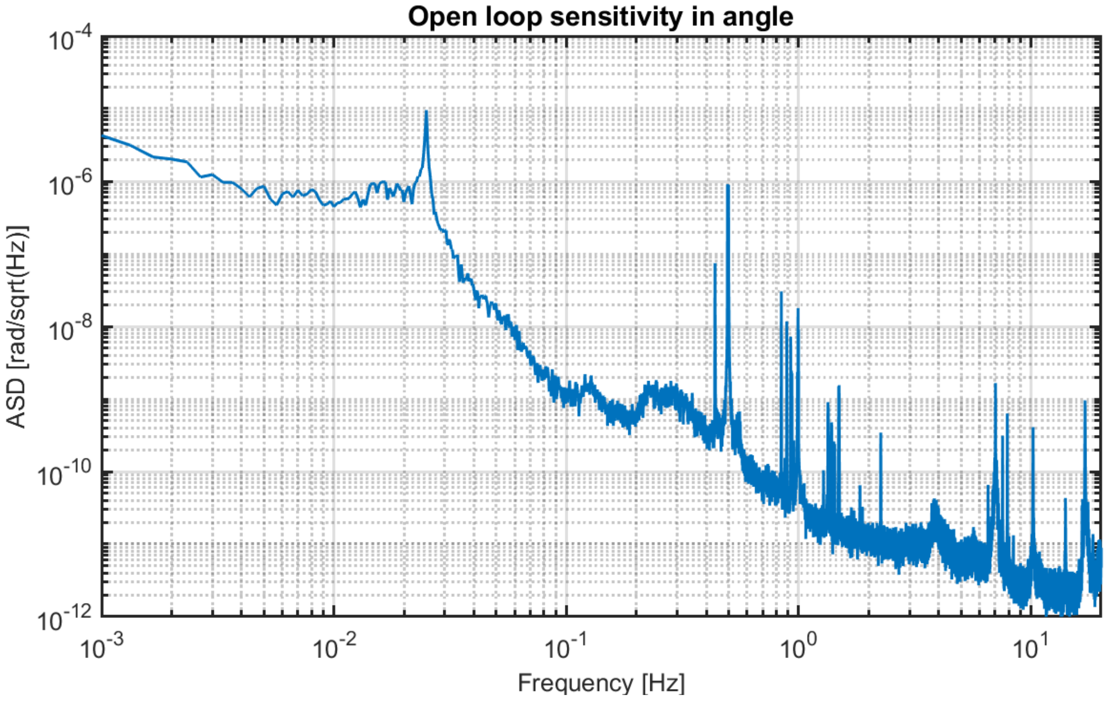


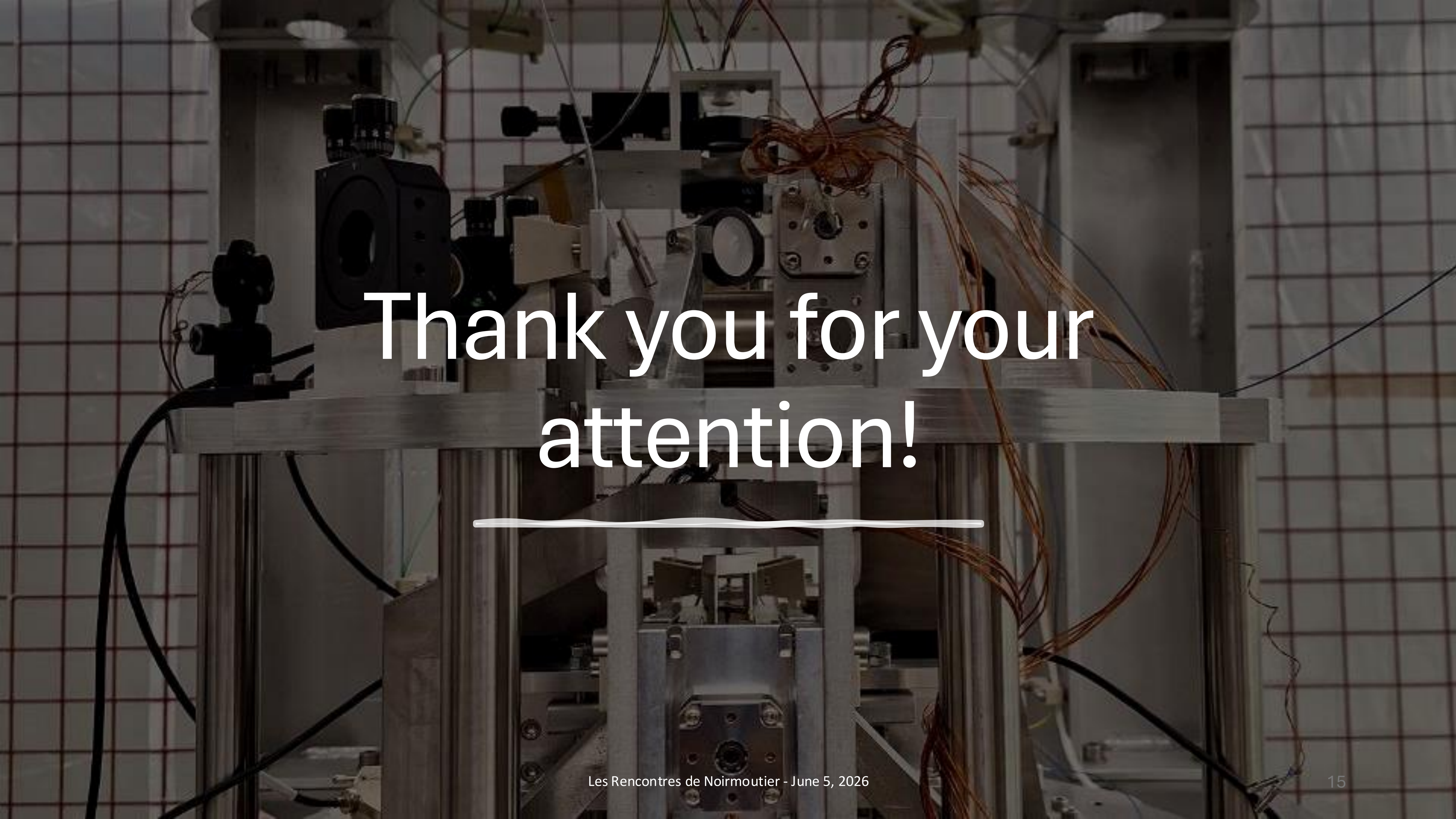
Status of the experiment

System installation at room temperature fully completed since April 2025.
First data taking in October 2025.

Best sensitivity in the world in the 1-10 Hz range
2e-12 rad/sqrt(Hz)







Thank you for your attention!

Bibliography

E. Calloni. L. Di Fiore, G. Esposito, L. Milano, L. Rosa - Phys. Letters A, 297, 328-333, (2002)

G. Bimonte, E Calloni, Di Fiore, G. Esposito, L. Milano, L. Rosa - CQG 21 647 (2004)

G. Bimonte, E. Calloni , G. Esposito, L. Rosa - Phys. Rev D 74, 085011 (2006)

G.Bimonte, E. Calloni, G. Esposito, L. Rosa - Phys. Rev D 76:025008 (2007)

G. Bimonte, E. Calloni, L. Rosa - Phys. Rev D 77, 044026 (2008)

A. Allocca G. Bimonte, E. Calloni, G. Esposito, U. Huebner, E. Il'ichev, L. Rosa, F. Tafuri., Jour. Of. Supercond. And Novel Magnetism. 25, 2557-2565 (2012)

E. Calloni et al., Eur. Phys. J. Plus (2021) 136:335

A. Allocca, E. Calloni, L. Errico et al, Eur. Phys. J. Plus (2021) 136: 1069

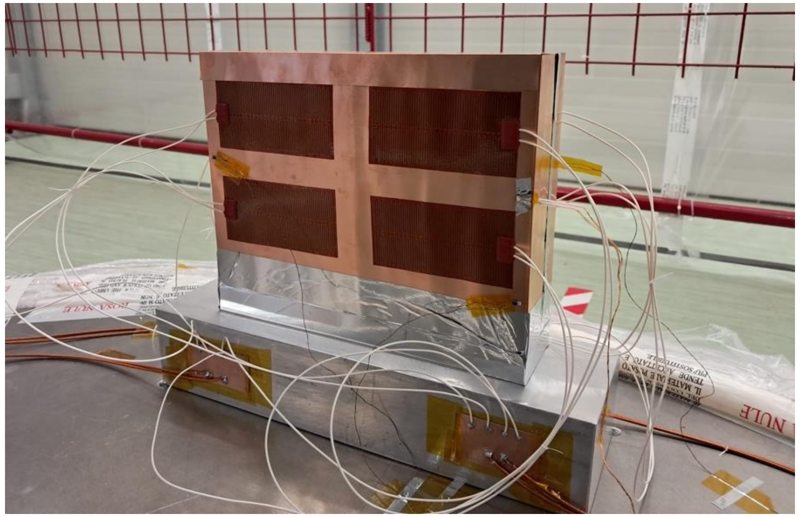
L. Rosa et al, Eur. Phys. J. Plus 137, 826 (2022)

A. Allocca et al., Phys. Rev. B 106, 134502 (2022)

Calloni, E. et al. Eur. Phys. J. Plus 139, 158 (2024) - https://www.epj.org/epjplus-news/2736-epjplus-highlight-beam-balance-designs-could-elucidate-the-origins-of-dark-energy

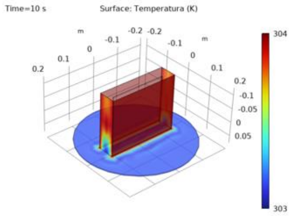
V. Mangano et al. PoS TAUP2023 (2023), 317 doi:10.22323/1.441.0317

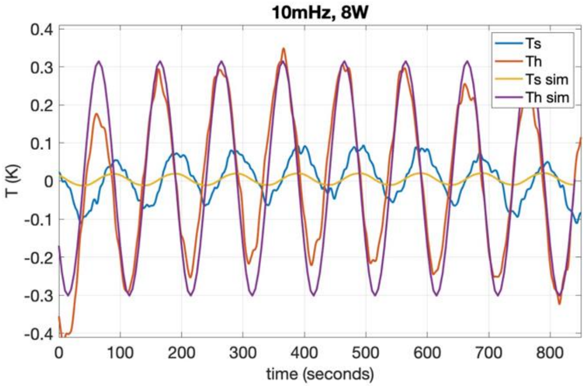
Room-Temperature Modulation Prototype



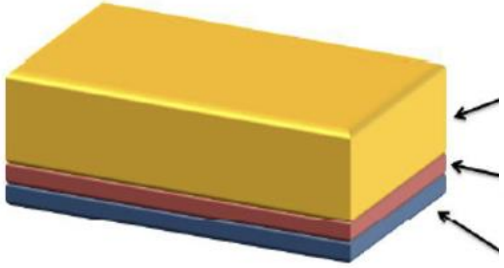
Thermal modulation through radiative process (not to introduce any radiation pressure effect on the sample) studied both at room temperature and at cryogenic temperature

Room temperature setup (NA) installed at EGO-Virgo 1500W test facility





Vacuum Energy and superconductive phase transition



ALADIN experiment (2005-2012): test if vacuum fluctuations affects the superconducting phase transition in type I superconductors.

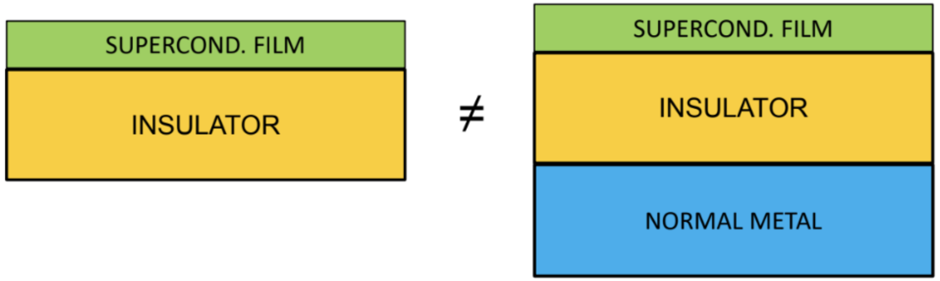
When the film is part of a Casimir cavity, we have to augment the right-hand side of the eq. by the difference between the Casimir energy in the normal and superconducting phase

$$V\frac{H_c^2(T)}{8\pi} = \mathcal{E}_{cond}(T)$$

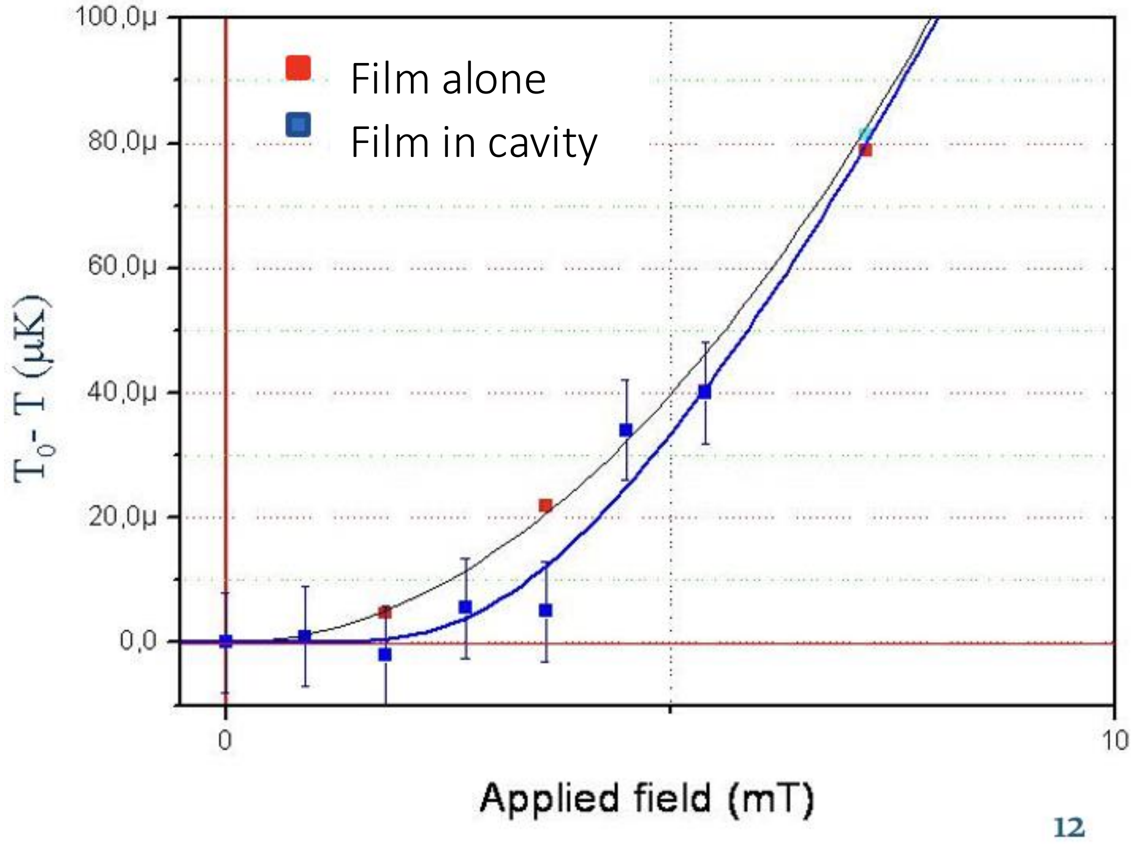
Superconductivity lab of Federico II in Naples (Prof. F. Tafuri)

$$V\frac{H_c^2(T)}{8\pi} = \mathcal{E}_{cond}(T) + \Delta\mathcal{E}_{Cas}(T)$$

Indication of a phase transition influenced by vacuum fluctuations.



Casimir Cavities with type I superconductors



$$\frac{\delta H_{c_\parallel}}{H_{c_\parallel}} = \frac{H_{c_\parallel}^{cav} - H_{c_\parallel}}{H_{c_\parallel}} = \sqrt{\frac{\Delta\mathcal{E}_{\mathrm{cas}}}{\varepsilon_{cond}} + 1} - 1$$

Condensation energy is very small so the variation of Casimir Energy can be comparable to the total transition energy

$$\frac{\Delta\mathcal{E}_{\mathrm{cas}}}{\mathcal{E}_{\mathrm{cas}}} \simeq 10^{-6}$$

Data compatible with the theory and the region of energy of different behavior is the expected one

A. Allocca et Al. Jour. Of. Supercond. And Novel MaG. Bimonte et Al. - J. Phys. A: Math. Theor. 41 164023 (2008)
gnetism. 25, 2557-2565 (2012)