# The Archimedes Experiment

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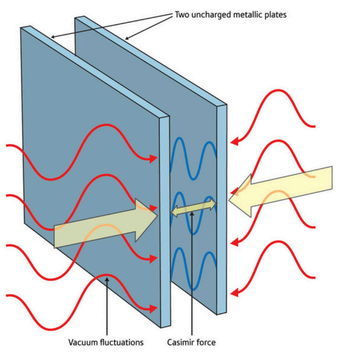
Archimedes is an INFN-funded pathfinder experiment aimed at verifying the feasibility of measuring the interaction of vacuum fluctuations with gravity. The final experiment will measure the force exerted by the gravitational field on a Casimir cavity whose vacuum energy is modulated with a superconductive transition, by using a balance as a small force detector. Archimedes is two-year project devoted to test the most critical experimental aspects, in particular the balance resonance frequency and quality factor, the thermal modulation efficiency and the superconductive sample realization.

## From the cosmological constant problem:

*why does vacuum energy exibit a gravitational contribution enormously lower than the predicted one? Does vacuum gravitate or not?*

## The Casimir Energy




A: Plate area
a: Plates distance

**The Casimir effect is a macroscopic manifestation of vacuum fluctuations. It is derived considering the zero point e.m. energy contained in a Casimir cavity, i.e. in the volume defined by two perfectly reflecting parallel plates**

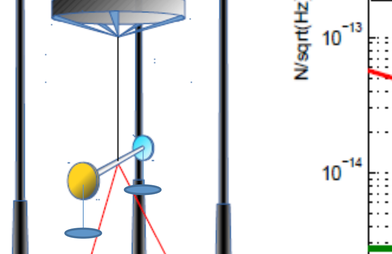
**If the plates are perfectly reflecting the modes that can oscillate must have discrete wavenumbers on vertical axes $k_z = n\pi/a$ while all values are allowed for $k_x$ e $k_y$**

$$E(a) = \frac{hcA}{2}\sum_{n=-\infty}^{n=\infty}\int\frac{d^2k}{(2\pi)^2}\sqrt{k^2+\left(\frac{n\pi}{a}\right)^2} \quad \rightarrow \quad \infty$$

**The regularization is made by determing the Casimir Energy as the change in energy when the plates are at distance "a" with respect to the plates having a→infinity**

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

## The vacuum weight




**If the vacuum «weights» then there is a force, directed upward, equal to the weight of the modes expelled from the cavity when it becomes superconducting.**

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

## The Experiment

- Seismically isolated balance
- Temperature modulation around Tc
- Balance tilt possibly read with an optical lever






*Signal and Sensitivity for Archimedes final : expected signal amplitude for a fixed modulation frequency (blue curve) - total noise for interferometric detection (black curve) and optical lever (pink dashed curve)*

## Conclusions

***Archimedes is a two-year feasibility study concerning***

- Theory and modulation of vacuum energy in layered Superconductoring systems
- **Experimental Improvement of seismic performances at low frequency**
- Experimental Improvements of high quality superconductors temperature modulation

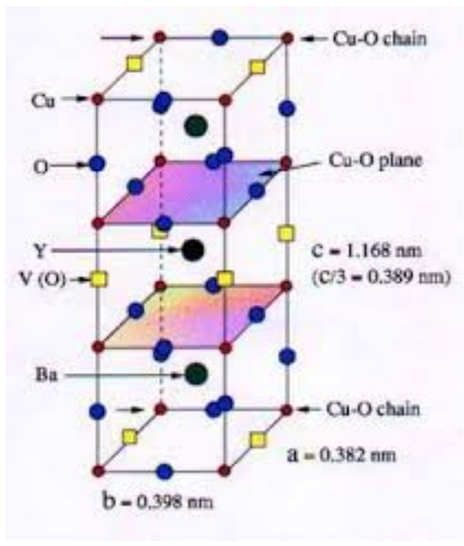
## How to measure it?

The idea is to weigh a **rigid** Casimir cavity when the vacuum energy is modulated by changing the reflectivity of the plates.

1) High Tc layered superconductors as natural multi Casimir-cavities
2) High variation of Casimir energy at the transition → Taking advantage from the fact that in normal state the plane (that will become superconducting) is a very poor conductor

### *Cuprates are «natural» stacks of Casimir cavity*

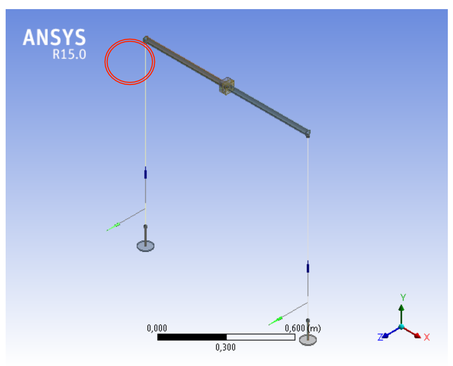
At the transition the vacuum energy is expected to vary significantly due to the variation of the reflectivity of the planes becoming superconducting



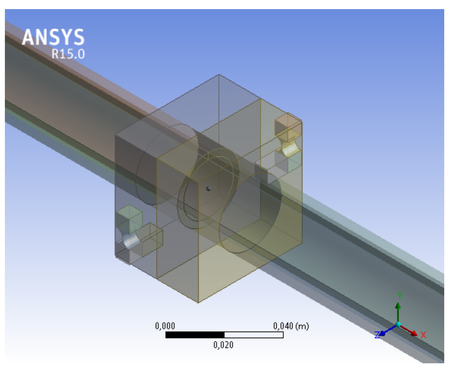

- The cuprate, when makes the transition, has parallel superconducting planes separated by dielectric planes.
- These planes expel part of the vacuum energy due to the increased reflectivity.
- Variation of Casimir energy comparable with the whole condensation energy -> to be Theoretically deep-checked to evaluate the precise contribution
- Approximate theory for high_Tc superconductor (plasma sheet no dissipation – zero temperature) – Kempf hypothesis (based on order of magnitude estimation): the contribution to free energy is comparable to condensation energy in particular layered superconductors like YBCO
- In the final experiment also if the actual contribution were only of few percent we could ascertain if it gravitates or not
- The Casimir Signature: the dependence of the effect from layers separation is known: the verification of the effect is by changing the layers separation – possible with standard techniques

**Expected force $10^{-16}$ N**

## The Balance




Scheme of the balance with suspended samples




Zoom on the flexural joints where The balance will be suspended

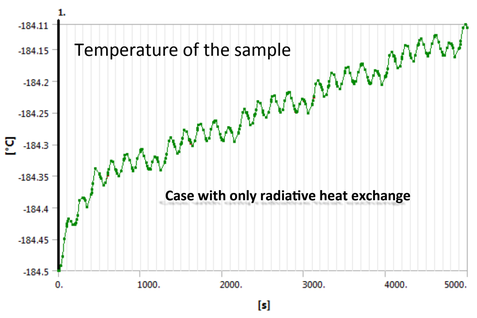
The center of mass must lie within few micron from the flexural rotation point (bending point).

## The thermal actuation

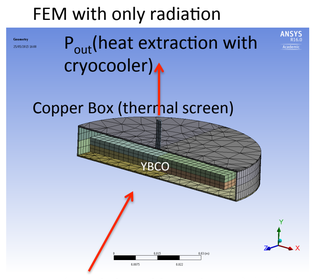
**Requirements**

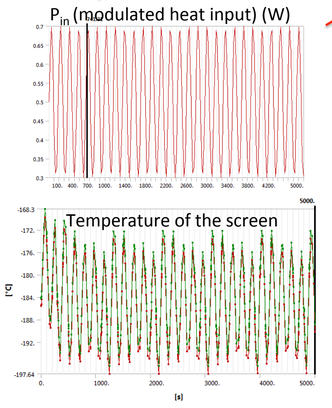
- Modulate the sample temperature of 1K around the $T_c$ transition temperature.
- Use only radiative mechanism between the thermal screen and the sample.
- Thermal times depend on the thermal properties of materials:
  - heat capacity
  - emissivity
  - thermal conductivity
- Optimized design needed for fullfilling the requirements

→ Remove any conduction mechanism between the screen and the sample.

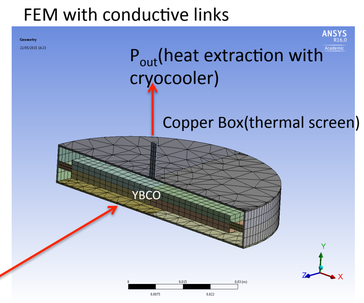


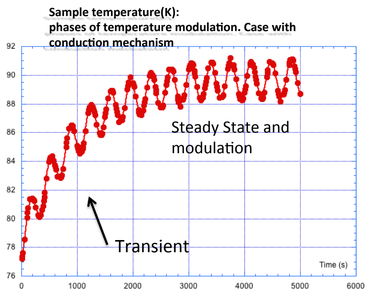

FEM with only radiation




FEM with conductive links




## References

**E.Calloni, M.De Laurentis, R. De Rosa, F. Garufi, L. Rosa, L, Di Fiore,G. Esposito, C.Rovelli, P. Ruggi, F. Tafuri: "Towards weighing the condensation energy to ascertain the Archimedes force of vacuum" Phys. Rev. D 90, 022002 (2014)**

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