cQED@Tn - From Quantum Devices to Analogues on Superconducting Circuits

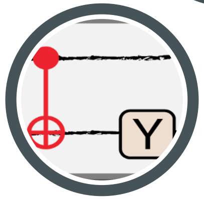
C GATTI, I CARUSOTTO, P FALFERI, A VINANTE, B MARGESIN, F MANTEGAZZINI, D BABUSCI

ale

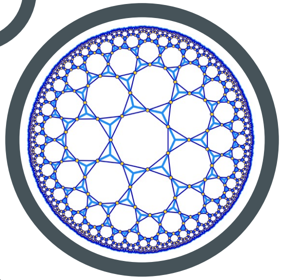
UNIVERS
DI TRENT

FONDAZIONE
BRUNO KESSLER

Amplifiers

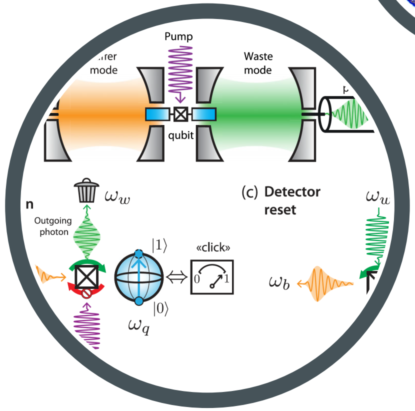


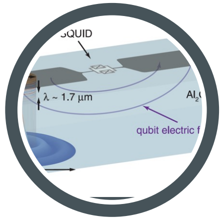
Quantum Information



Analogues

Sensing



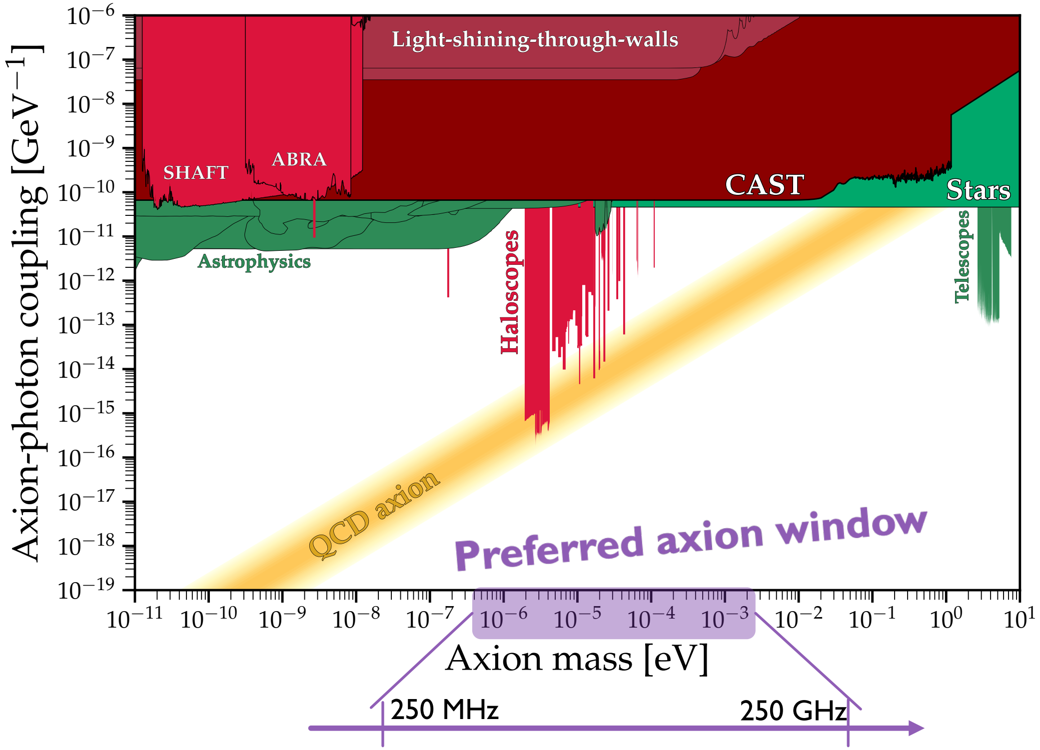


Hybrid Systems

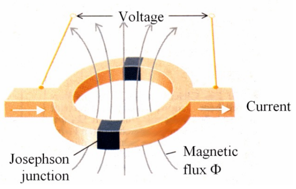
Intro – why single photon detection in the microwaves

A. Rettaroli

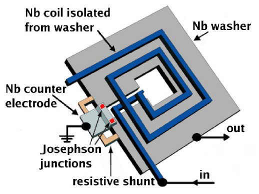
The physics case: search for light dm (axions, ALPs, hidden photons…)



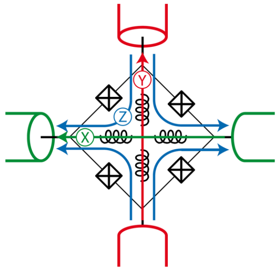
Linear-amplifier noise is prohibitively increased by standard quantum limit above 10-20 GHz while bolometers and photon counters are not sensitive enough (or too noisy) below the THz



SQUID (→1 GHz)



MSA SQUID (→ few GHz)

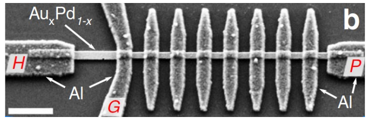


JPA (→ 10-20 GHz)

Quantum limit

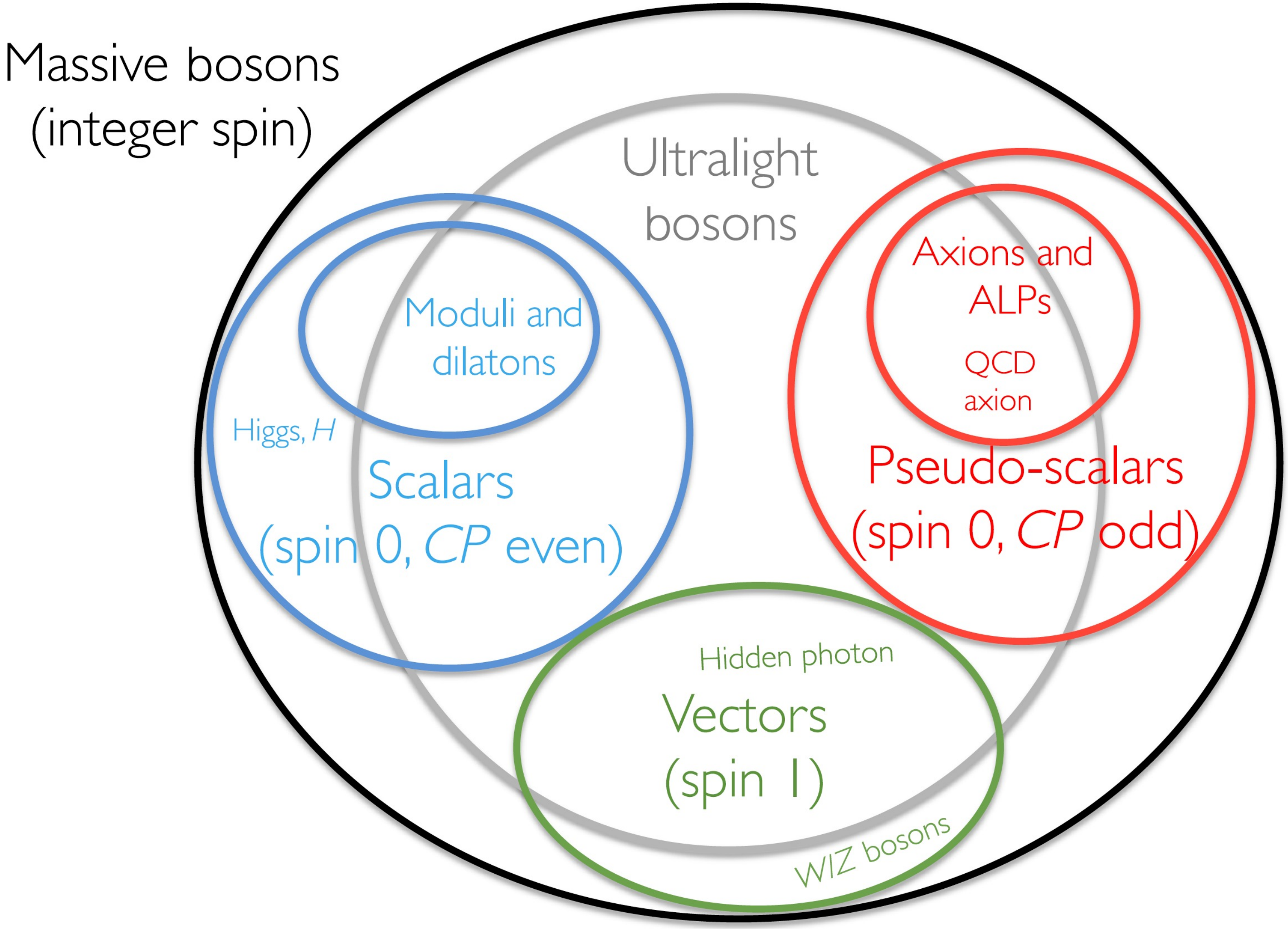
$T_{noise}[mK] \approx 50 \times \nu[GHz]$

Bolometers, photon counters



NEP=20 zW/√Hz → 400 GHz

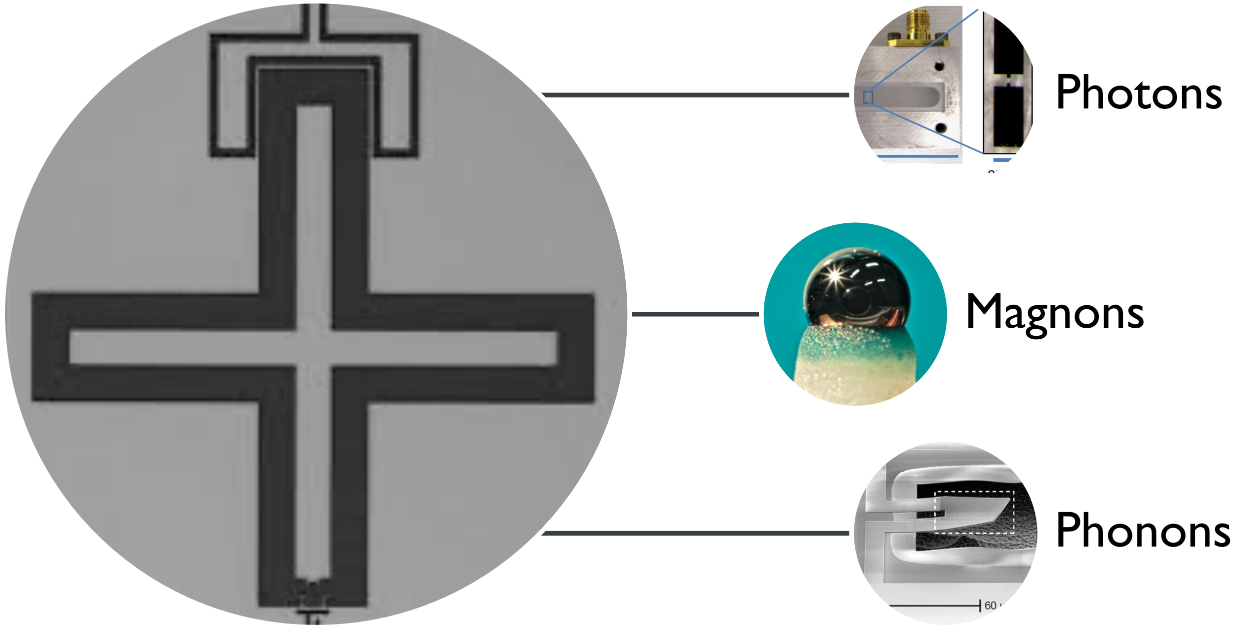
Kokkoniemi et al. Nat. Com. Phys. https://doi.org/10.1038/s42005-019-0225-6



Chadha-Day et al., Sci. Adv. 8 eabj3618 (2022)

Quantum Sensing and Hybrid Systems

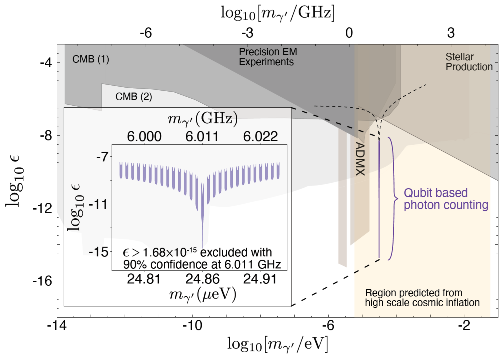
Recent progresses in the ability to measure and manipulate individual quanta such as microwave-photons, phonons and magnons are opening new directions in the detection of Dark Matter and of Fifth Forces, in tests of Quantum Gravity and of Quantum Mechanics in macroscopic objects.



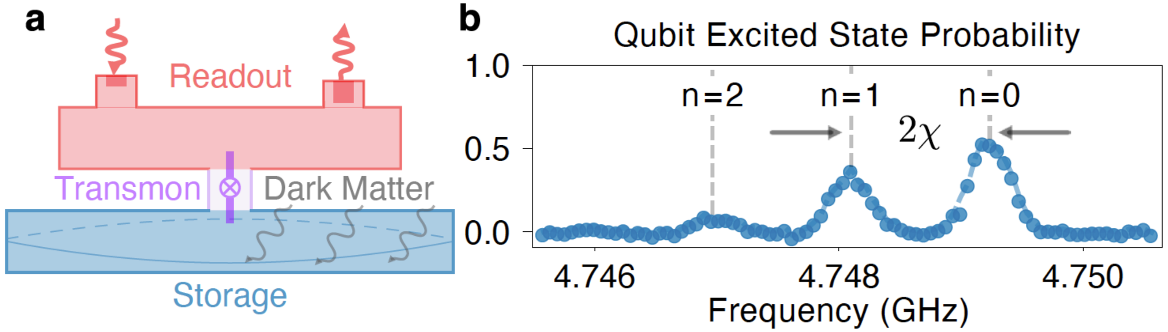
Dark Matter Searches with SC Qubits - State of Art

Photon Sensing - Dark Photons

Photon sensing with qubit recently used to search dark matter composed of Dark Photons.



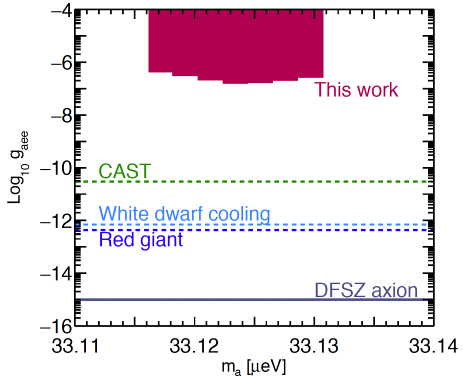
A V Dixit et al., "Searching for Dark Matter with a Superconducting Qubit," Phys. Rev. Lett. 126, 141302 (2021).



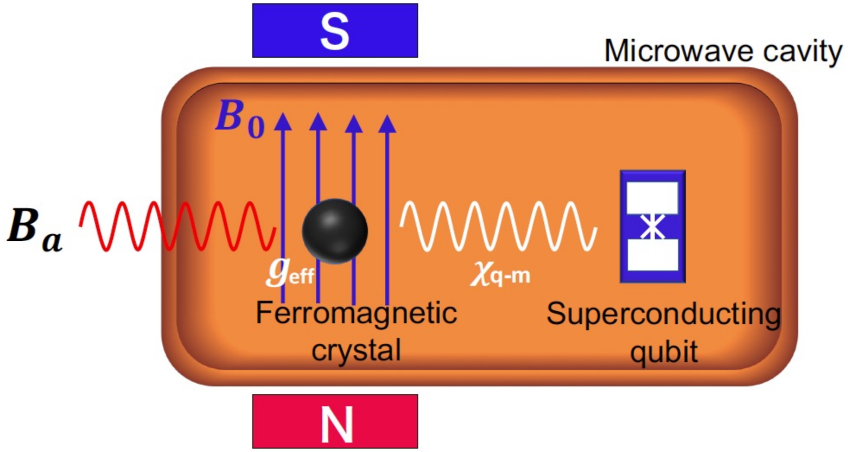
See talks of Albertinale, Corti, Felicetti, Rettaroli, Lisitskiy

Magnon Sensing - Axions

Magnon sensing with qubit recently used to search dark matter composed of axions, via axion-spin coupling.



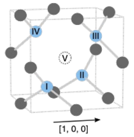
T Ikeda et al. "Axion search with quantum nondemolition detection of magnons," arXiv:2102.08764.

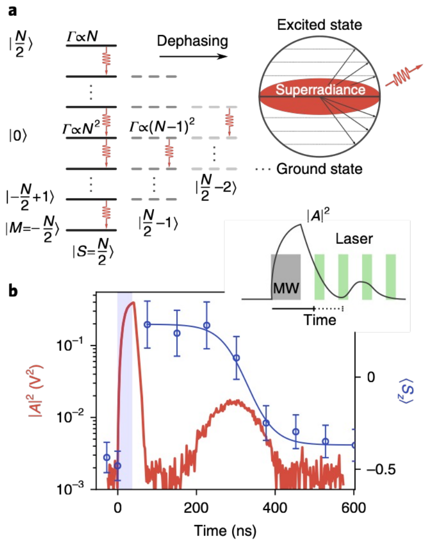


See talks of Albertinale, Affronte, Leo

New Phenomena & Applications with Hybrid-Spin Systems

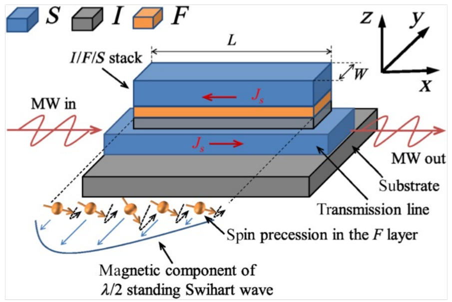
- fast and protected QIP
- nonlinear optics
- superradiance
- enhancement of quantum phenomena

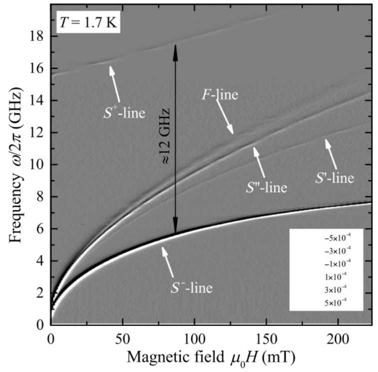




NATURE PHYSICS | VOL 14 | DECEMBER 2018 | 1168–1172 |

PHYS. REV. APPLIED **16,** 034029 (2021)



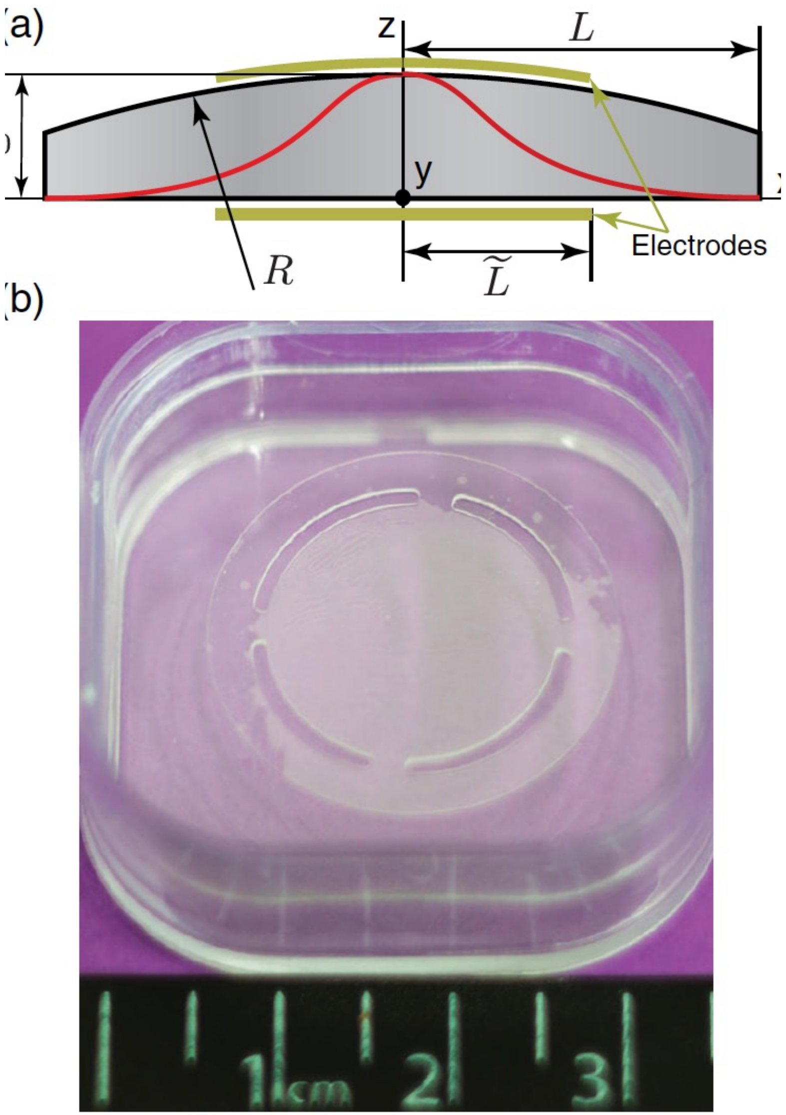


$g/\omega = 0.6$!

M Affronte

Light Dark Matter and GW with Mechanical Resonators

Light Dark Matter or high frequency GW can induce oscillation (from MHz to GHz) of piezoelectric quartz bulk acoustic wave (BAW) resonators cooled at mK temperatures.



- M Goryachev and M E Tobar, "Gravitational wave detector with high frequency phonon trapping acoustic cavities "PHYSICAL REVIEW D 90, 102005 (2014)
- D Carney et al, "Mechanical quantum sensing in the search for dark matter," Quantum Sci. Technol. 6 (2021) 024002.
- A Arvanitaki et al, "The sound of dark matter: searching for light scalars with resonant-mass detectors", Phis Rev Lett 116 031102 (2016).

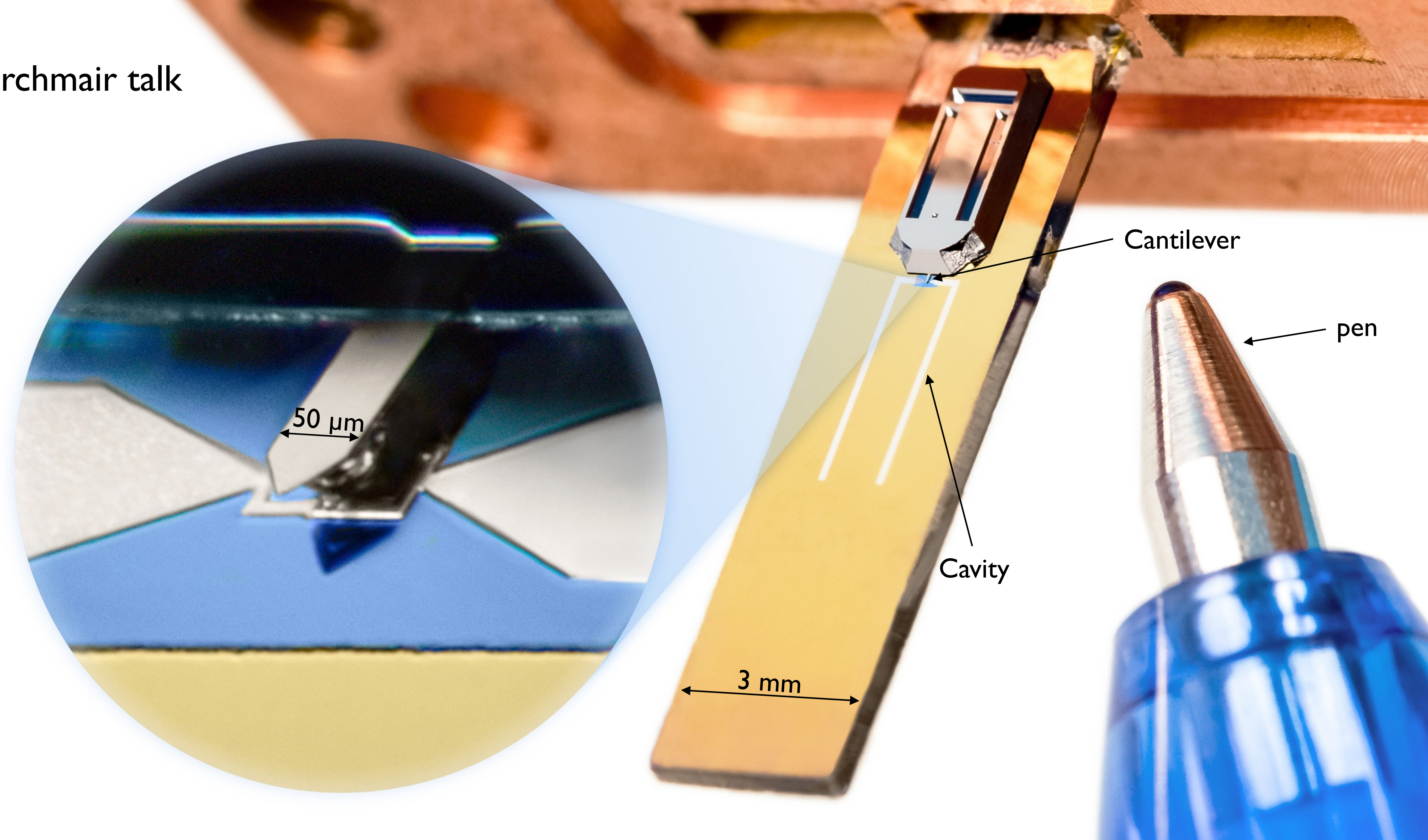
PRL **116,** 031102 (2016) PHYSICAL REVIEW LETTERS week ending 22 JANUARY 2016

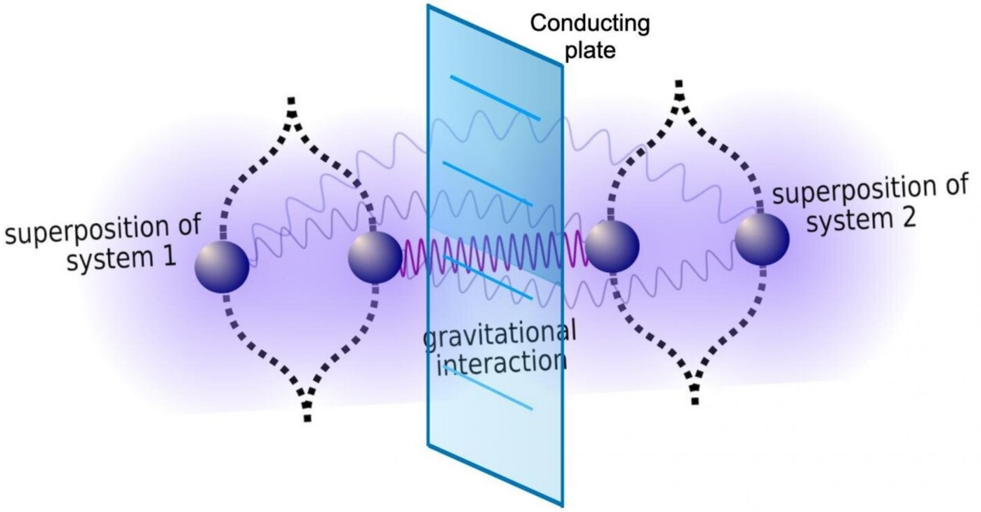
Sound of Dark Matter: Searching for Light Scalars with Resonant-Mass Detectors

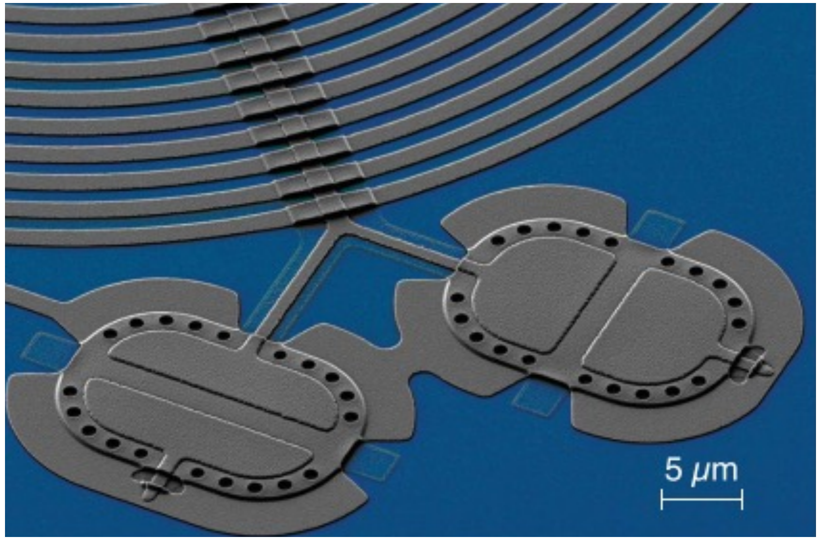
Asimina Arvanitaki,[1,*] Savas Dimopoulos,[2,†] and Ken Van Tilburg[2,‡]
[1]*Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada*
[2]*Stanford Institute for Theoretical Physics, Stanford University, Stanford, California 94305, USA*
(Received 23 August 2015; revised manuscript received 17 October 2015; published 22 January 2016)

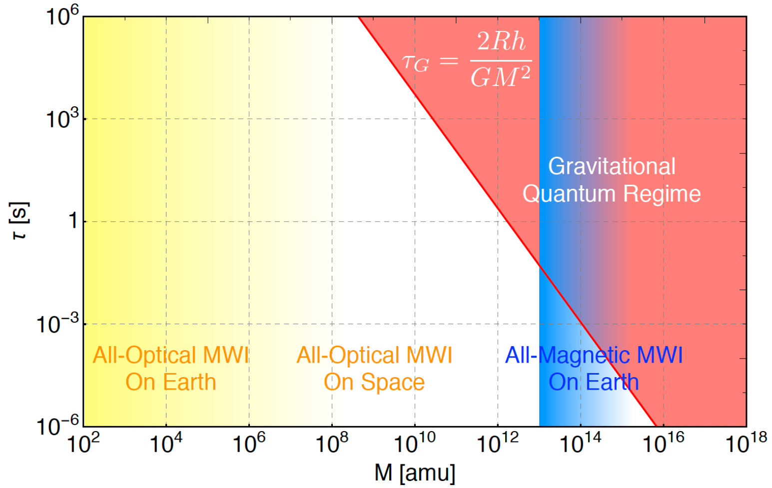
The fine-structure constant and the electron mass in string theory are determined by the values of scalar fields called moduli. If the dark matter takes on the form of such a light modulus, it oscillates with a frequency equal to its mass and an amplitude determined by the local dark-matter density. This translates into an oscillation of the size of a solid that can be observed by resonant-mass antennas. Existing and planned experiments, combined with a dedicated resonant-mass detector proposed in this Letter, can probe dark-matter moduli with frequencies between 1 kHz and 1 GHz, with much better sensitivity than searches for fifth forces.

Kirchmair talk

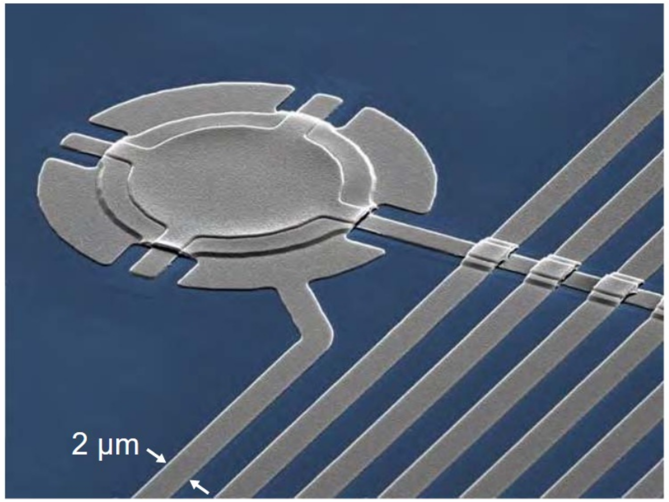








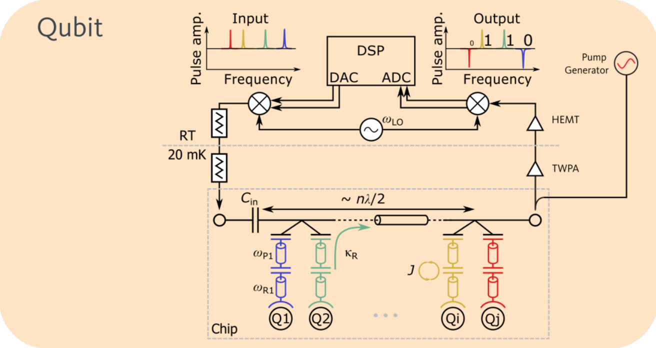
arXiv:1603.01553v3

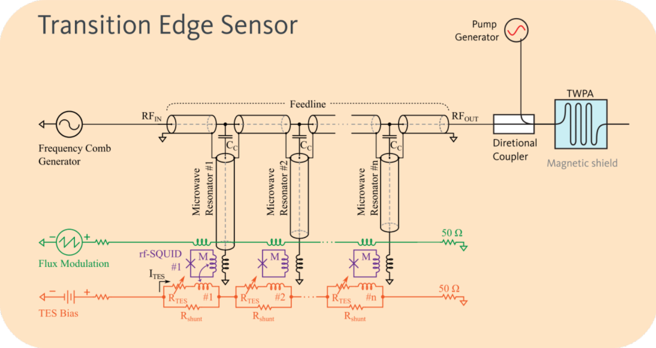


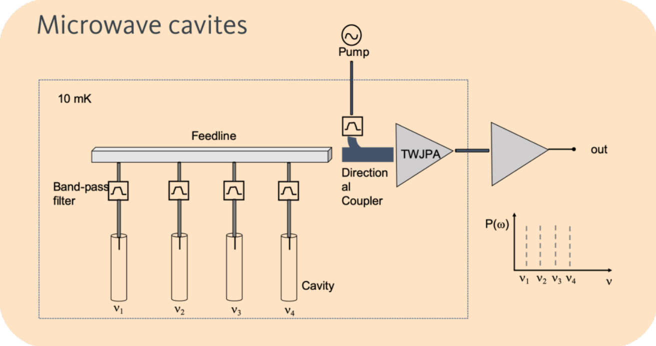
See Kirchmair talk

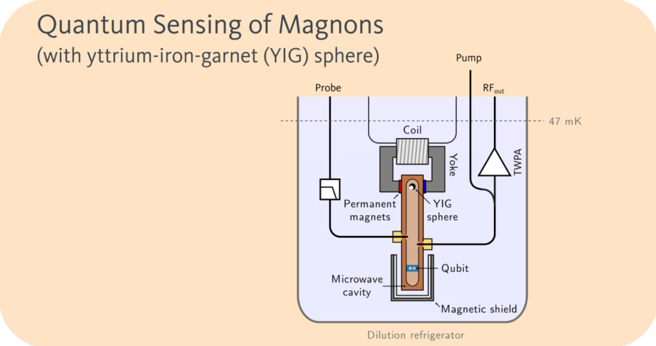
AMPLIFIERS

- M Faverzani



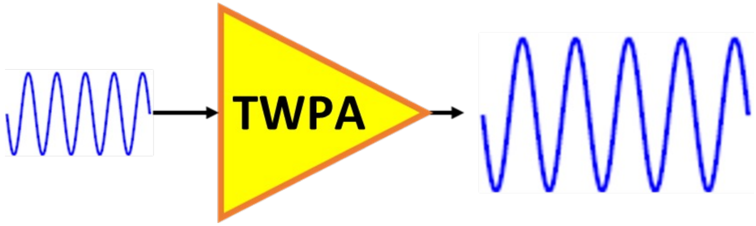


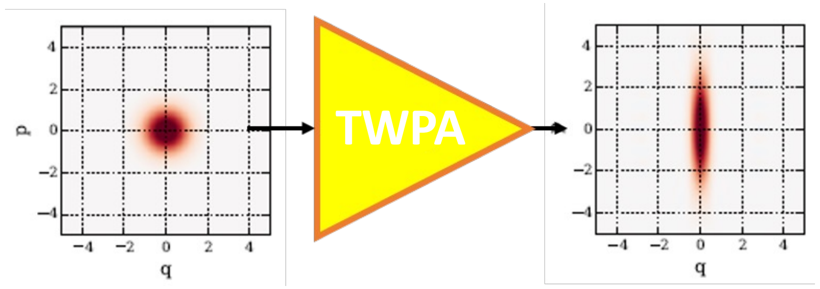




See talks by Guarcello, Faverzani, Granata, Enrico, Esposito

M Esposito





Microwave frequencies:

Quantum enhanced detection

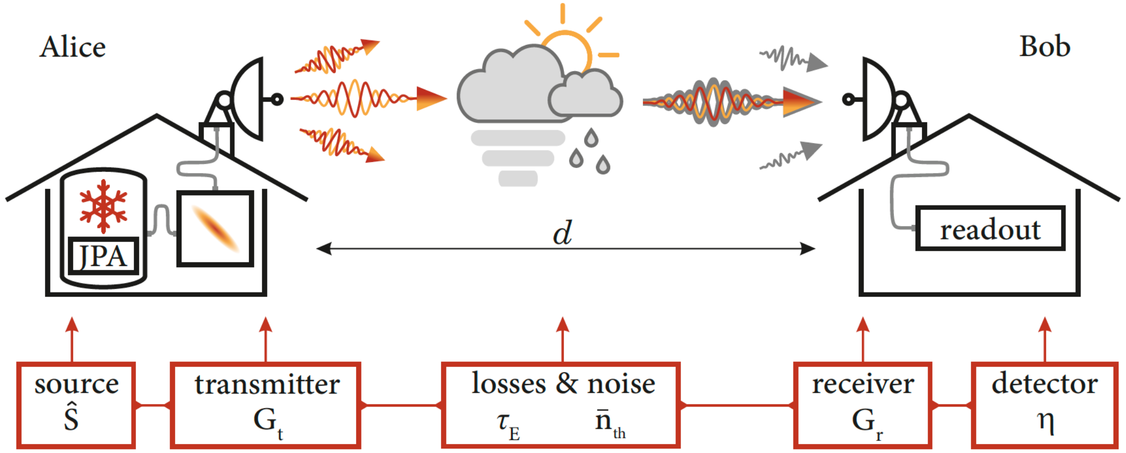
Squeezed Vacuum Used to Accelerate the Search for a Weak Classical Signal

M. Malnou, D. A. Palken, B. M. Brubaker, Leila R. Vale, Gene C. Hilton, and K. W. Lehnert
Phys. Rev. X **9**, 021023 – Published 3 May 2019; Erratum Phys. Rev. X **10**, 039902 (2020)

Article **nature**

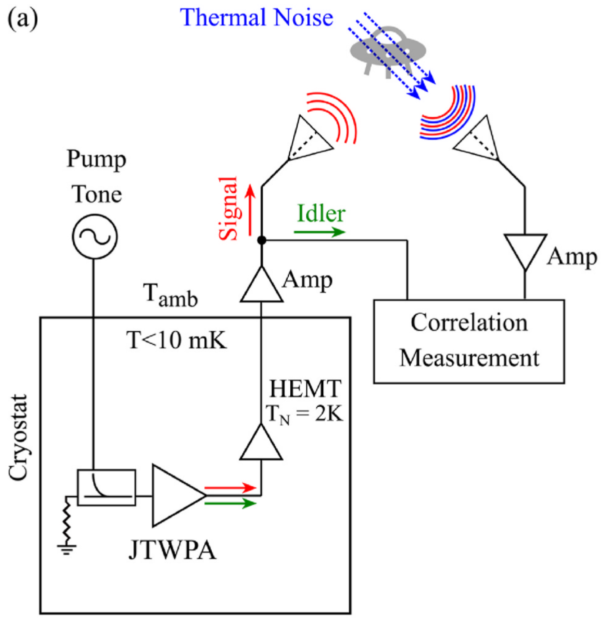
A quantum enhanced search for dark matter axions

K. M. Backes[1,6,✉], D. A. Palken[2,3,6], S. Al Kenany[4], B. M. Brubaker[2,3], S. B. Cahn[1], A. Droster[4], Gene C. Hilton[5], Sumita Ghosh[1], H. Jackson[4], S. K. Lamoreaux[1], A. F. Leder[4], K. W. Lehnert[2,3,5], S. M. Lewis[4], M. Malnou[2,5], R. H. Maruyama[1], N. M. Rapidis[4], M. Simanovskaia[4], Sukhman Singh[1], D. H. Speller[1], I. Urdinaran[4], Leila R. Vale[5], E. C. van Assendelft[1], K. van Bibber[4] & H. Wang[1]



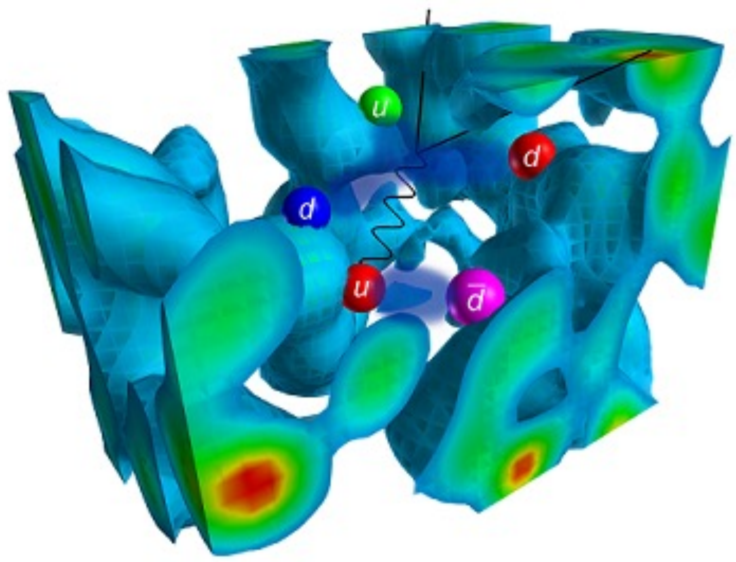
Microwave Quantum Communication

arXiv:2203.05530



Quantum Radar

Measurement: Sensors 18 (2021) 100349



Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981

Quantum Information

- “The physical world is quantum mechanical, and therefore the proper problem is the simulation of quantum physics”

SUPERCONDUCTING QUANTUM PROCESSOR

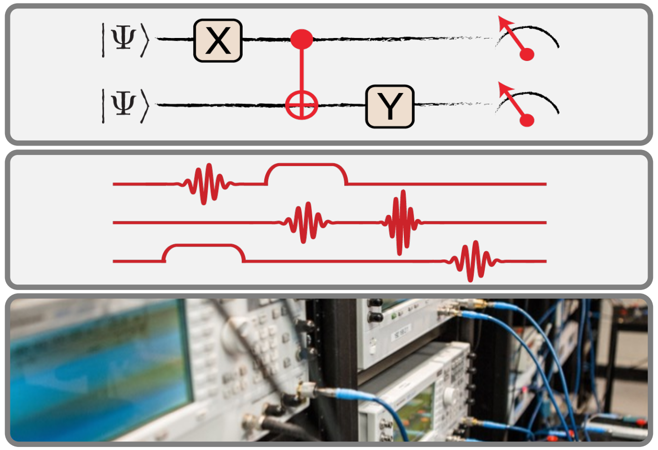
See talks by Corti, Tancredi, Preti

G Tancredi

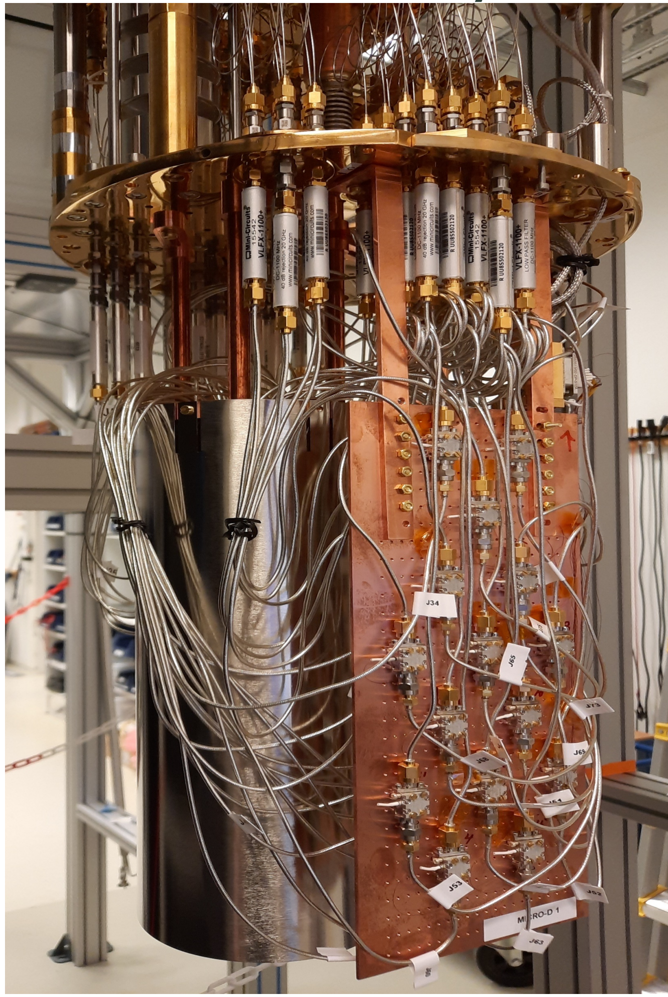
- A Swedish quantum computer
- Application to use cases within optimization and quantum chemistry
- Full stack HW and SW development
- Collaboration within EU Flagship

SW stack and FW

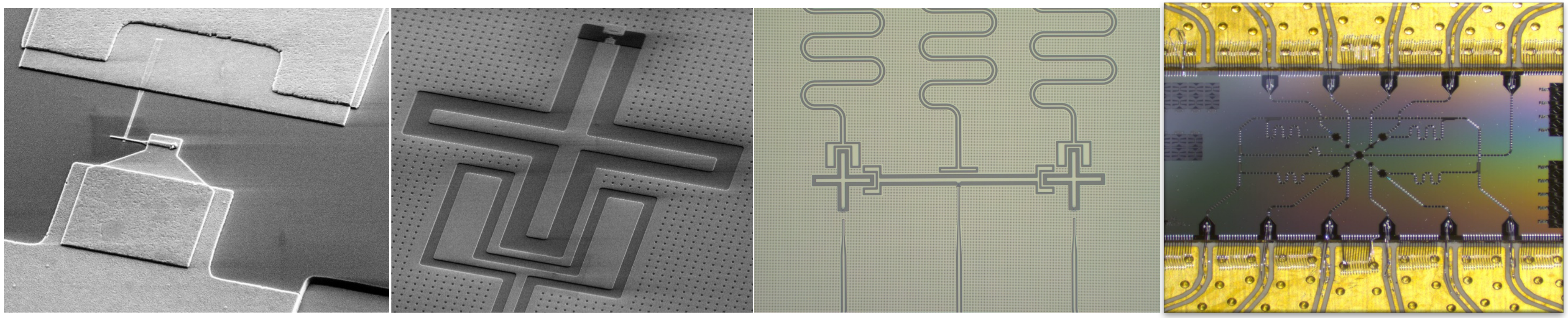
```
let shorCorrector (qs:Qubits) =
    let out = xflipSyndrome qs.[0 .. 2]
    if (out > 0) then
        X [qs.[out - 1]]
```



Measurement system

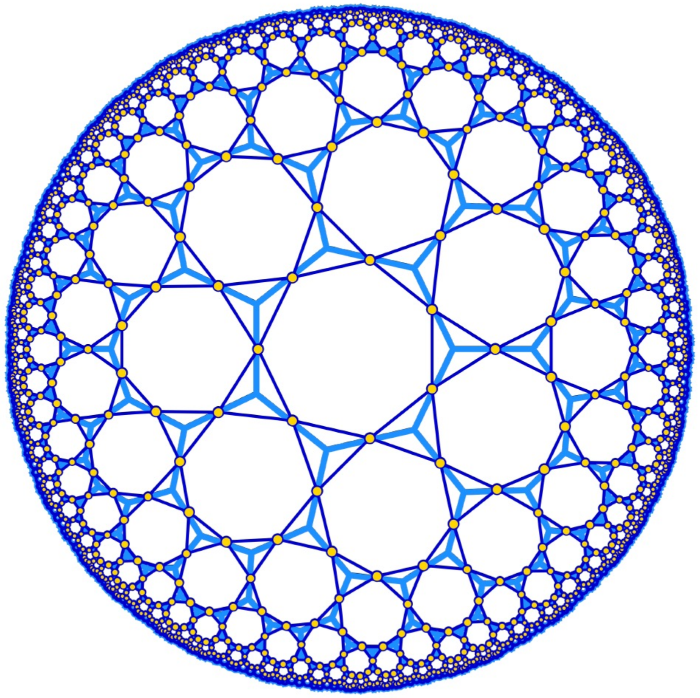


Quantum HW

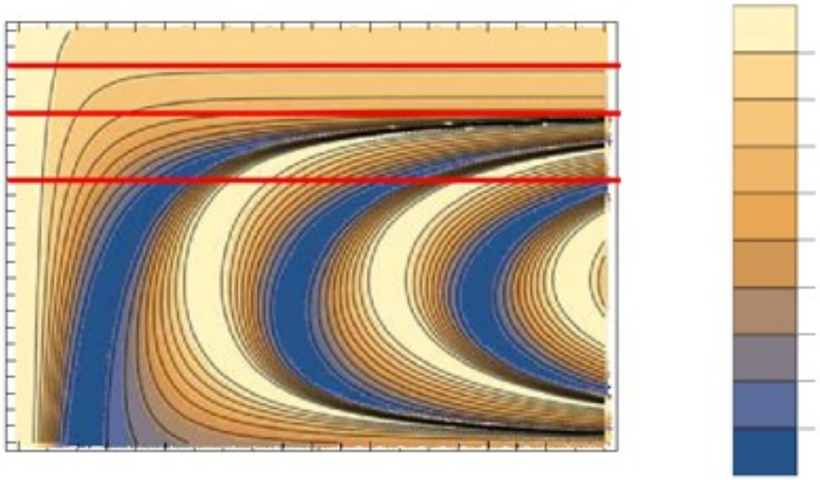


ANALOGUES

Non Euclidean Geometries

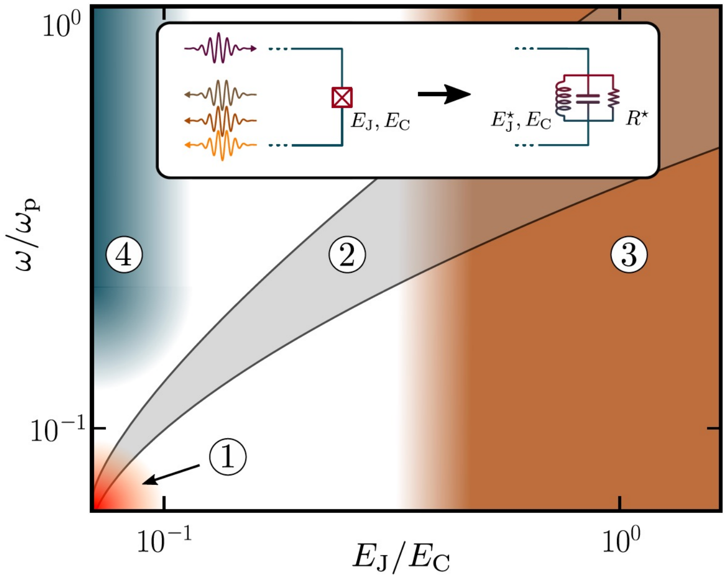


Violations of discrete symmetries such as Charge and Parity Conjugation and Time Reversal



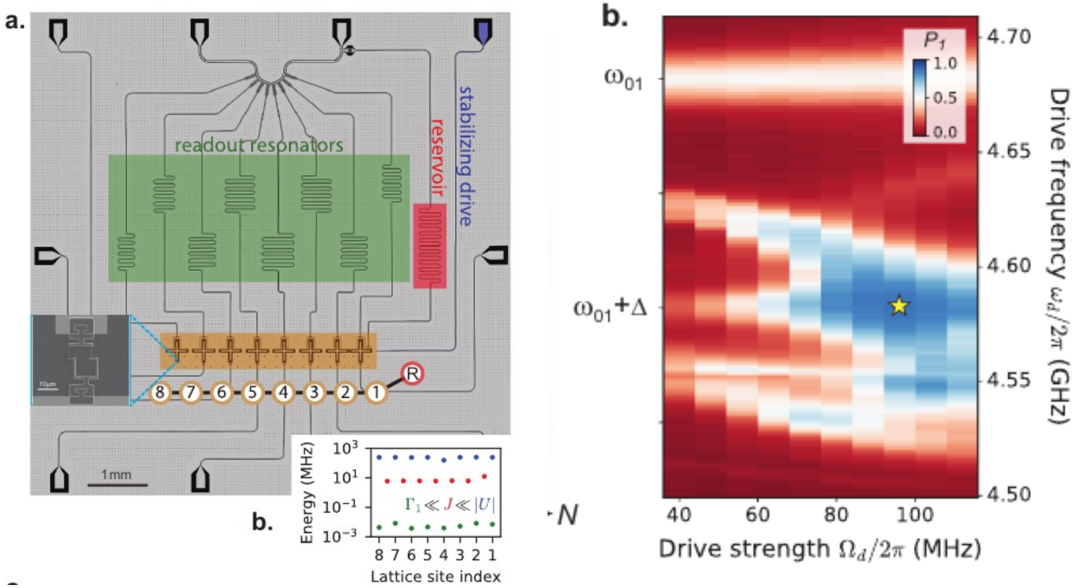
PT violation

Many body effects

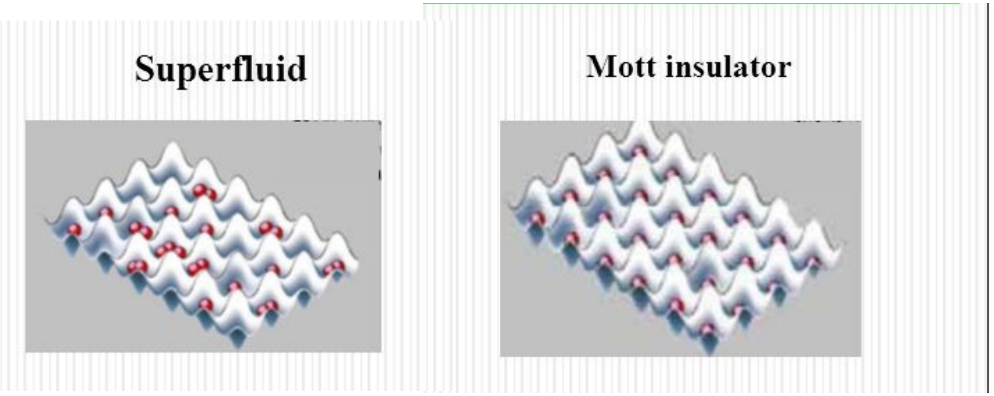


See talks by Kollar, Roch, Paraoanu, Crescini, Rastelli

Future challenges: Quantum fluids of light in arrays of cavities/qubits



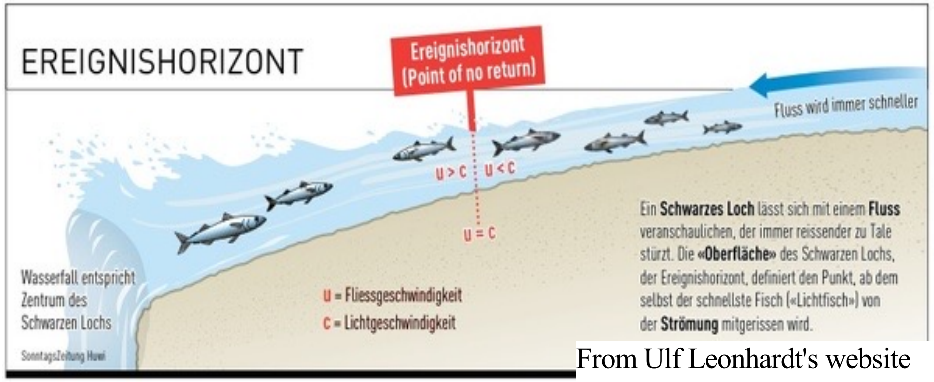
First expt: Ma *et al.* Nature 2019



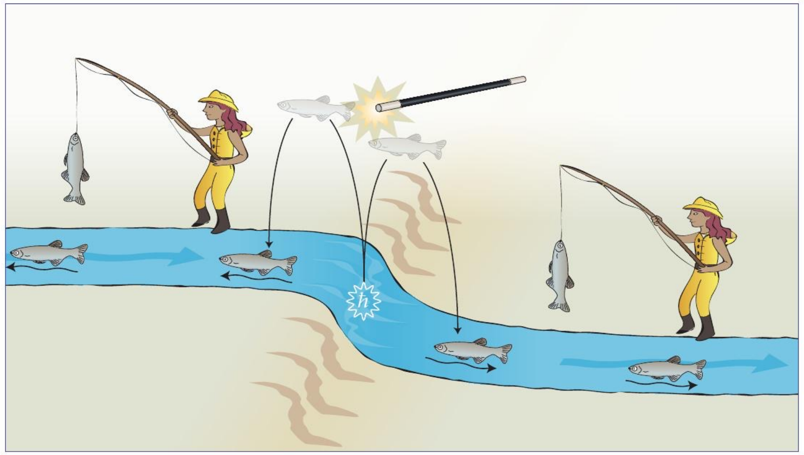
Mott insulator of impenetrable photons – all the contrary we have learnt in undergrad e.m.

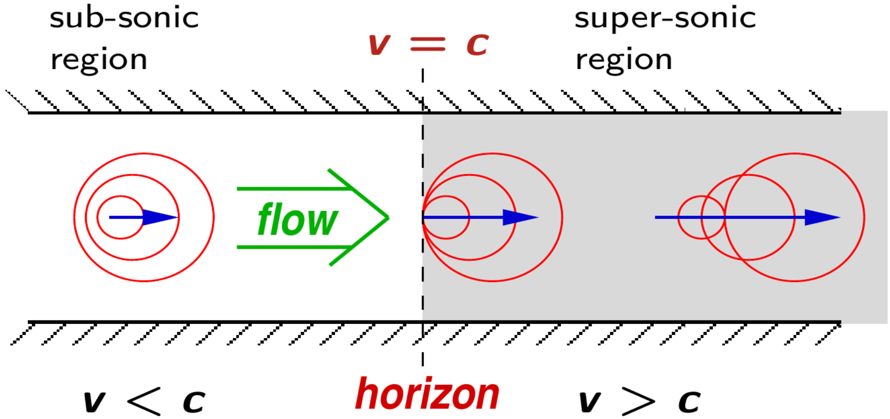
Review: IC,… A. J. Kollar, … Photonic materials in circuit QED, Nature Physics 2020

<u>Future challenges:</u> analog gravity, a.k.a. quantum simulation of QFTs on curved space-time



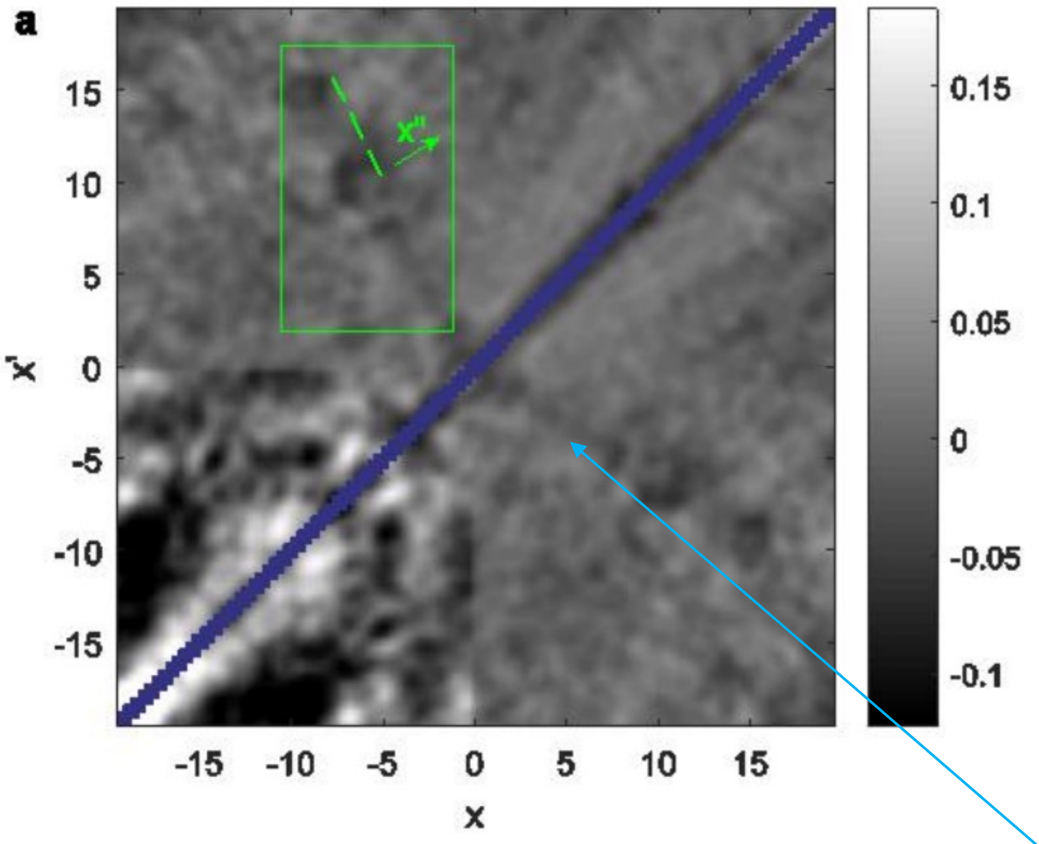
From Ulf Leonhardt's website



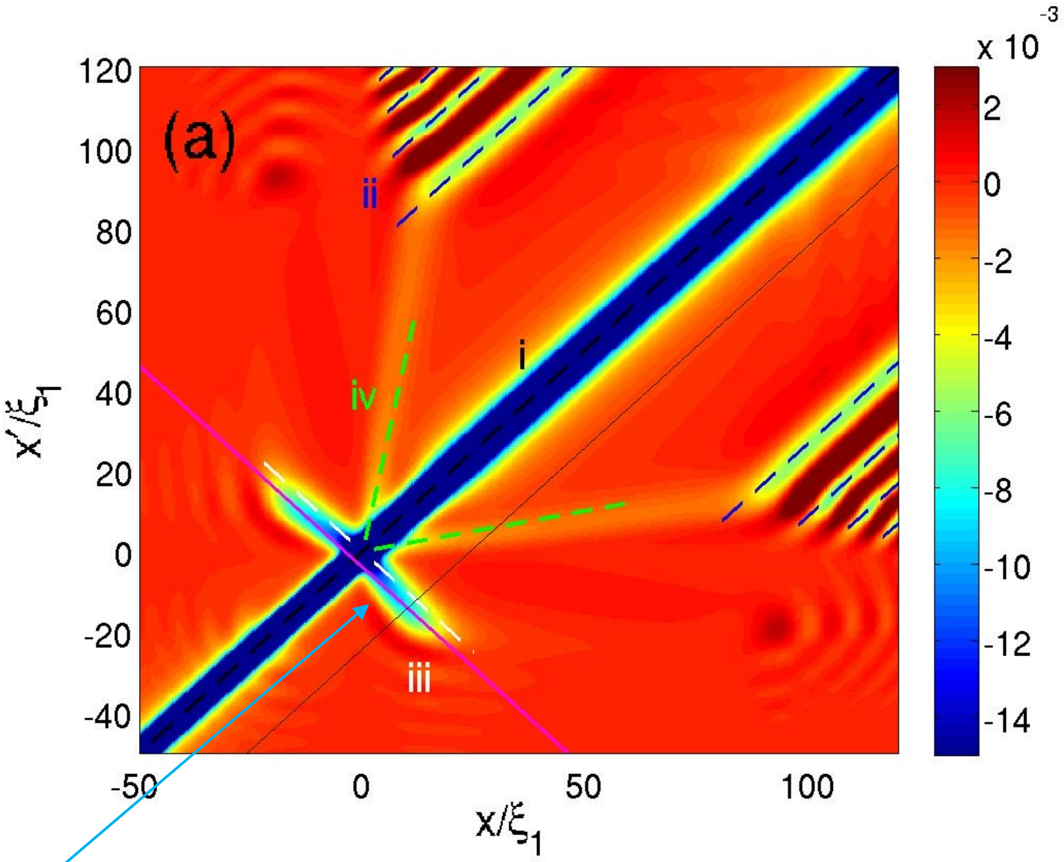


Quantum emission of fish via Hawking mechanism ?

Quantum emission of phonon from the sub- to super-sonic horizon in flowing fluid ?



Expt: Steinhauer Nat. Phys. '16

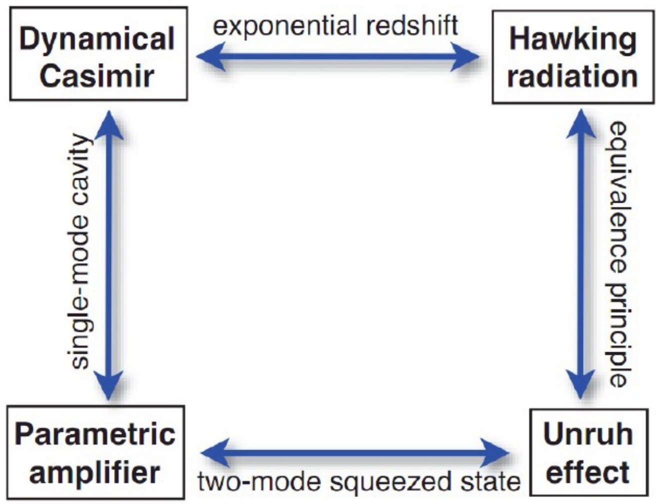


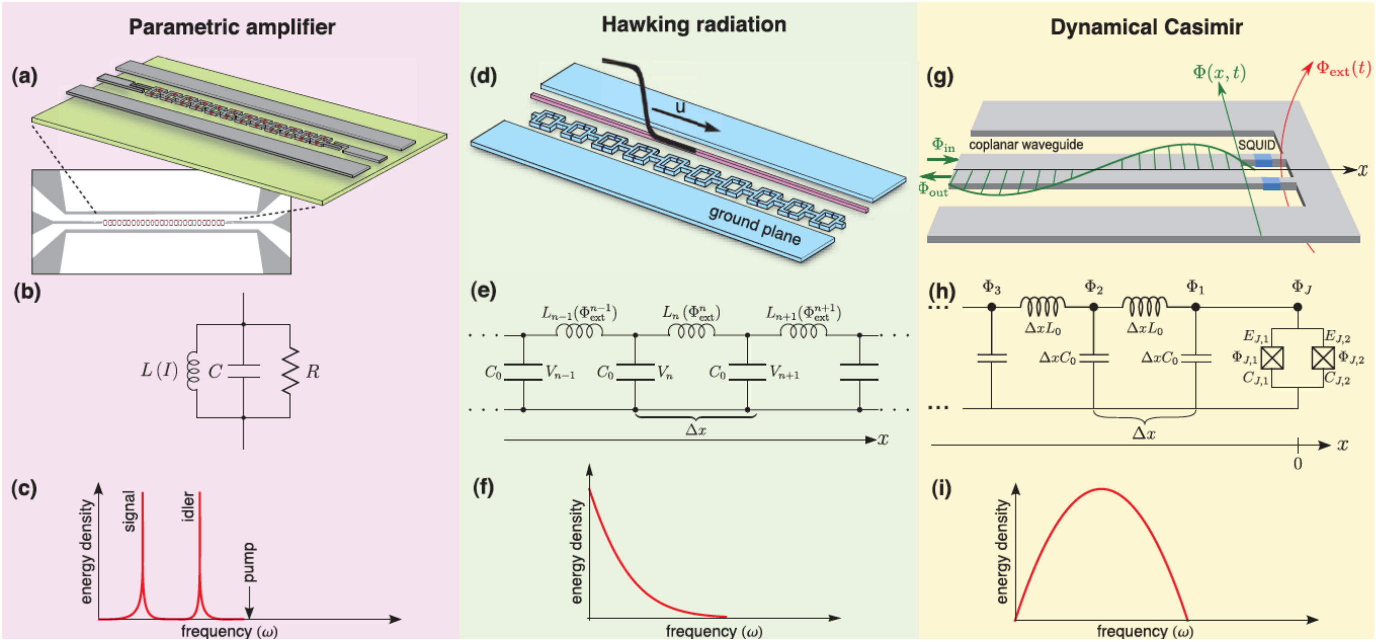
Theory: IC et al., NJP 2008

Balbinot-Fabbri moustache

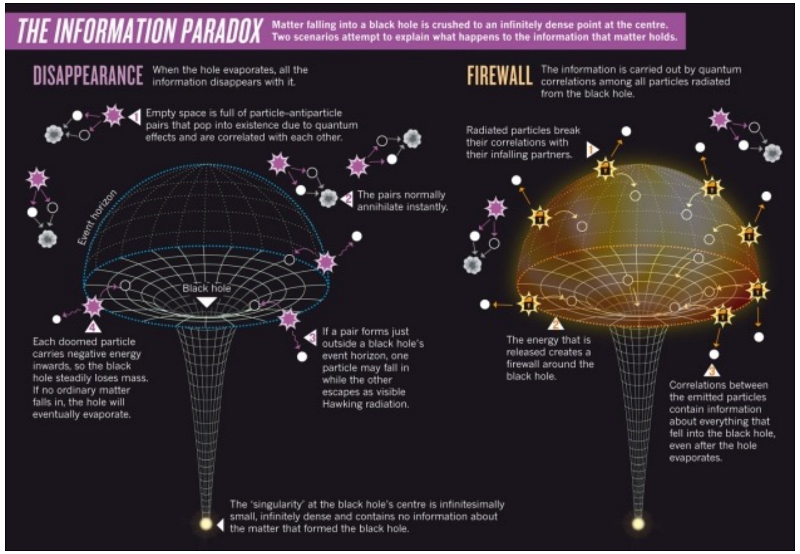
IN SUPERCONDUCTOR SYSTEMS

- REVIEWS OF MODERN PHYSICS, VOLUME 84, JANUARY–MARCH 2012



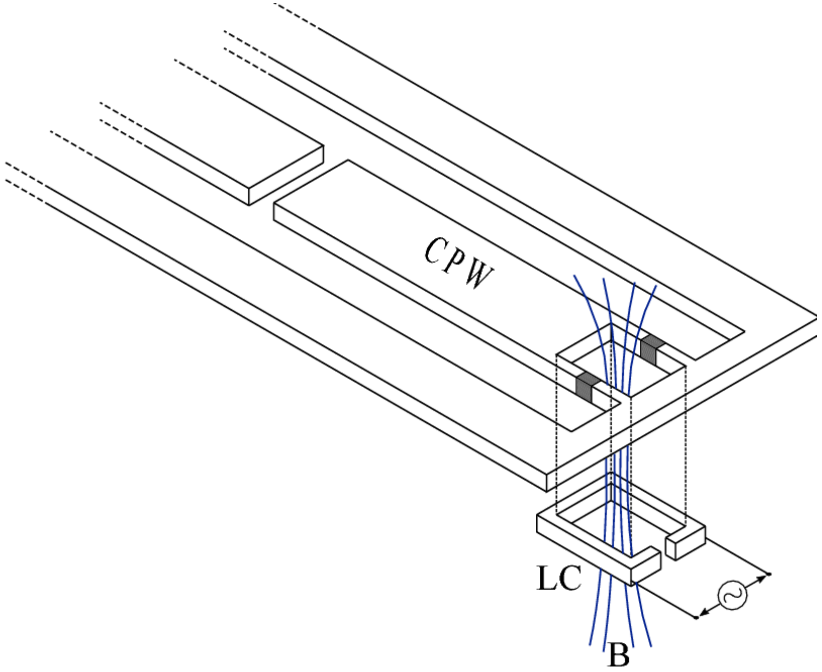


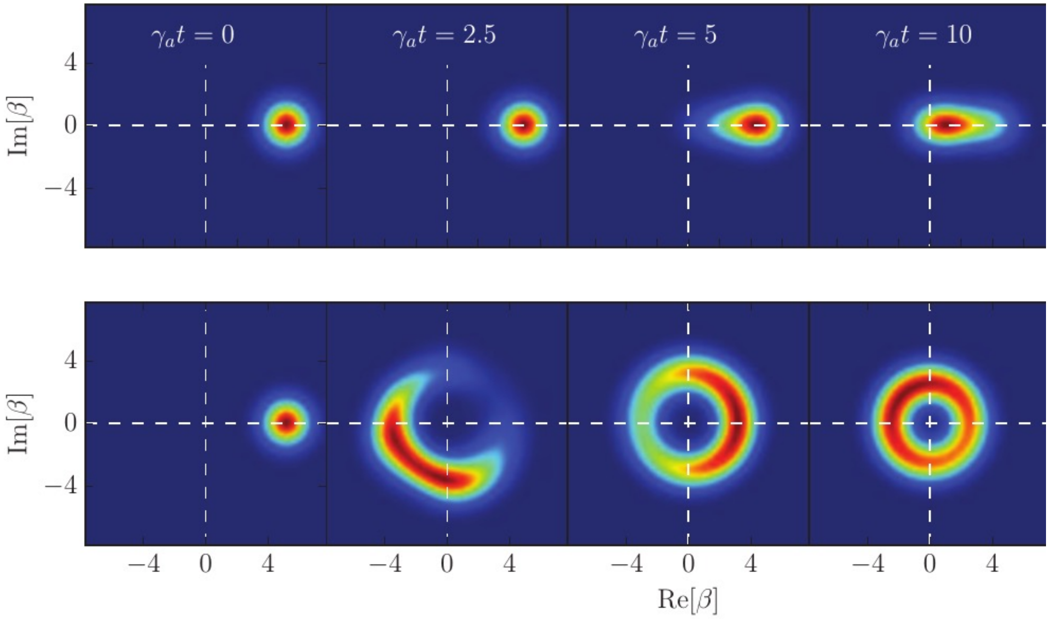
Expts. Wilson-Delsing & Paraoanu



<u>Big question:</u> what is long-time fate of a BH ?

Baby toy model: friction force on dynamical Casimir emission
(extends Wilson-Delsing & Paraoanu's expts)





S. G. Butera & IC, *Quantum fluctuations of the friction force induced by the dynamical Casimir emission*, EPL 128, 24002 (2020).

Workshop Round Table

- Which are the recent advances in these fields?
- What are the offered possibilities?
- What kind of physics can be explored through circuit engineering?
- Which are the future technologies for fundamental and applied physics?
- ….