

What if dark matter were nothing more than quantum fluctuations of vacuum ?

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06 Mai 2026

Dark Matter appears when probing gravitation in low acceleration regime ($\lesssim 10^{-10}$ m/s²)

Is there anything missing in our understanding of gravitation ?

Yes... Quantum fluctuations of the vacuum energy density are absent in General Relativity

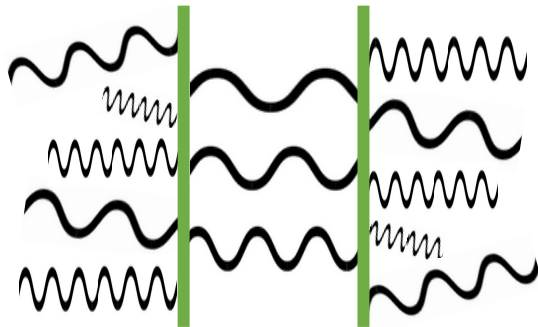
Quantum Vacuum and Gravitation

Quantum Field Theory & QED

Vacuum is a dynamical quantum medium, filled with quantum energy density fluctuations of the zero-point electromagnetic field

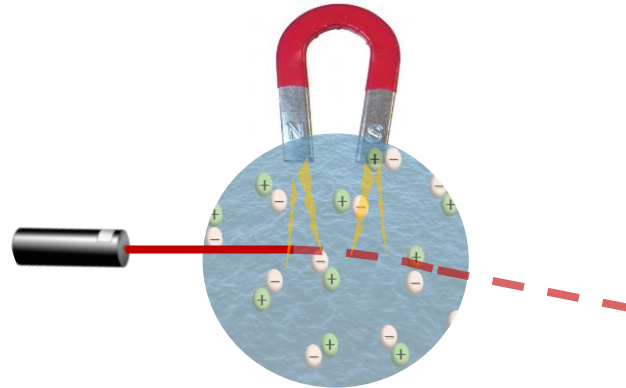
- A sum of stationary electromagnetic vibration modes with energy per mode $e_v(k) = \hbar\omega_k/2$
- Continuous appearance and disappearance of virtual pairs e^+/e^-

Vacuum density modified by a cavity



→ Casimir force

Vacuum polarized by E,B

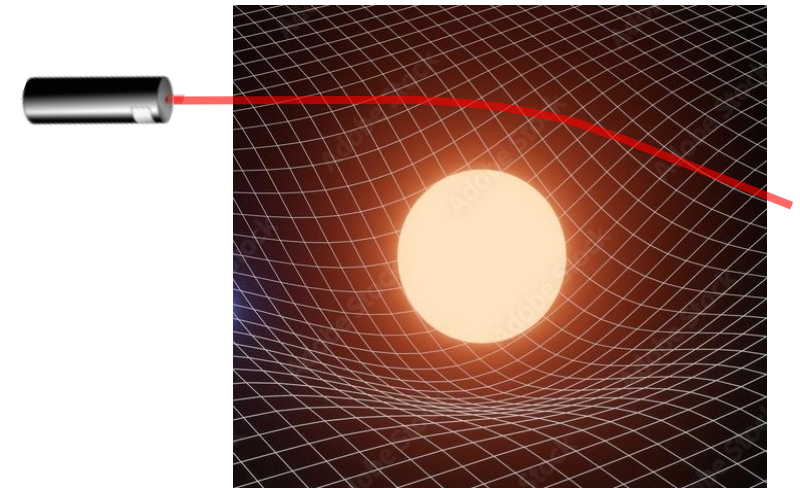


→ light velocity is reduced
DeLLight: electromagnetic lensing in vacuum

General Relativity

Vacuum = space-time metric which is curved in the presence of a gravitational field

Quantum fluctuations of the vacuum energy density are absent



QED Vacuum and Gravitation

- What about quantum fluctuations of the vacuum energy densities in a gravitational field ?
- Do they gravitate ? Do they fall ?
- If yes, it would generate an over-density of the quantum energy density fluctuation in vacuum close to the mass
- Could it be the origin of the missing mass (the dark matter) ?
(see *arXiv:2302.01624*)

Vacuum catastrophe in General Relativity ?

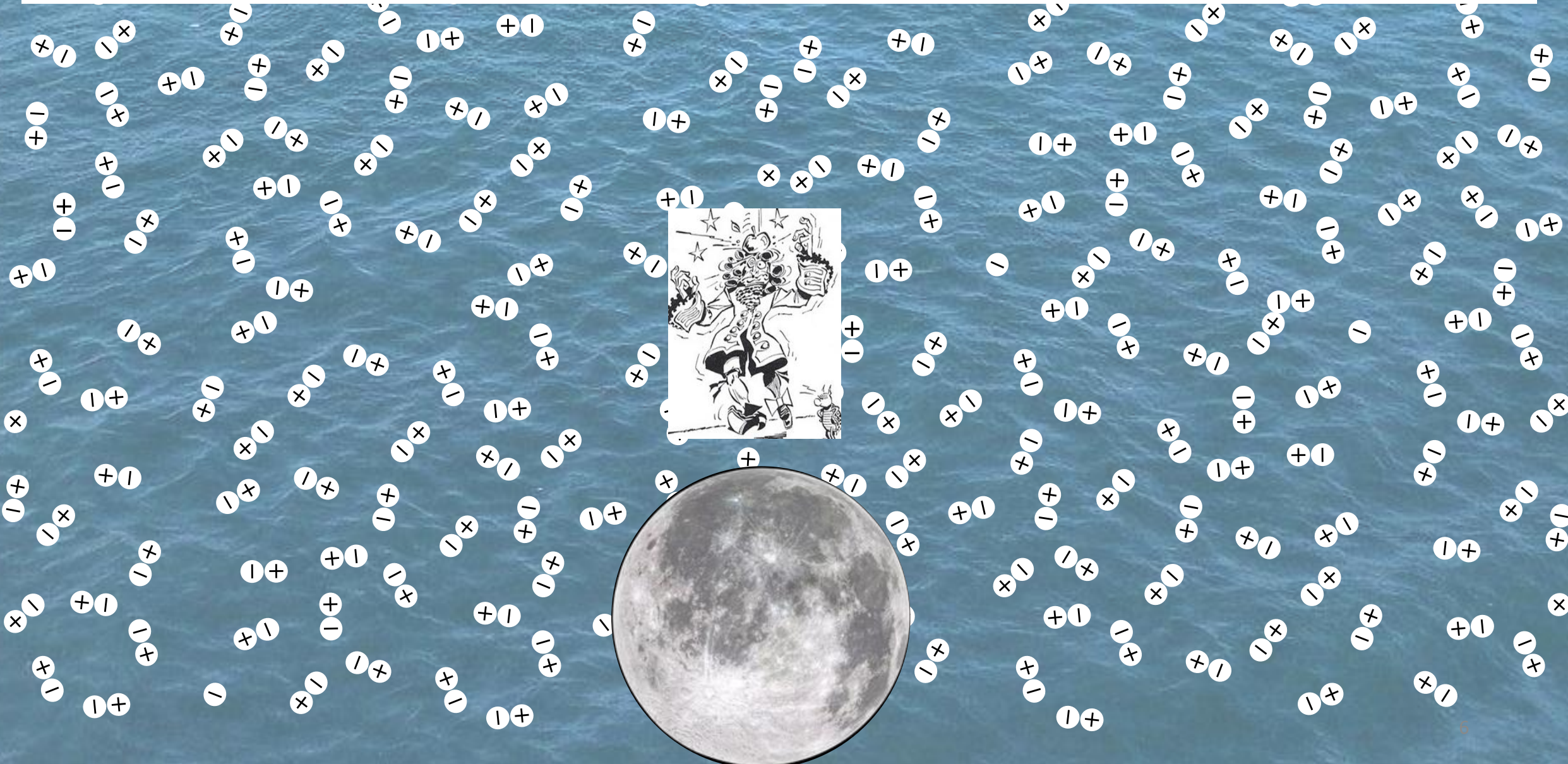
→ The mean value of the vacuum energy does not contribute to gravitation

In other words, a test mass set in the middle of the infinite uniform isotropic vacuum does not feel gravitation force



Now, a gravitation mass is added

→ Our test mass will undoubtedly feel the gravitational force caused by this asymmetry



Do vacuum energy density fluctuations gravitate ?

Do virtual e^+/e^- pairs gravitate ?

Is the vacuum density modified by gravitation ?

Could it be the origin of the dark matter ?



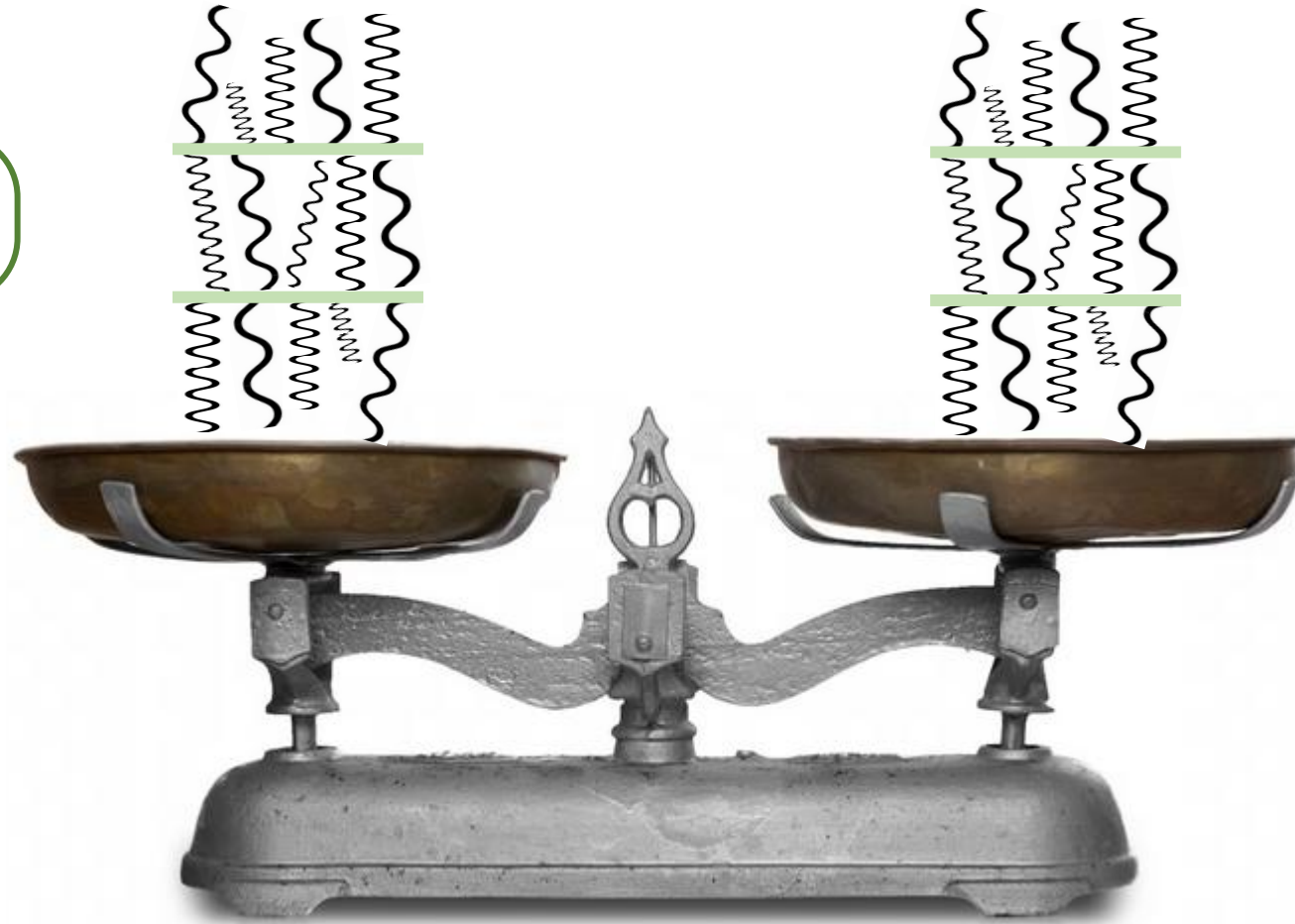
Do energy density fluctuations
of the QED vacuum gravitate ?



QED Vacuum and Gravitation

Do the quantum vacuum gravitate ?

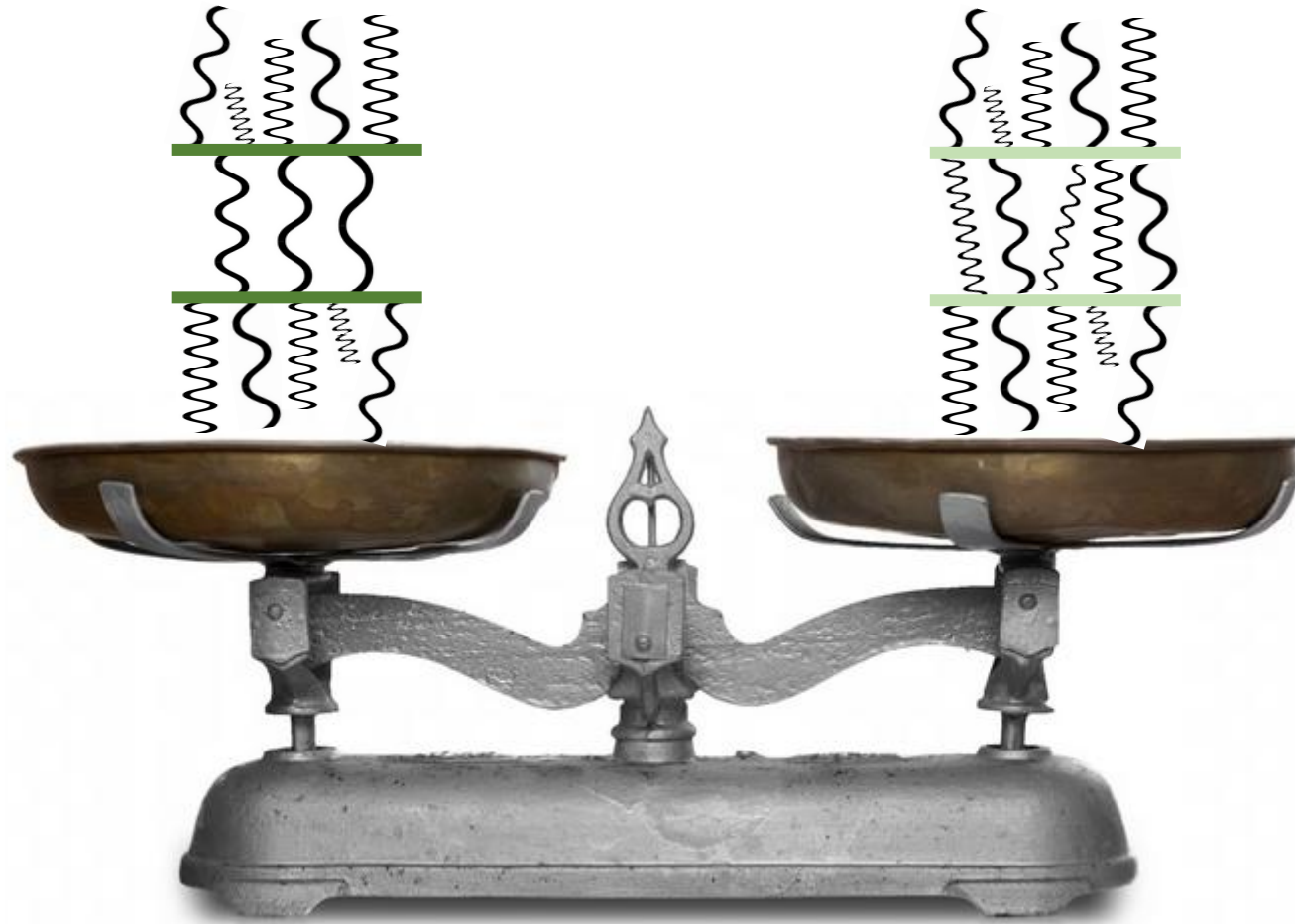
Passive (transparent)
Cavity



QED Vacuum and Gravitation

Do the quantum vacuum gravitate ?

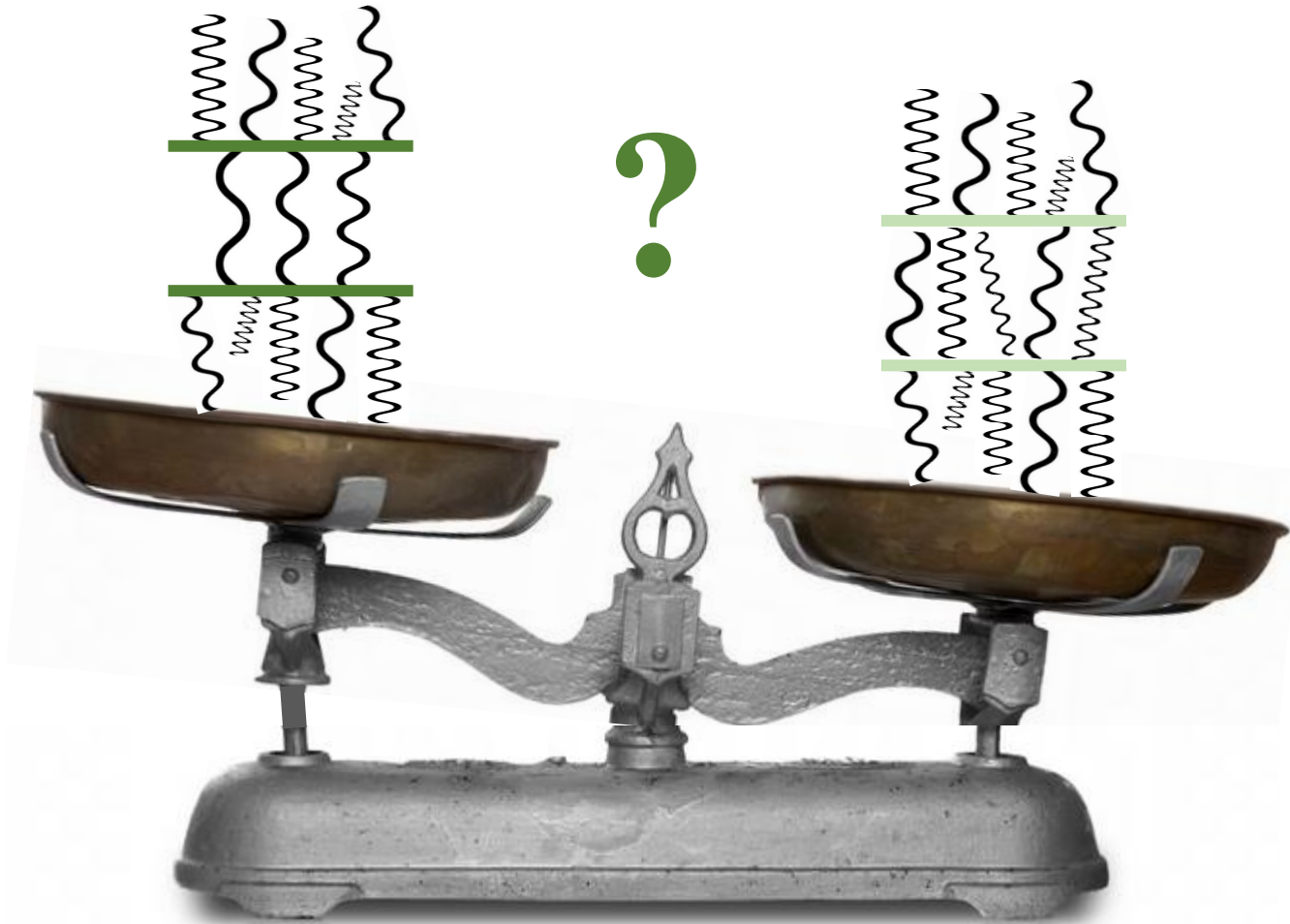
Superconducting
Resonant Cavity



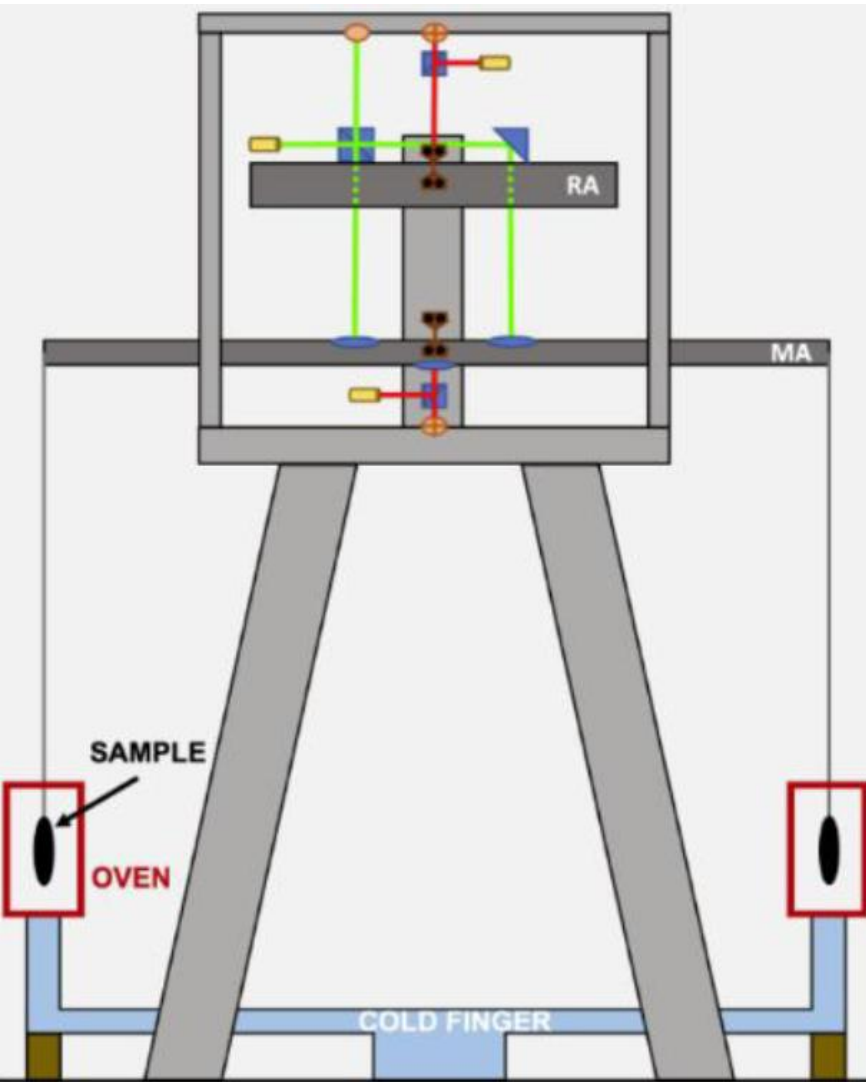
QED Vacuum and Gravitation

Do the quantum vacuum gravitate ?

Superconducting
Resonant Cavity



Archimedes Experiment



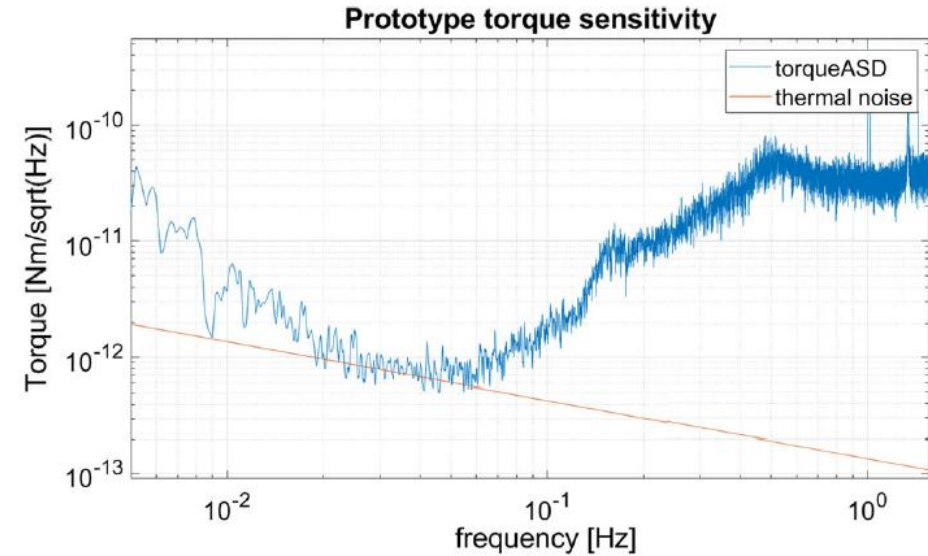
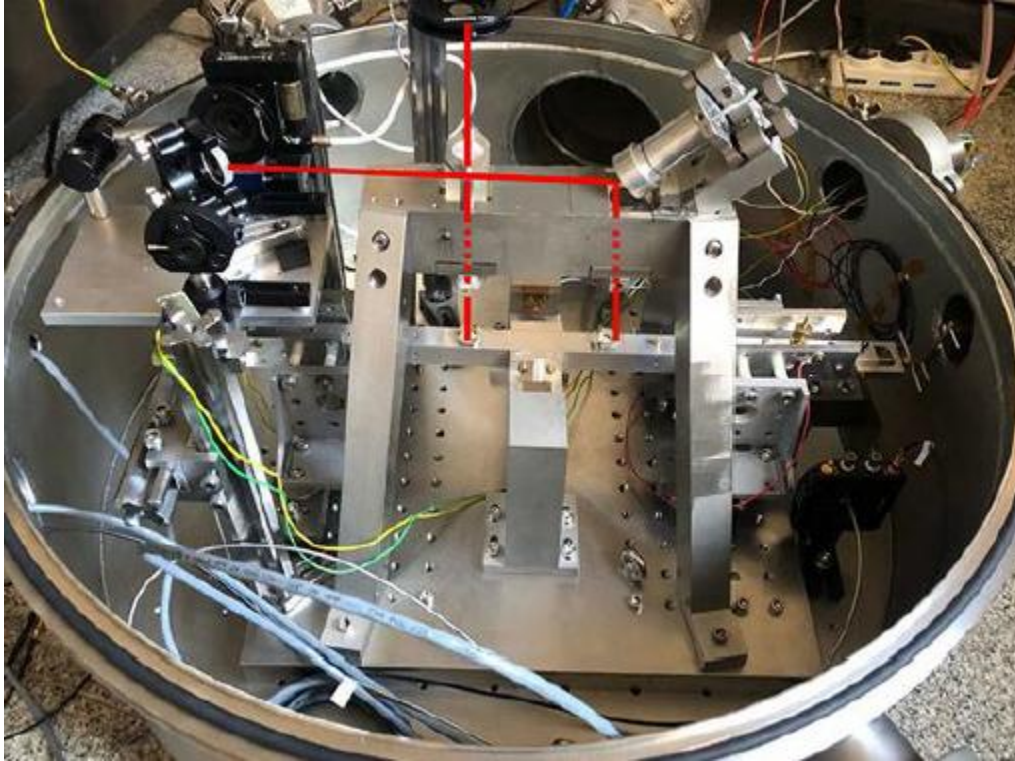
Balance arm length = 1.4 m

Archimedes experiment @ Sar-Grav surface laboratories (Sardinia, Italy)

- Ultra sensitive interferometric balance (reference arm and balance arm)
- Modulate the reflectivity of the Casimir plates to modulate the density of vacuum modes inside the Casimir cavity
- Suspend samples composed of Casimir cavities to the balance arm and try to detect a possible weight variation at the modulation frequency
- Superconducting YBCO crystal ($T_c=92\text{K}$) as natural multilayered Casimir cavity
- Disk-shape $R=5\text{cm}$, $e=5\text{mm}$ $\rightarrow F= 5\times 10^{-16}\text{ N}$ \rightarrow Torque $\tau = 3.5\times 10^{-16}\text{ N.m}$
Eur. Phys. J. Plus 137, 826 (2022)
Phys. Rev. B 106, 134502 (2022)
- Thermal modulation of the crystal @ 10mHz for heterodyne detection
- Spectral signal (integration 10^6 s): $\tau_s = 3.5\times 10^{-13}\text{ N.m}/\sqrt{\text{Hz}}$

Archimedes Experiment

The balance prototype



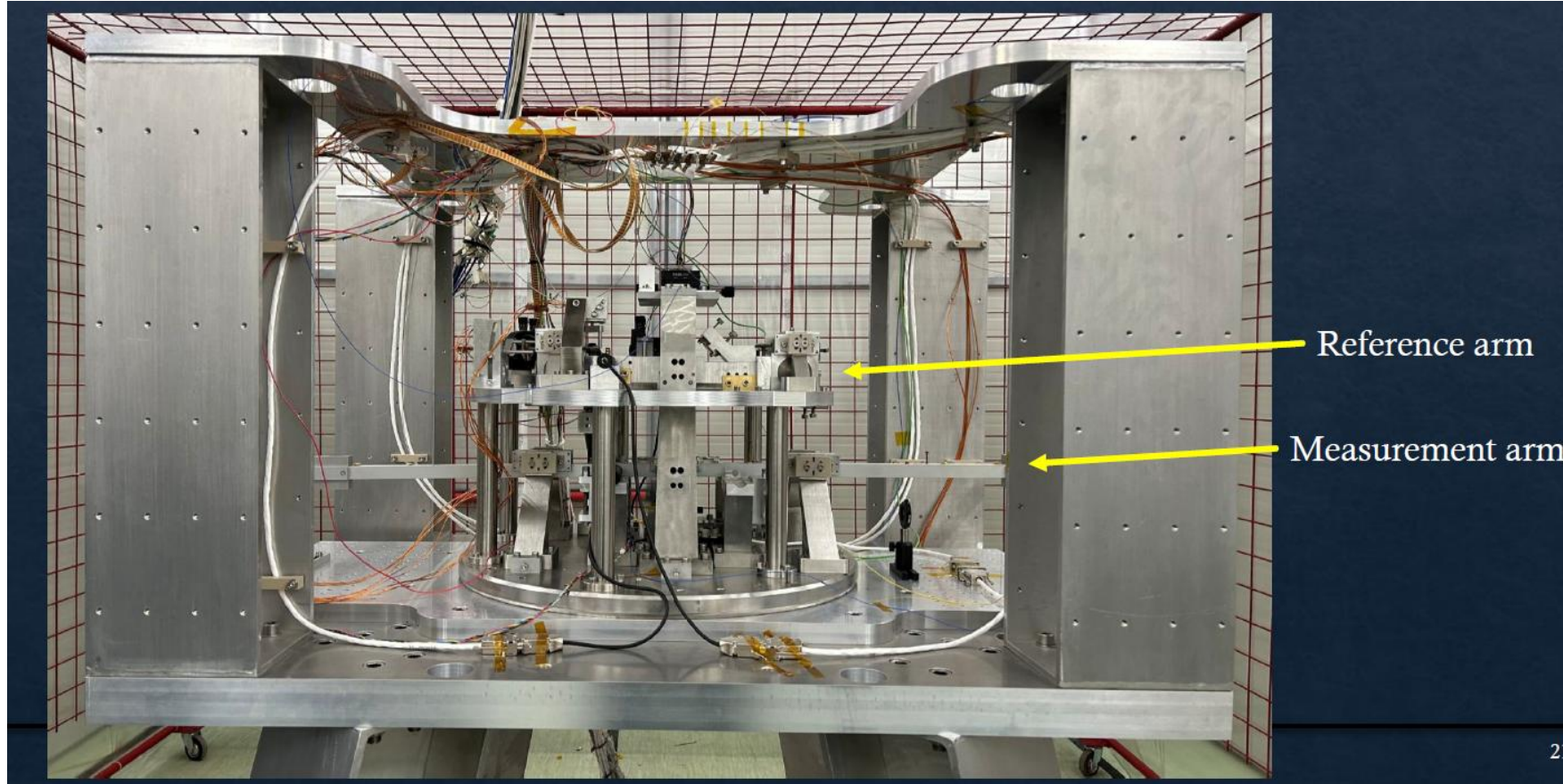
Torque sensitivity achieved at room temperature with the prototype: $\sim 10^{-12}$ N.m/ $\sqrt{\text{Hz}}$

Only a factor ~ 10 above the required sensitivity

A. Allocca et al., Eur. Phys. J. Plus 139 (2024)

Archimedes Experiment

Archimedes final balance



Setup in cryogeny by the end of 2026 for first measurements campaign of sensitivity

Conclusion

- Dark Matter appears when probing gravitation in low acceleration regime
- Something is missing in our understanding of gravitation ?
- Quantum fluctuations of the vacuum energy density are absent in General Relativity

But they are present in the nature !?! → Do they gravitate ? Do they fall ?

- If yes, it would generate an over-density of the quantum energy density fluctuation in vacuum close to the mass which could be the origin of the missing mass (*arXiv:2302.01624*)
- QED quantification in a gravitational potential is still missing...
- But today, we have the knowledge needed to verify this experimentally

→ The **Archimedes experiment**