Thermal Modulation of YBCO samples through Radiation Heat Transfer for the Archimedes Experiment

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Scientific Motivations and Goal of the Experiment

Archimedes is an INFN-funded experiment inaugurated on **18th September 2021** in the **SarGrav laboratory**, a research facility hosted in the former mine of **Sos Enattos** (Lula, Nuoro). **The main scientific objective of Archimedes is to determine whether and how vacuum fluctuations interact with gravity**, shedding light on the nature of the dark energy and cosmological constant.

By modulating the temperature of YBCO superconducting disks around their critical temperature, the vacuum energy contained in them will be modulated and, if it gravitates, its weight. This modulation can only occur through the radiative heat exchange mechanism.
Here, the conceptual scheme and the preliminary results are reported.

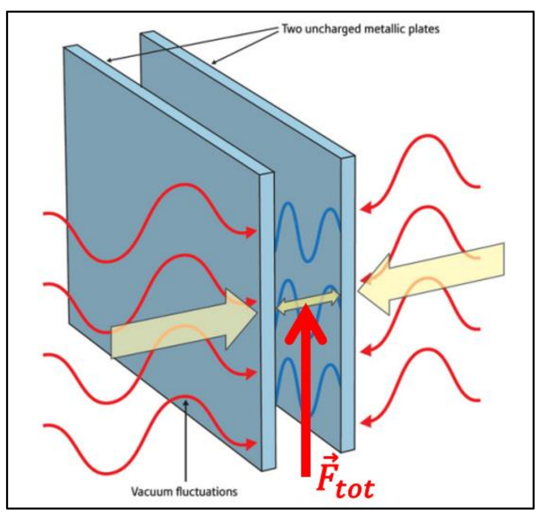
A high sensitive balance will measure the small weight variations of these YBCO superconducting samples, suspended at the ends of its arm, at rest in a gravitational field [*see **Allocca and Errico's poster***].

Archimedes will also provide important data for the detailed reconstruction of the seismic and anthropic noise profile of the Sos Enattos area, one of the quietest places in Europe and candidate site for hosting the third generation GW detector Einstein Telescope [*see **Pesenti and Rozza's poster***].

Casimir Energy and Vacuum Weight

Archimedes will measure the coupling between vacuum energy and gravity by **weighing the vacuum energy stored in a Casimir cavity** (E_c) formed by parallel conductive plates:
only some modes can resonate inside the Casimir cavity, the ones which do not satisfy specific boundary conditions are expelled and the total vacuum energy changes.

If the vacuum weighs, then there is a force, directed upwards, that acts on the cavity and is equal to the weight of the modes expelled from the cavity.
The expected value of this force is about 10^{-16} N.

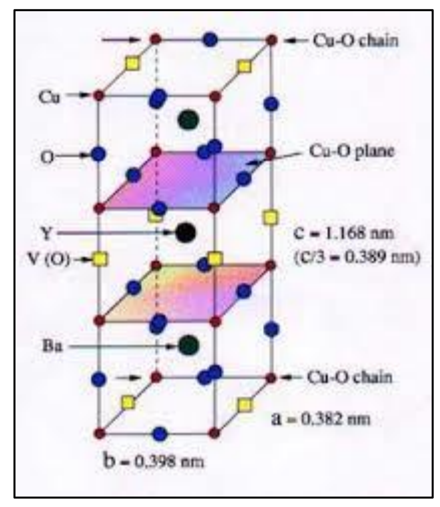


$$\vec{F}_{tot} = -\frac{|E_C|}{c^2}\vec{g}$$

$$E_C = E(a) - E(\infty) = -\frac{\pi^2 L^2 hc}{720 a^3}$$

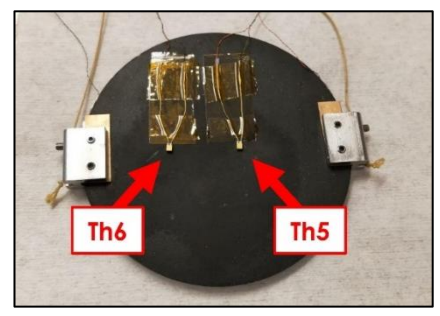
How to Measure the Vacuum Weight

The measurement strategy to **modulate the weight of a Casimir cavity** is to **modulate the reflectivity of its plates** in such a way to periodically expel the vacuum energy from the Casimir cavity.



When the plates become **superconductive**, the reflectivity changes and the vacuum energy contained between the plates is better expelled from the cavity, resulting in a lowering of the energy and, if it gravitates, of the weight.

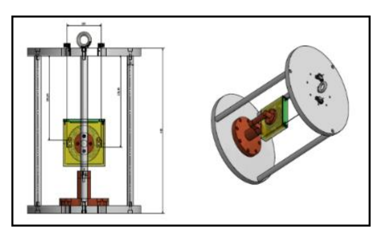
The **modulation of the temperature of a superconductor** around its critical temperature (T_c) is needed to force the superconductor to enter and exit the superconducting state to obtain the desired modulation of the Casimir energy.

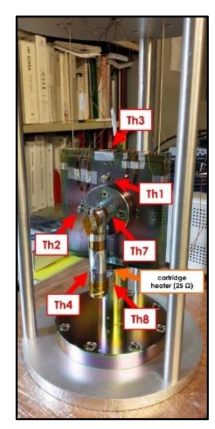


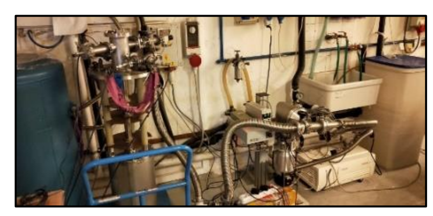
The variation of Casimir energy is particularly relevant in case of high T_c layered superconductors, like the Yttrium Barium Copper Oxide (**YBCO**).
YBCO has a microscopic structure consisting of many superconducting layers (approximately one million) separated by dielectric planes (a few nanometres apart) and, thus, forming a **natural multi-layer Casimir cavity**.

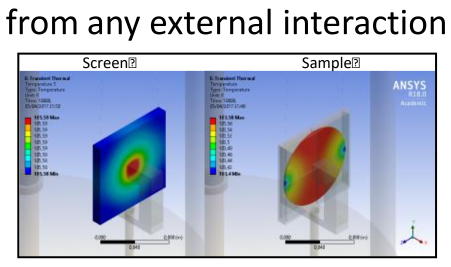
Thermal Modulation in Rome

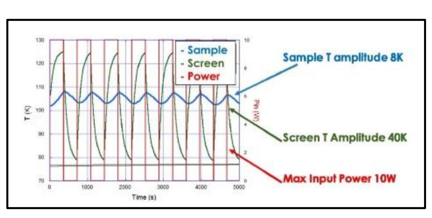
A YBCO sample has the property of **trapping** (**heavier** YBCO) or **expelling** (**lighter** YBCO) vacuum energy when its temperature is **greater** (**insulator**) or **lower** (**superconductor**) than its critical temperature (92 K): by modulating the temperature around T_c with a modulation frequency of a few mHz, the vacuum energy contained in it will be modulated as well.
Only the radiative heat exchange mechanism must be used to remove or add thermal energy to the sample as it must be isolated from any external interaction that could add energies other than that of vacuum.







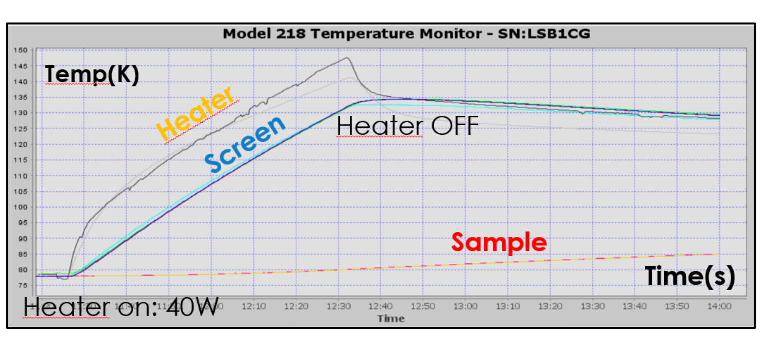


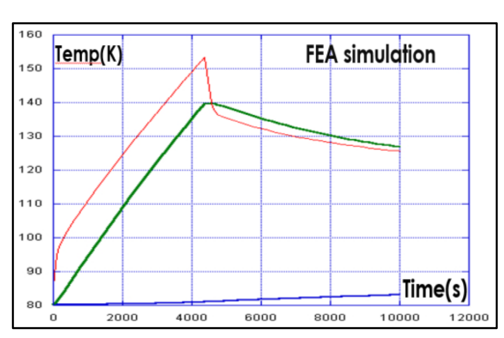


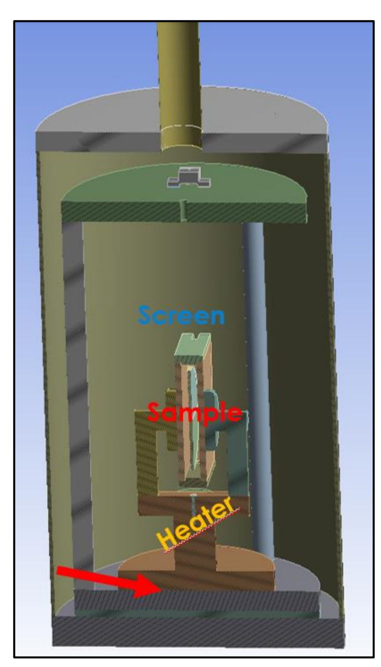
The INFN Roma group has developed a first small-scale prototype to study temperature variation of a suspended YBCO sample (100 mm wide and 3 mm thick) **through radiation heat transfer** between the sample itself and the copper screen which surrounds it:
- the frequency modulation and its amplitude around T_c depend on the thermal properties of the materials;
- a finite element study is important for the geometry definition and the material choice.

This prototype is tested in a small vacuum chamber cooled down to liquid nitrogen temperature (77 K) using helium gas inside a cryostat.

Preliminary Results and Next Steps...







Procedure:
1. cooling down the system to the liquid nitrogen temperature;
2. creating vacuum ($P \sim 10^{-5}$ mbar);
3. heating the copper screen using a resistance (40 W).

What happens:
1. the heat flows to the screen through the conductive copper support increasing its temperature;
2. the sample temperature increases through the heat radiative exchange with the screen;
3. the heating times are very different.
4. once the resistance is turned off, the temperature of the screen should decrease to 77 K through the thermal conduction:
since this does not happen, it means there is a high thermal resistance (red arrow) and the dominant mechanism is the radiation heat transfer.

What's next?
Improving the thermal contact between the system and the experimental chamber. Further investigations are being done with other samples.