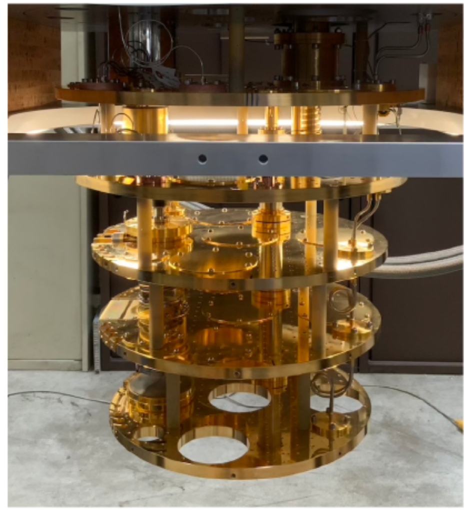
Quantum **I**nformation **S**cience devices and methods in fundamental physics

Speaker: Caterina Braggio

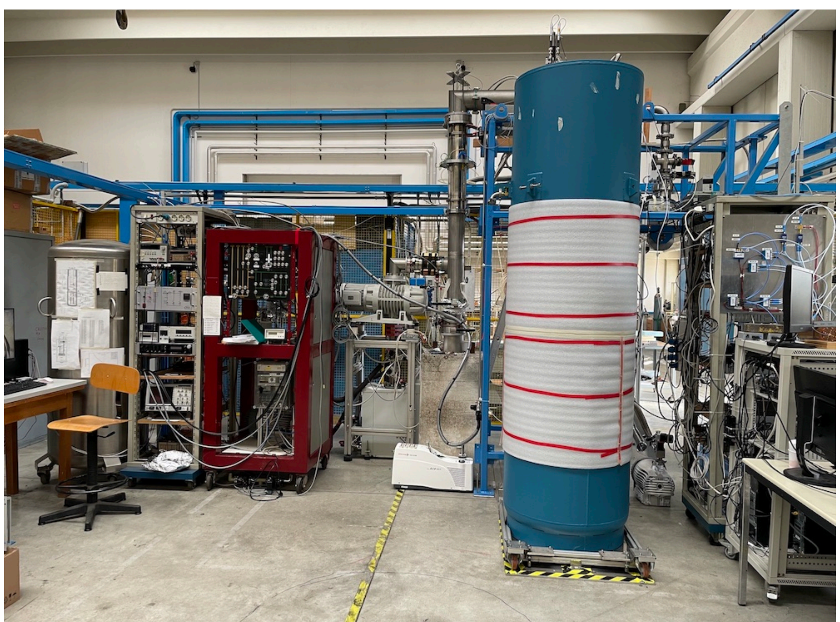
Group: G. Carugno, R. Di Vora, A. Gardikiotis, A. Ortolan, G. Ruoso



INFN
Istituto Nazionale di Fisica Nucleare

SQMS
SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

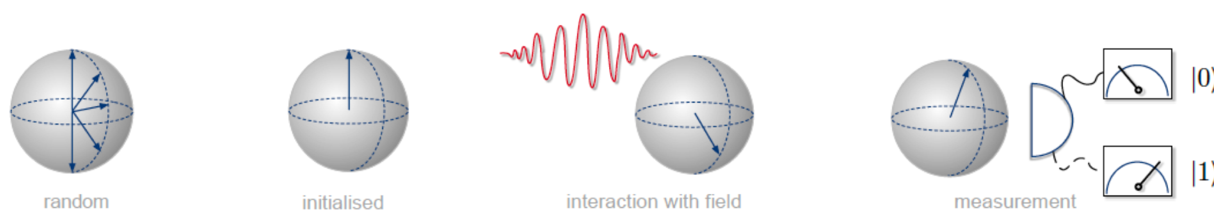
cea PARIS-SACLAY
Quantronics Group

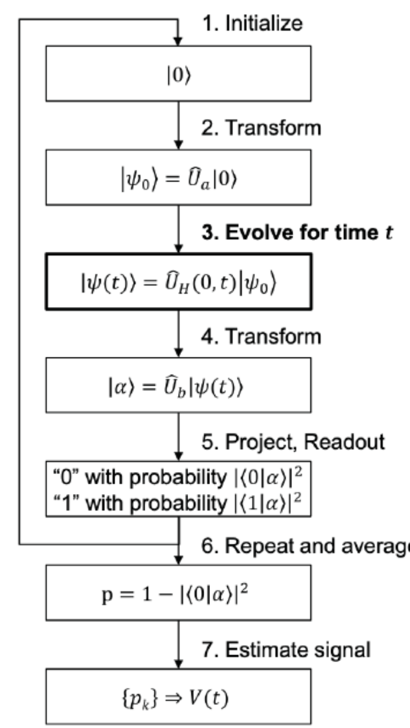


What is a quantum sensor?

"Quantum sensors are individual systems or ensembles of systems that use **quantum coherence**, **interference** and **entanglement** to determine physical quantities of interest."
Rev. Mod. Phys. 89, 035002 (2017)

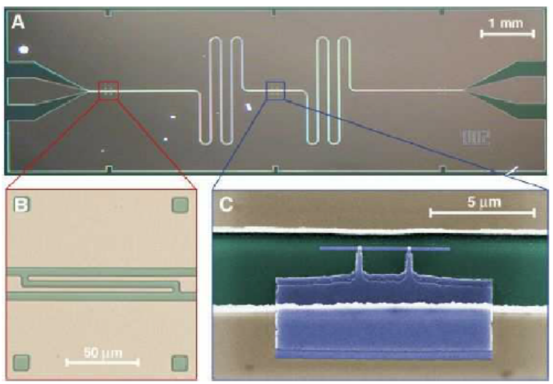
"A device whose measurement (sensing) capability is enabled by our ability to **manipulate and readout its quantum states**."
M. Safranova and D. Budker



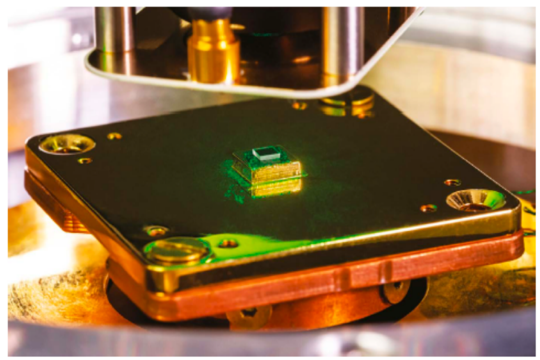


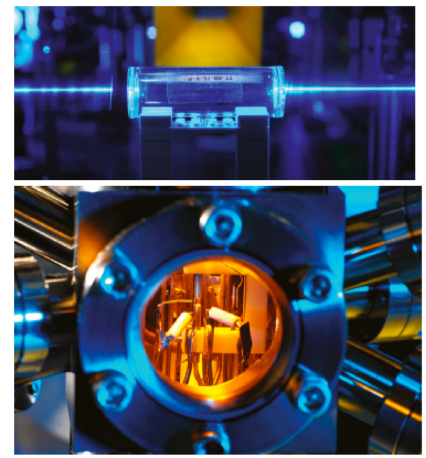
What is a quantum sensor?

Quantum sensors have been realised in **multiple physical systems with very different operating principles**.



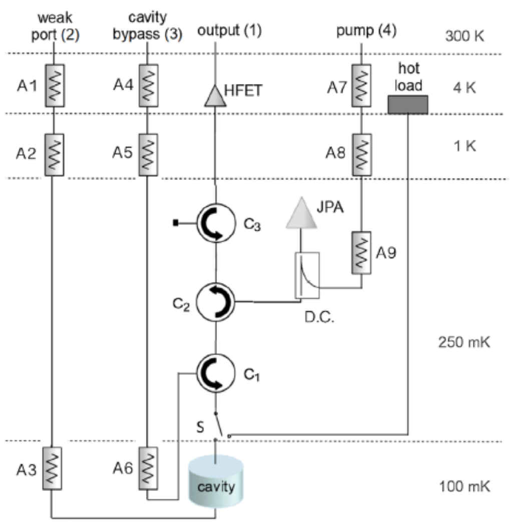
Superconducting circuits

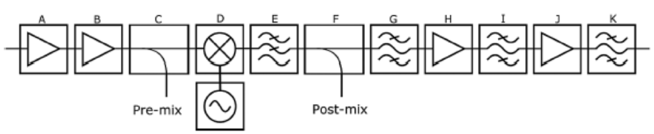

Solid-state spins


Atomic ensembles

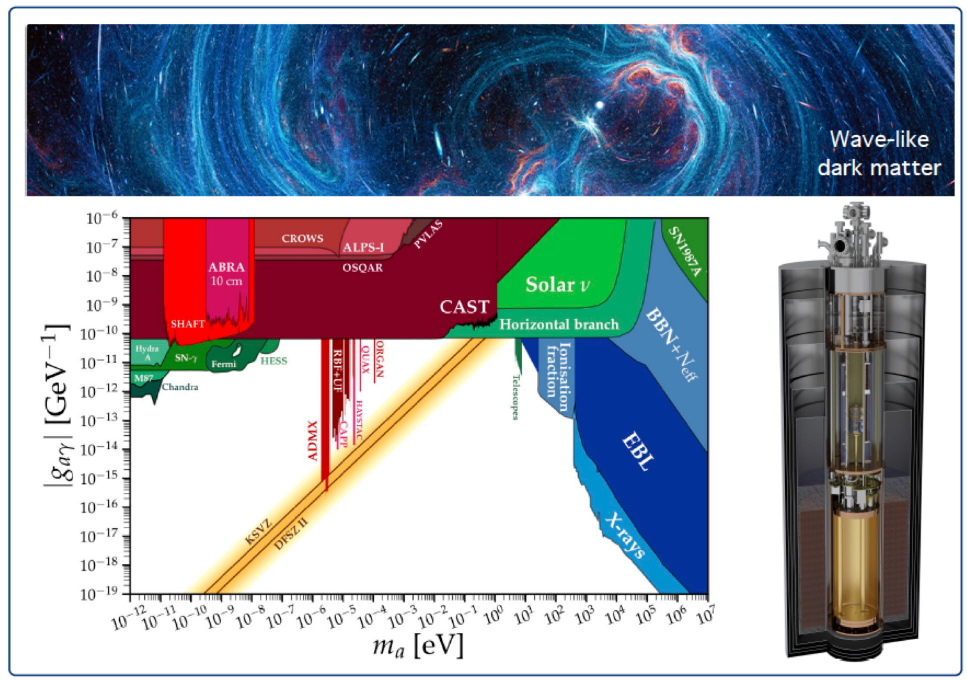
It might take some more time to adapt them in real-world settings, but **they are already in use in the lab**.
Applied to problems in which **significant** gain (up to 1000s) compared to conventional detectors is required.

Wave-like dark matter (DM) search





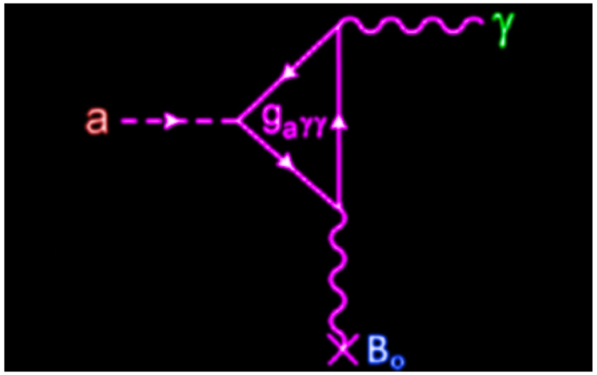
Dilution refrigerator (mK temperature)
Quantum-limited amplifiers
Heterodyne microwave receiver



$< 10^{-23}$ W

Unknown frequency (particle mass)

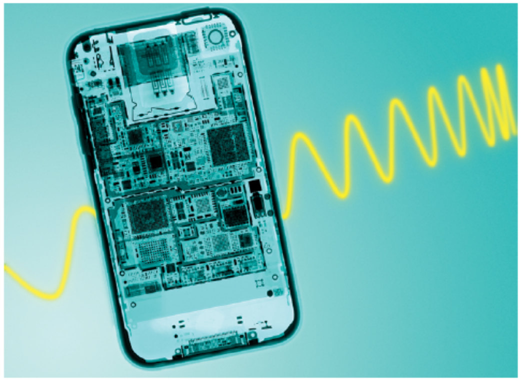
Wave-like dark matter (DM) search



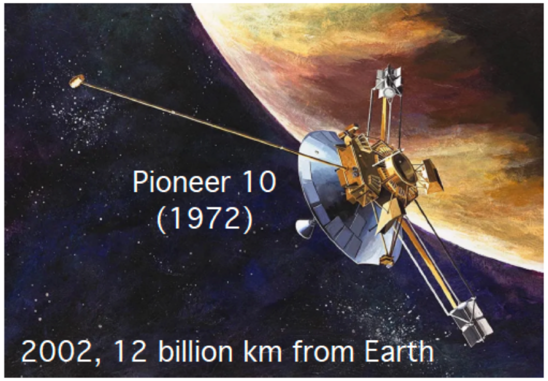
1. 3D microwave cavity for resonant amplification
   -think of an HO driven by an external force-
2. with **tuneable frequency** to match the axion mass
3. the cavity is within the bore of a **SC magnet**
4. cavity signal is readout with a **low noise receiver**
5. cavity and receiver preamplifier are kept at base temperature of a **dilution refrigerator** $(10-50)$ mK

Quantum microwaves in DM search

kW



(0.1-2) W

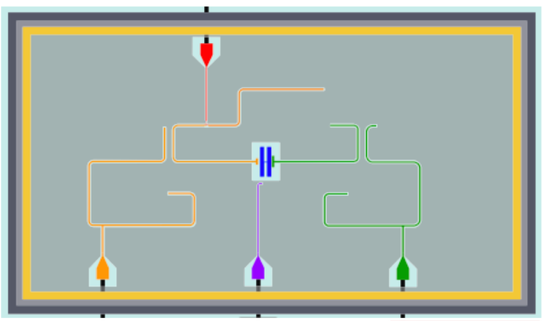


2.5×10^{-21} W

Quantum microwaves in DM search

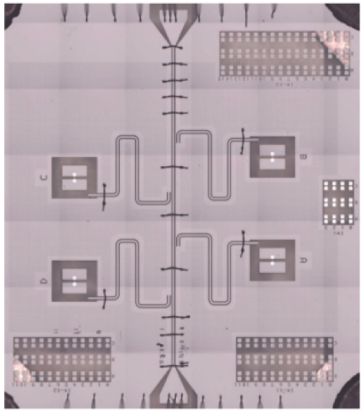
The sensors we use:

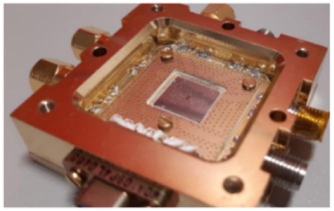
Single microwave photon counters



Quantronics Group

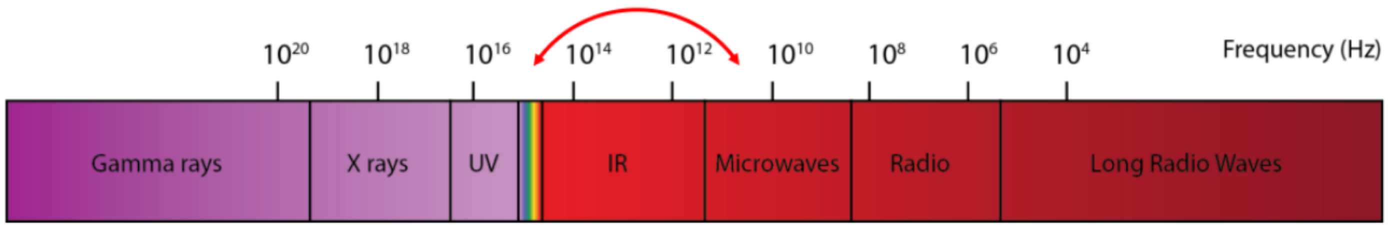
Josephson Parametric Amplifiers (JPA)
Traveling Wave (TWPA)



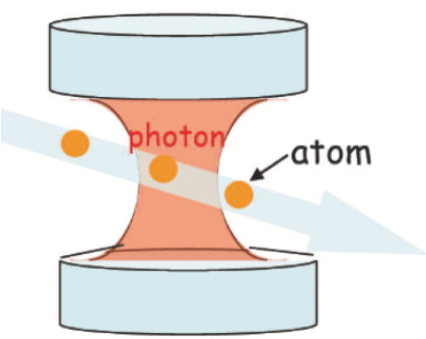


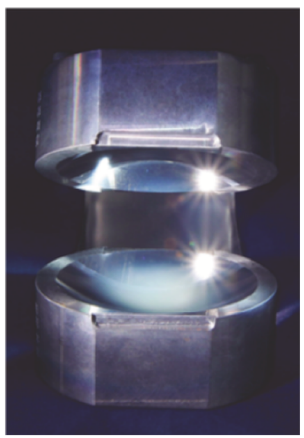
INSTITUT NÉEL

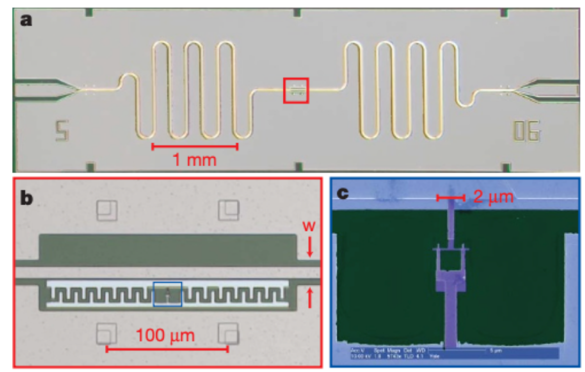
Quantum microwaves in DM search



The detection of individual **microwave photons** has been pioneered by **atomic cavity quantum electrodynamics experiments** and later on transposed to **circuit QED experiments**







Nature **400**, 239242 (1999)

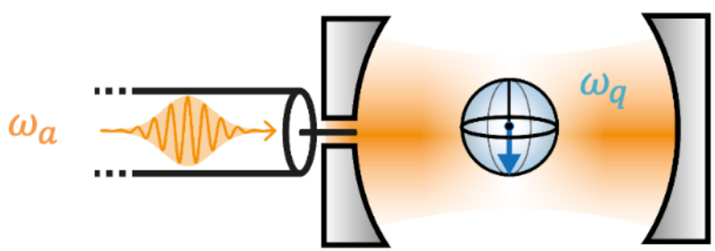
Nature **445**, 515518 (2007)

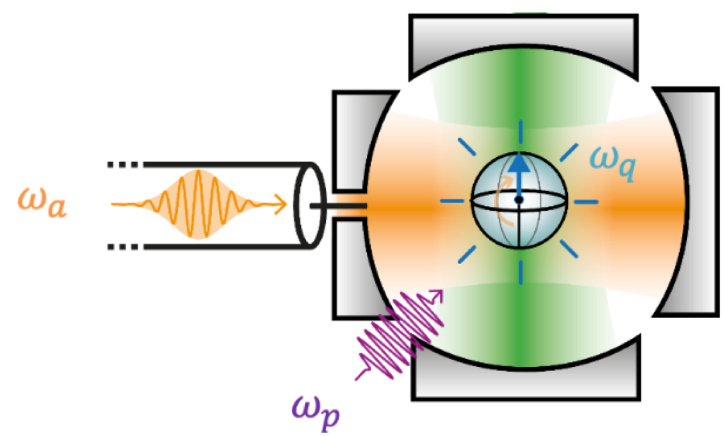
In both cases **two-level atoms** interact directly with a **microwave field mode*** in the cavity

* a quantum oscillator whose quanta are photons

Qubit-based photon counting

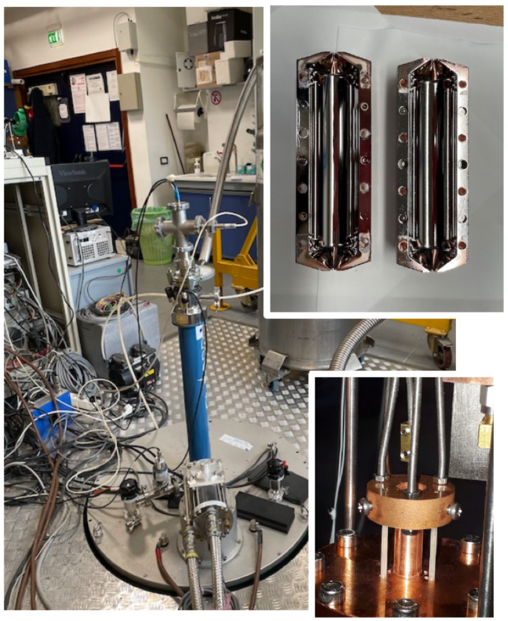
- the incoming photon is converted to a qubit excitation
- the state of the qubit is then probed with QIS methods (dispersive readout)

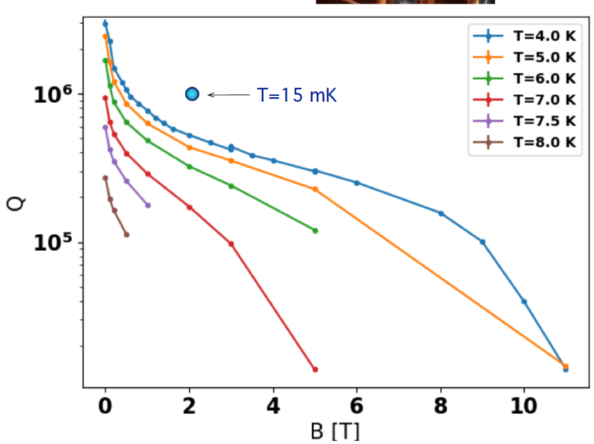




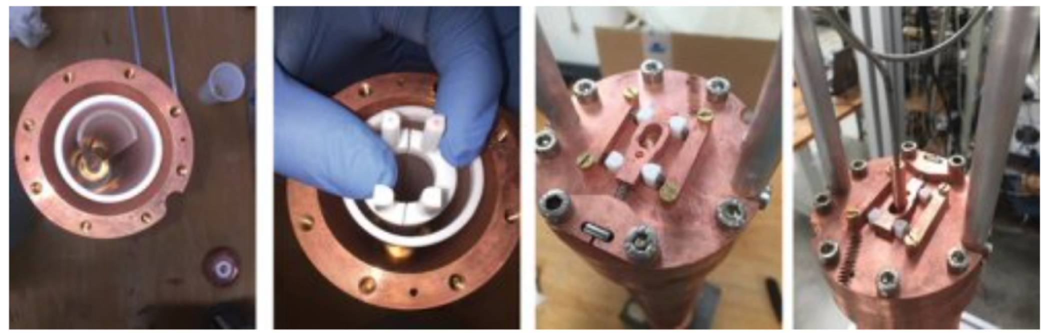
The 3D microwave resonators we develop:

SC cavity: thin film technology (C. Pira, INFN-LNL)

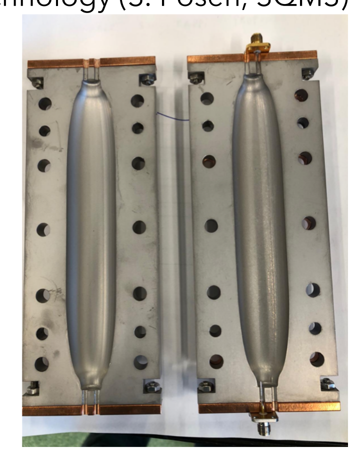




Dielectric resonators



SC cavity: thin film technology (S. Posen, SQMS)



We can probe fundamental physics with lab-scale experiments

Big learning curve with sensors at the frontier of quantum technology

Not just a small piece in a huge experiment

Contacts

Come to visit **the lab at LNL**, you're welcome!
Possibility to apply for **INFN scholarships** (both Bachelor and Master)

Speaker: office 254, via Marzolo 8
caterina.braggio@unipd.it

If you want to know more, please contact us!

Group: Giuseppe Ruoso (ruoso@lnl.infn.it),
Antonello Ortolan (ortolan@lnl.infn.it),
Raffaele Di Vora (divora@lnl.infn.it),
Giovanni Carugno (carugno@lnl.infn.it),
Antonios Gardikiotis (gardikiotis@pd.infn.it)