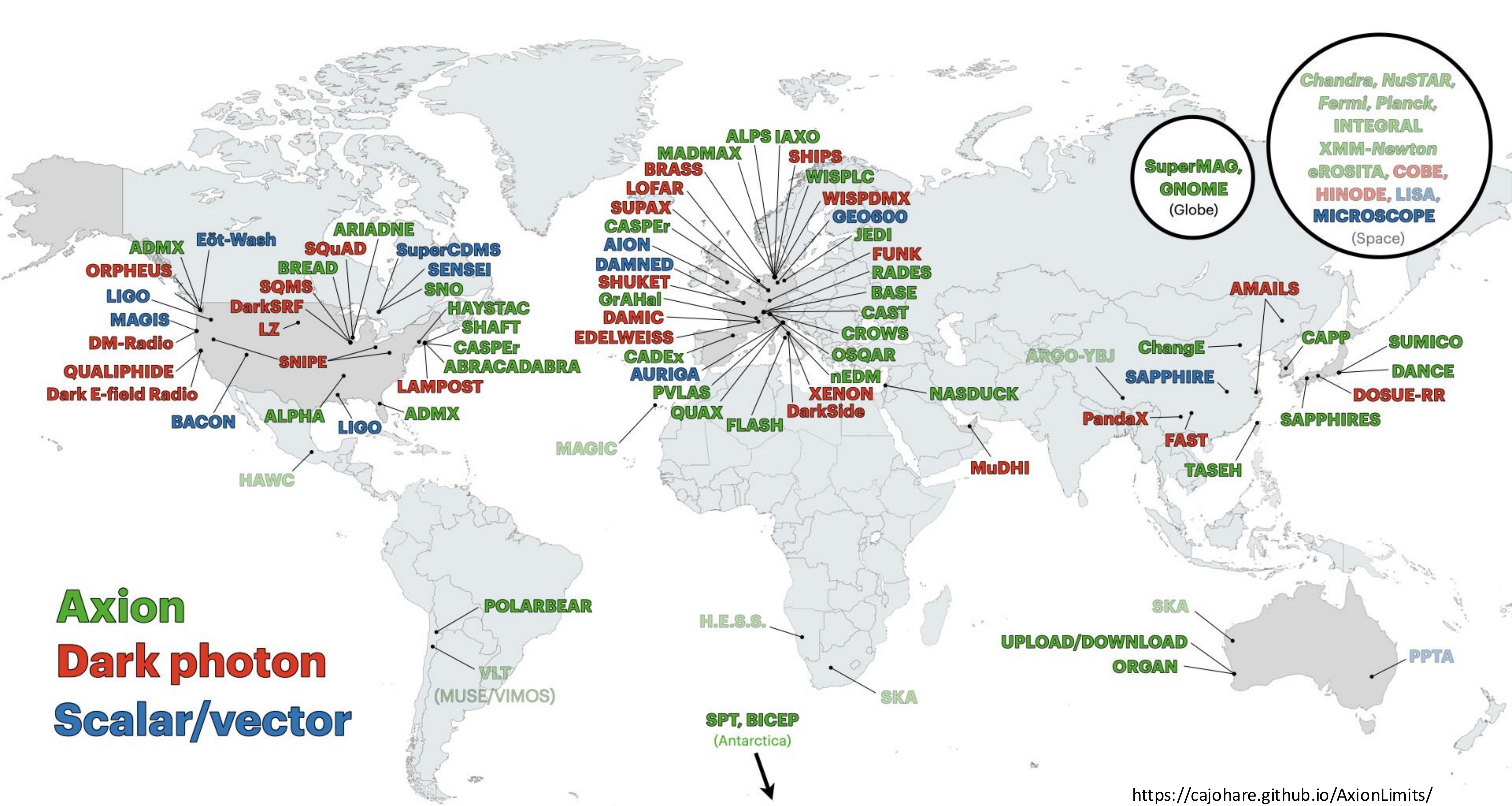
AXION Searches at INFN

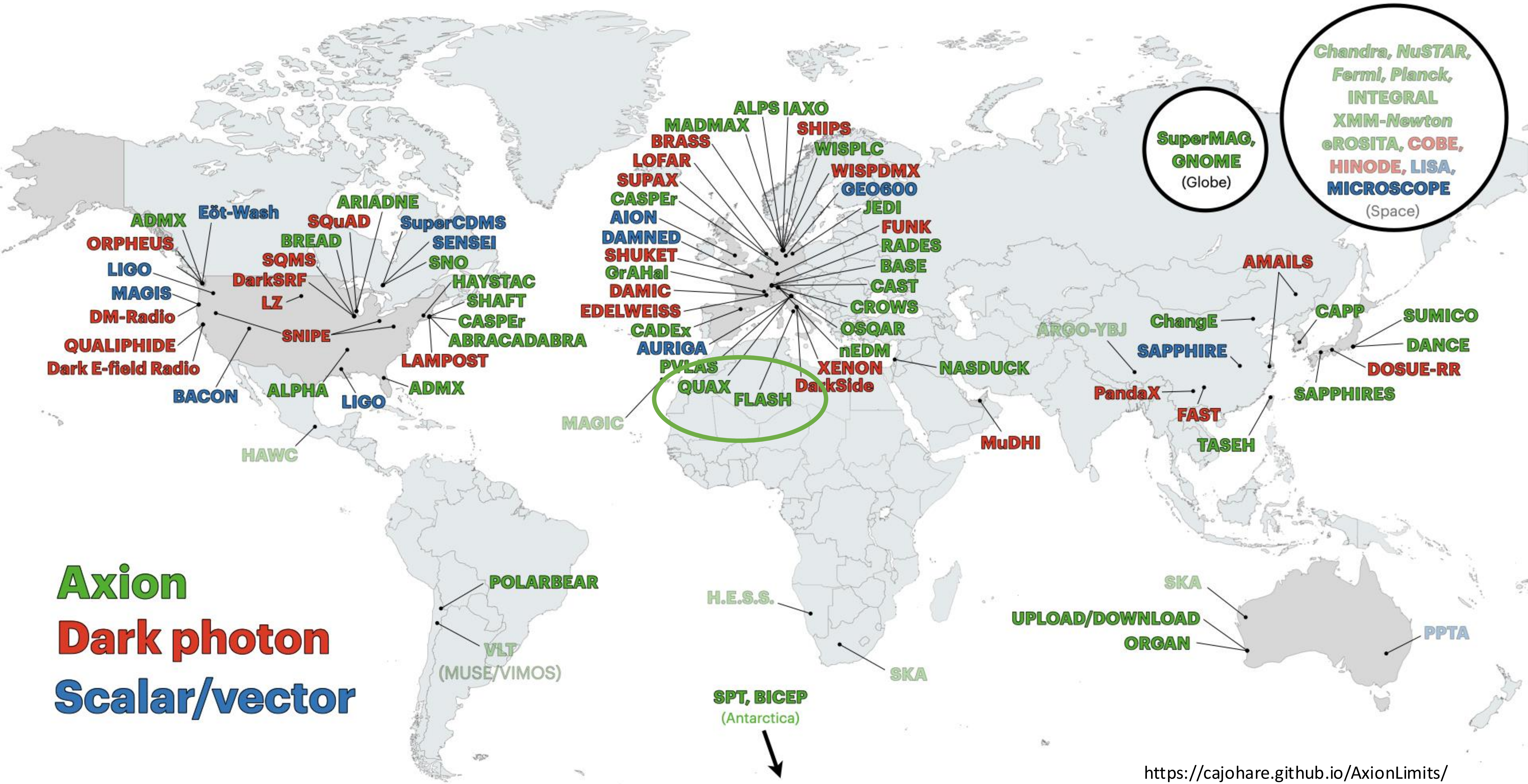
Claudio Gatti

Laboratori Nazionali di Frascati - INFN

Institute for Basic Science (IBS) in Daejeon, Korea 2-6 December 2024



https://cajohare.github.io/AxionLimits/



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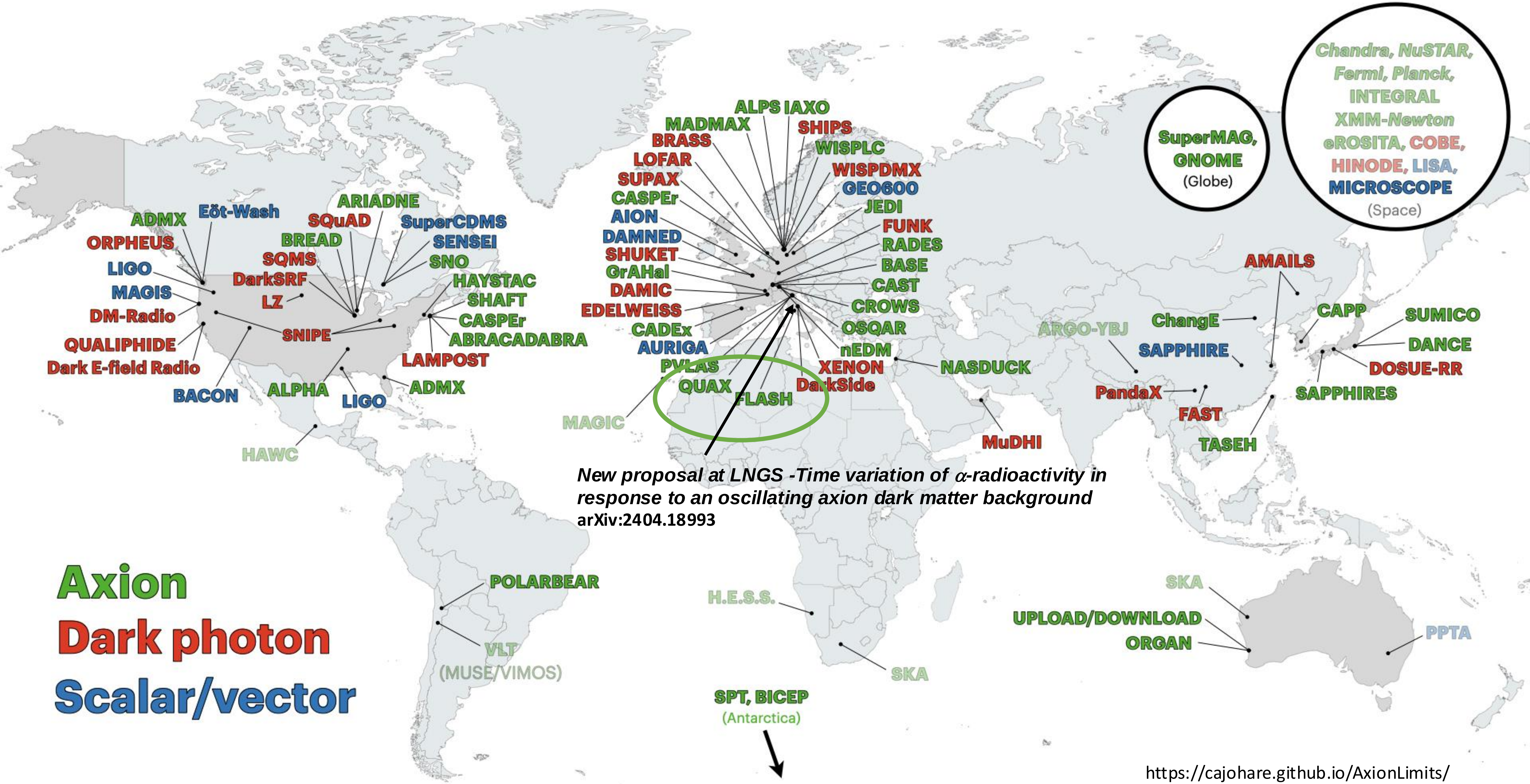


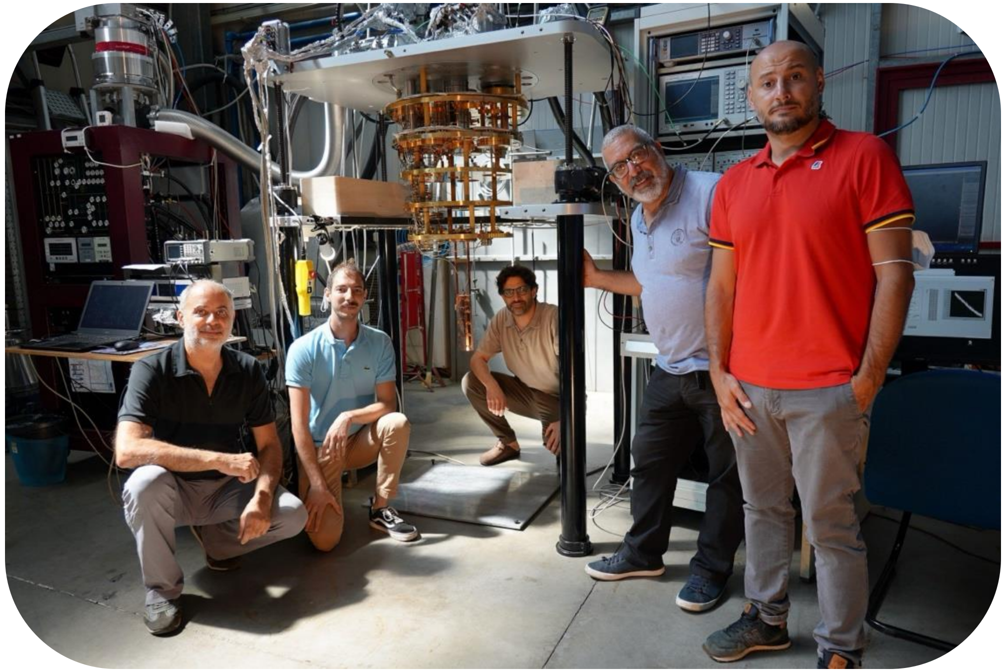
New proposal at LNGS -Time variation of α-radioactivity in response to an oscillating axion dark matter background
arXiv:2404.18993

https://cajohare.github.io/AxionLimits/

QUAX

Laboratori Nazionali di Legnaro (LNL)

Laboratori Nazionali di Frascati (LNF)



COLD@LNF

CryOgenic Laboratory for Detectors:

- Axion Dark Matter Experiments
- Quantum Sensing with Superconducting Devices
- Type II and HTC Superconducting Cavities

CA 21106

ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

Qub-IT

SAMARA

NQSTI National Quantum Science and Technology Institute

DART WARS

Resilience

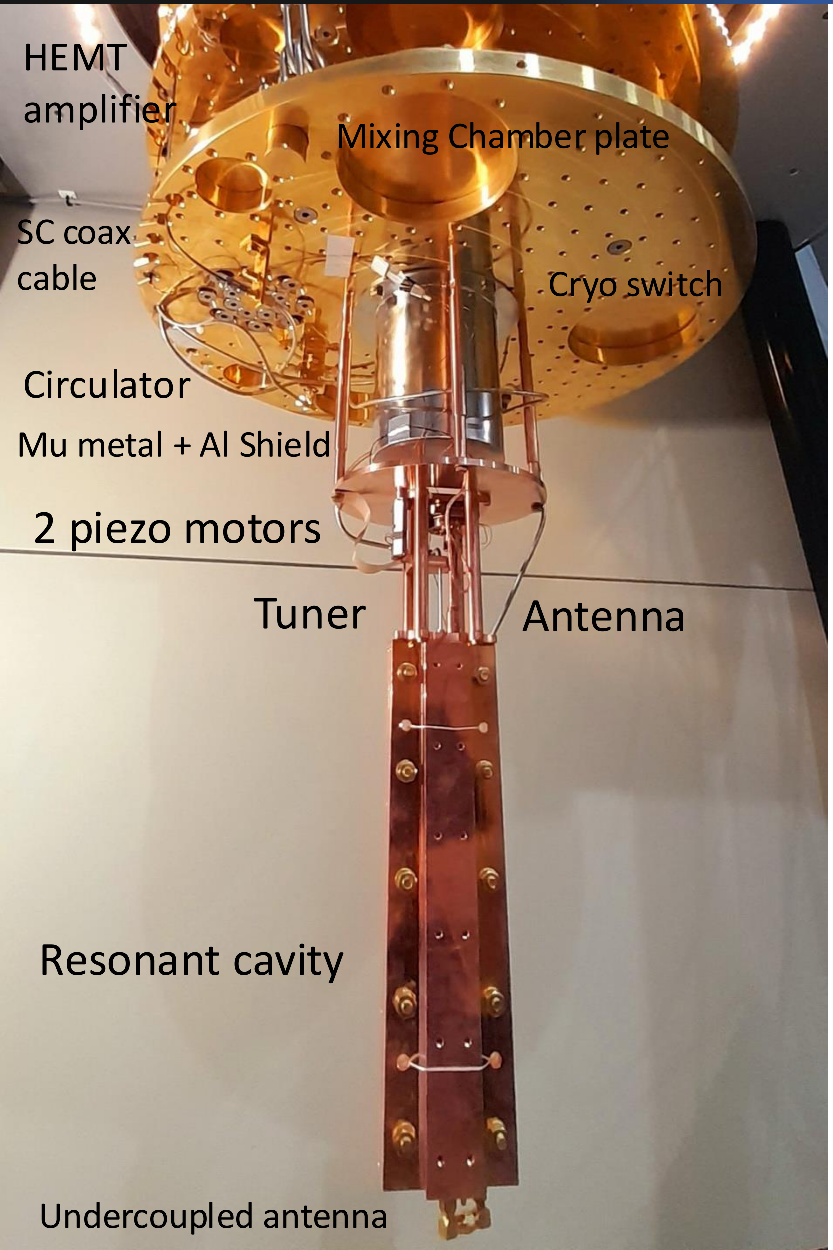
SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

SUPERGALAX

FET H2020

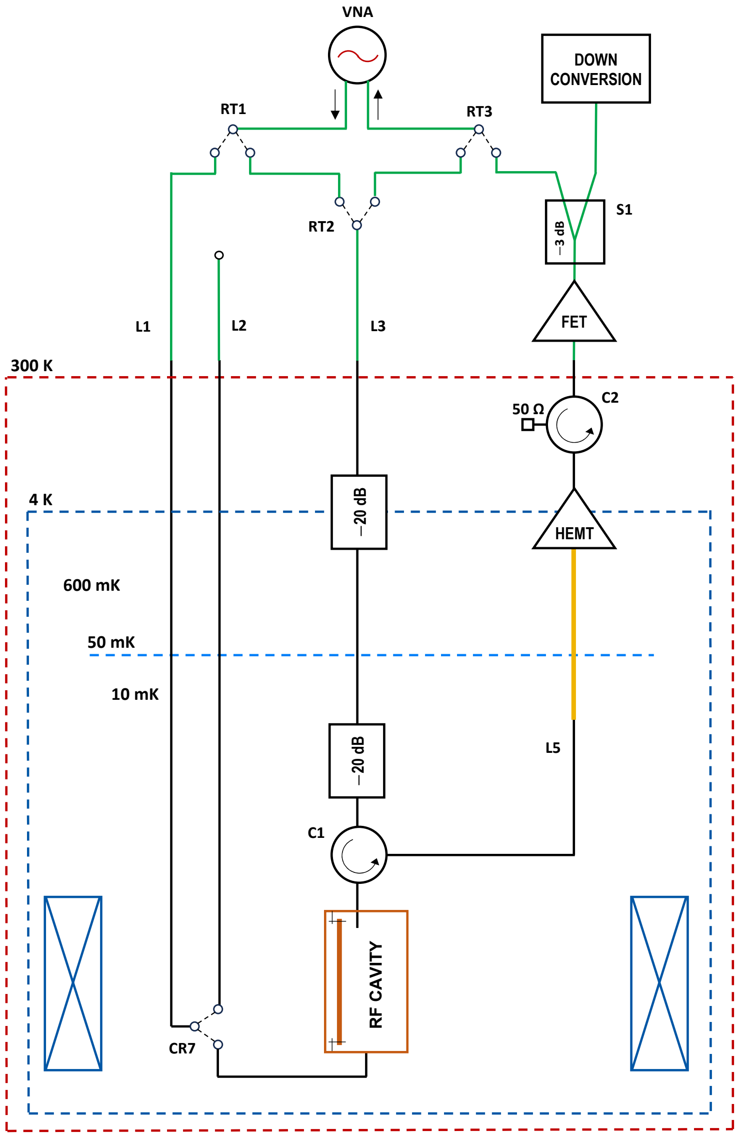
PRIN IronMoon

QUAX@LNF: The LNF Axion Haloscope

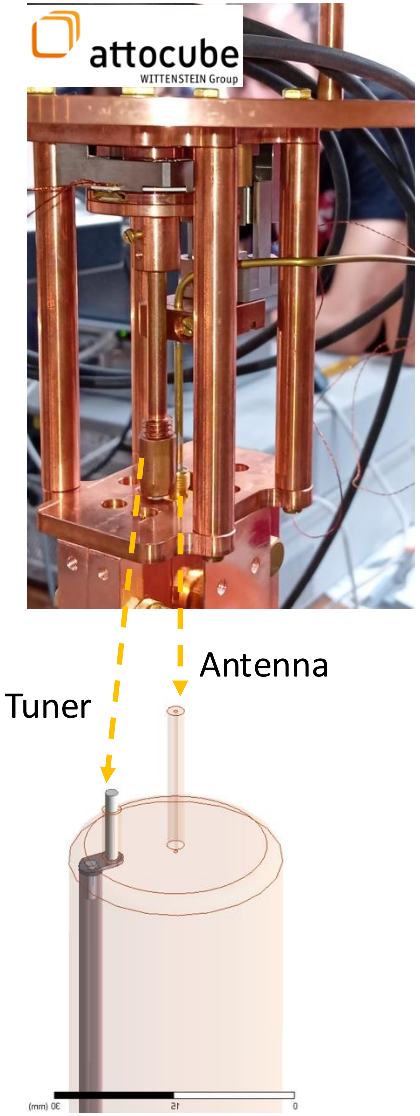


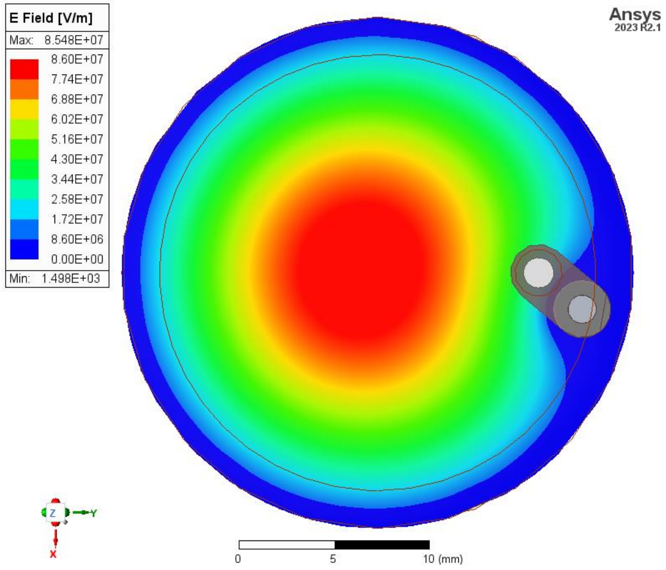
December 2023 Run

- Cavity temperature 30 mK
- Magnetic Field B=8 T
- Frequency 8.8 GHz
- Copper cavity Q_0=50,000 with tuner
- HEMT amplifier
- Tnoise 4K
- 2 weeks data taking
- 6 MHz scan

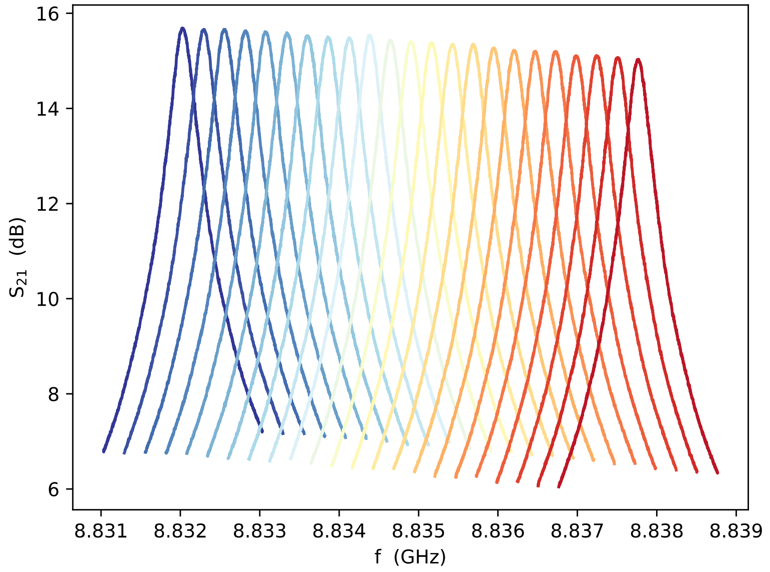


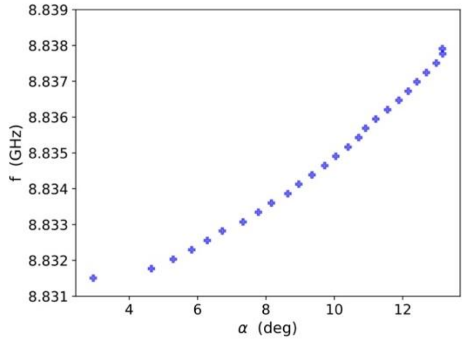
Cavity Tuning

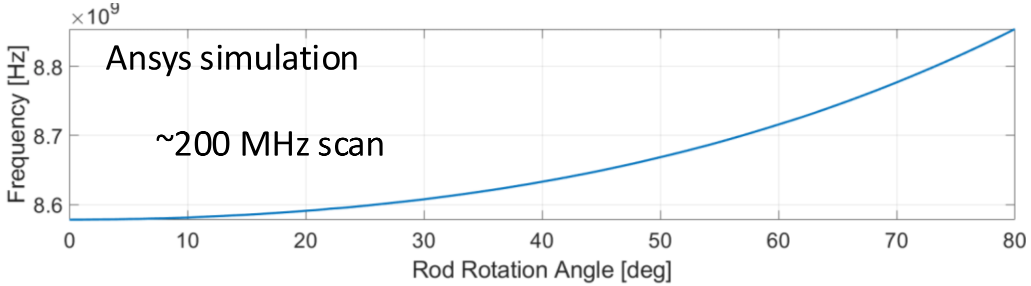




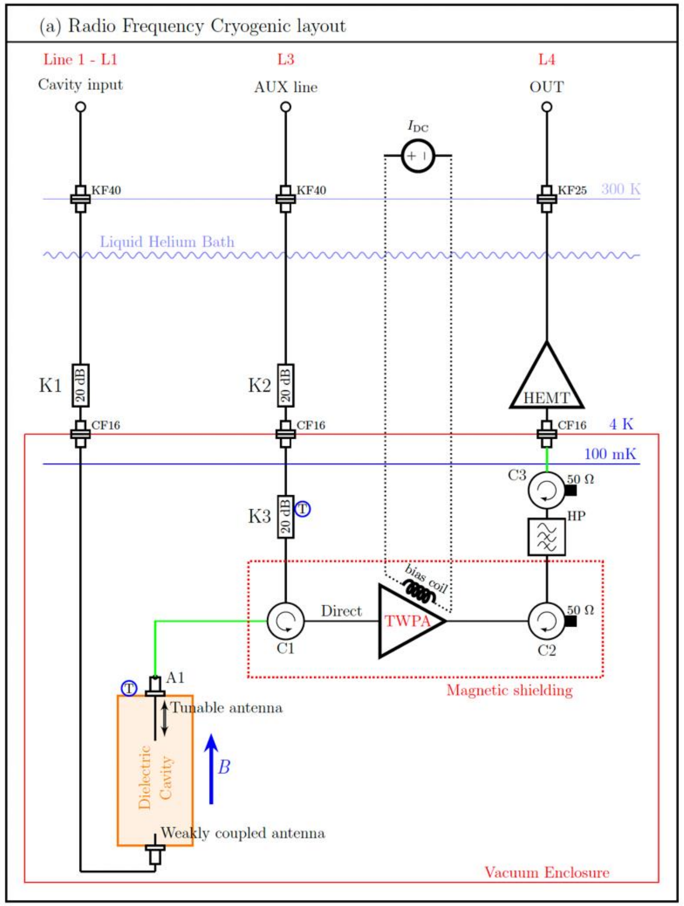
6 MHz of frequency scan



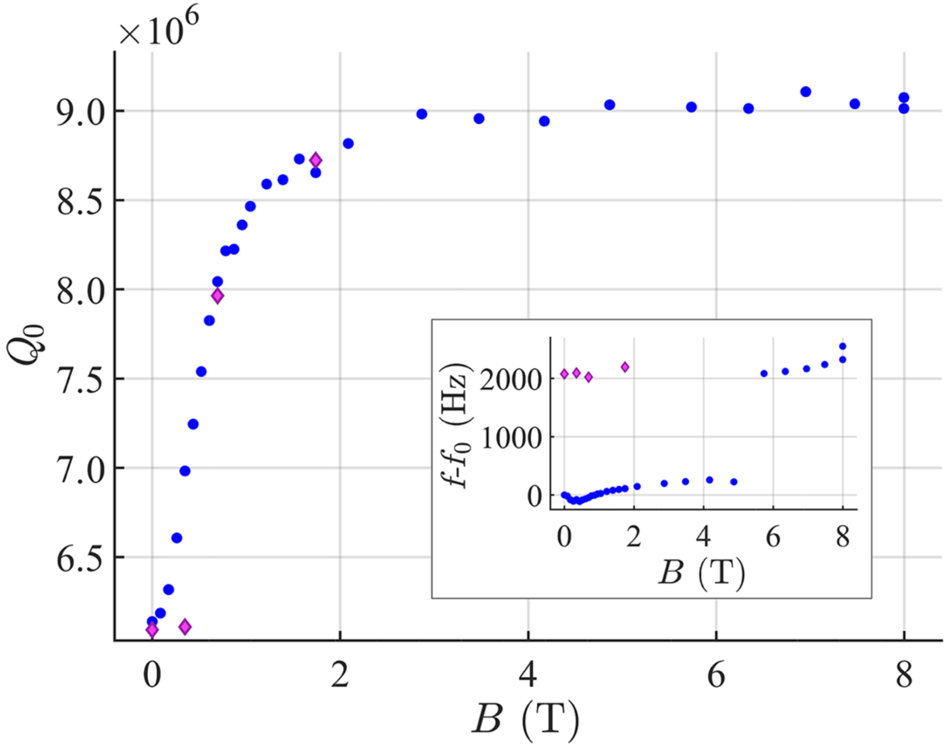




The QUAX@LNL Haloscope



- B=8 T
- Dilution Refrigerator
- Tcavity 110 mK
- TWPA
- T_{noise}=2 K
- Dielectric Cavity
- Sapphire tuner
- Q=2.5×10^5
- VC_{030}=0.034 L

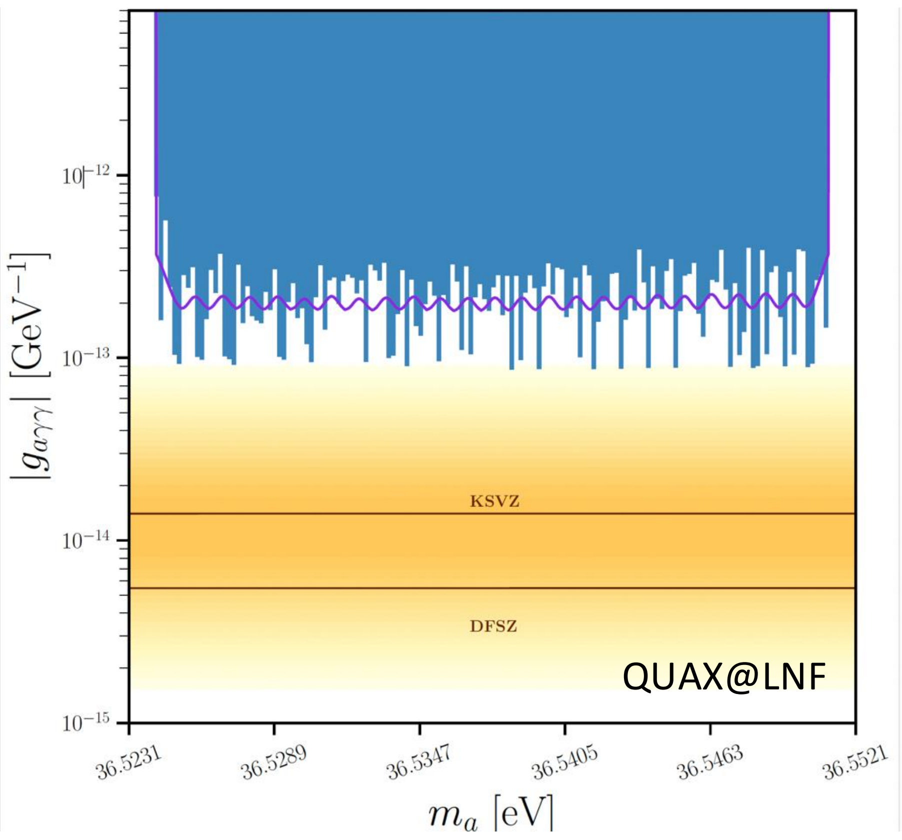


PHYSICAL REVIEW APPLIED 17, 054013 (2022)

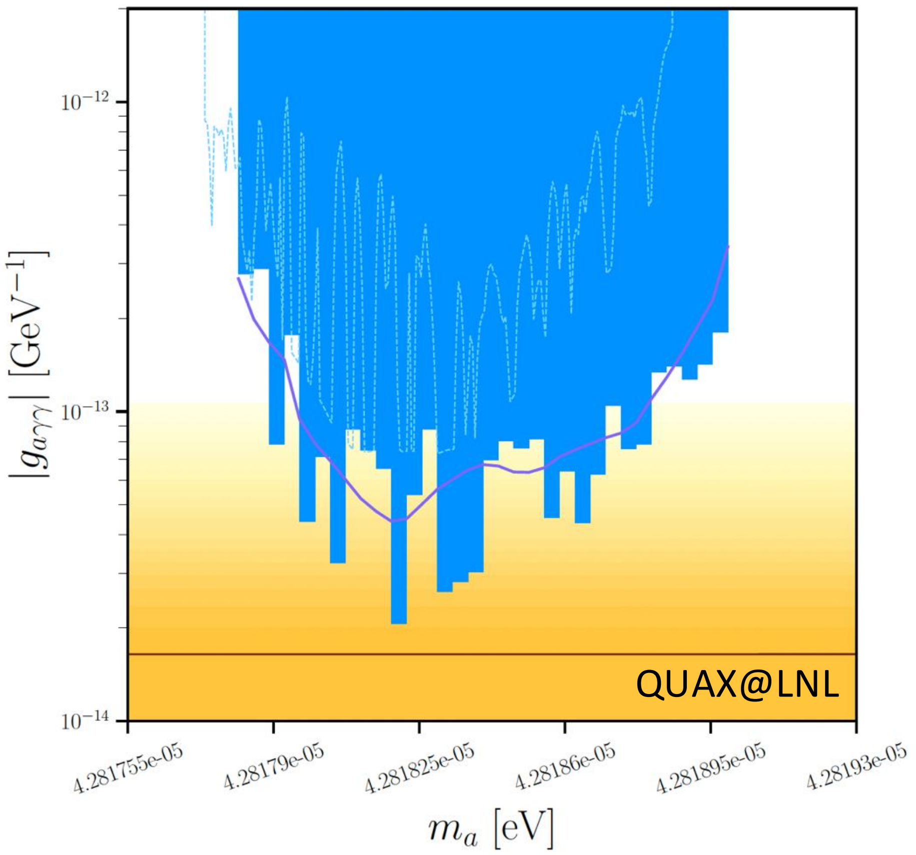
Search for galactic axions with a traveling wave parametric amplifier
PHYSICAL REVIEW D 108, 062005, arXiv:2304.7505 (2023)

QUAX Results for 2022 and 2023 Runs

- 24 runs, 1 hour each, 250 kHz of frequency steps
- Average exclusion 90% c.l. $g_{a\gamma\gamma} = 2 \times 10^{-13}\ GeV^{-1}$
- Phys. Rev. D 110, 022008 (2024)



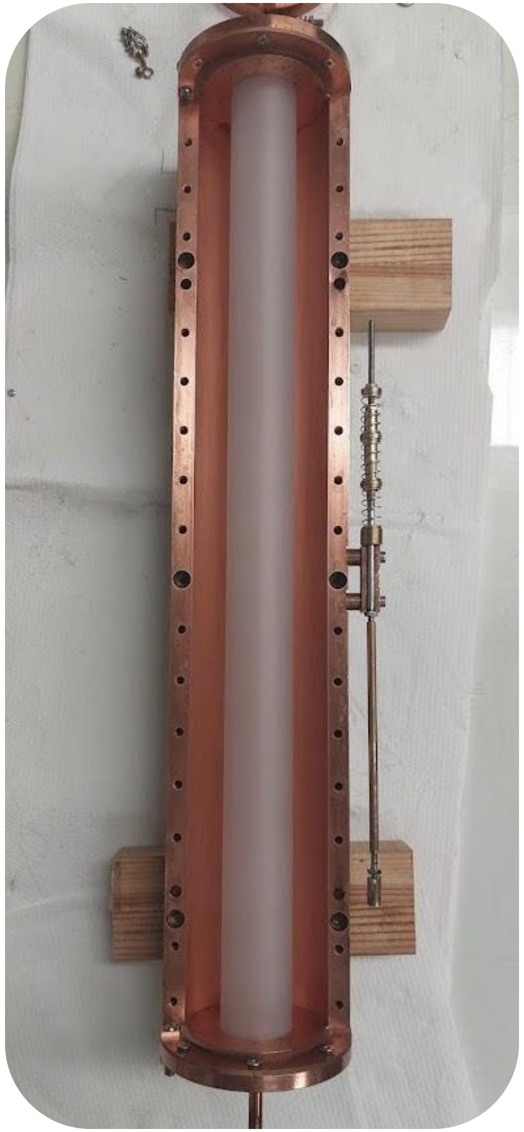
- 10 runs, 1 hour each, 30 kHz of frequency steps
- Average exclusion 90% c.l. $g_{a\gamma\gamma} = 4 \times 10^{-13}\ GeV^{-1}$
- Phys. Rev. D 108, 062005 (2023)



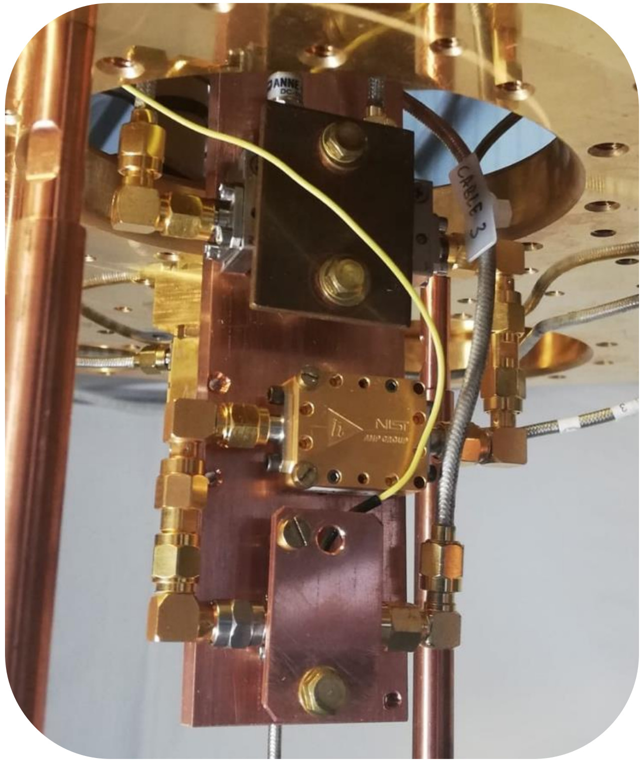
QUAX Upgrades

LNL:
Single-shell dielectric resonator with its axion-sensitive pseudo-TM030

arXiv:2410.07774



LNF:
Added a JPA from NIST as first stage amplification



NIST

SQMS
SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

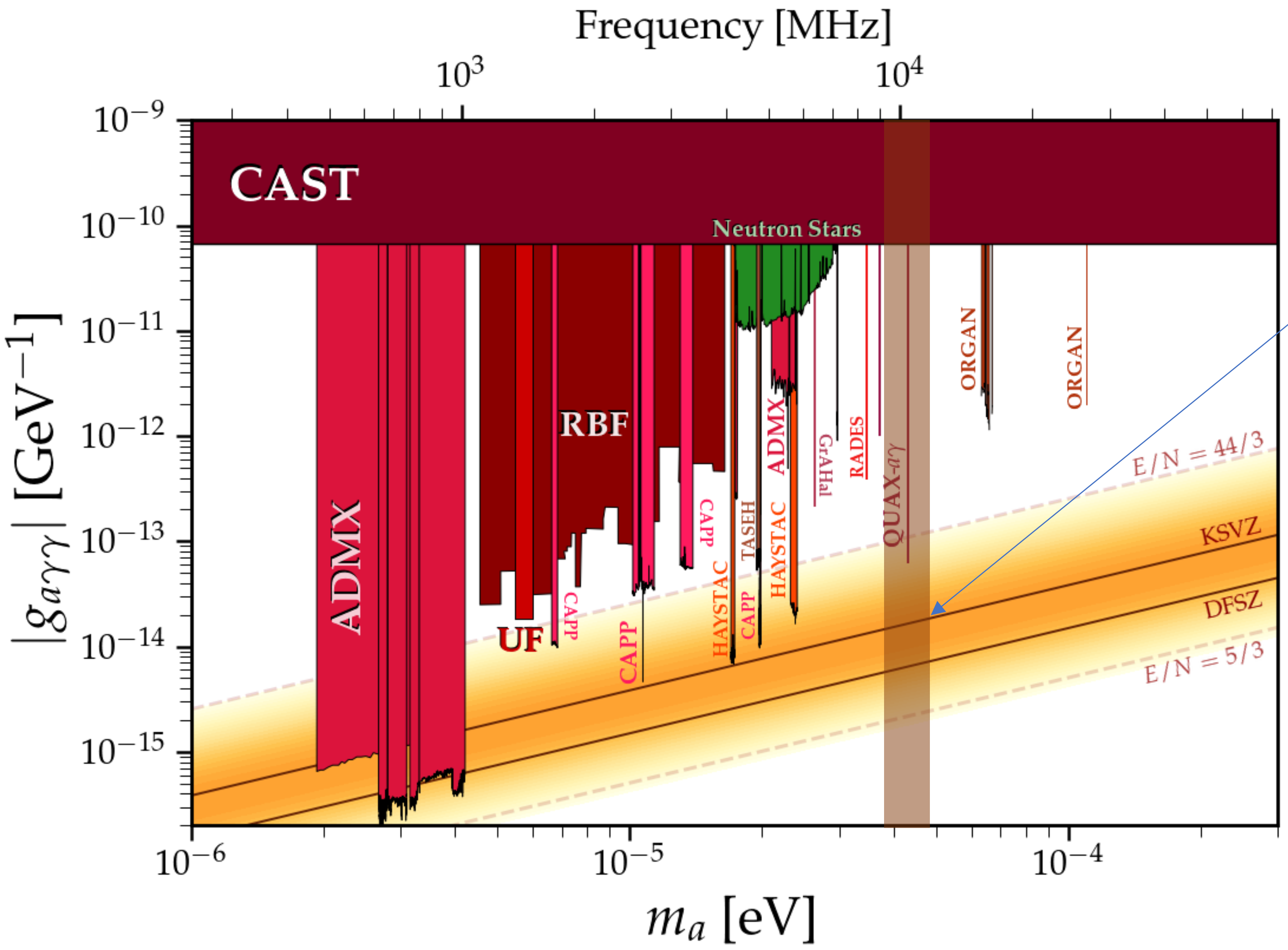
QUAX LNF&LNL Next Years

LNF:

- Superconducting cavity $Q_0 > 2\times10^5$
- B=9T
- Multicavity

LNL:

- Dielectric cavity $Q_0 > 10^6$
- B=14 T
- Single cavity



Next years with noise at Quantum Limit

https://cajohare.github.io/AxionLimits/

QUAX LNF&LNL Next Years

LNF:

- Superconducting cavity $Q_0 > 2\times10^5$
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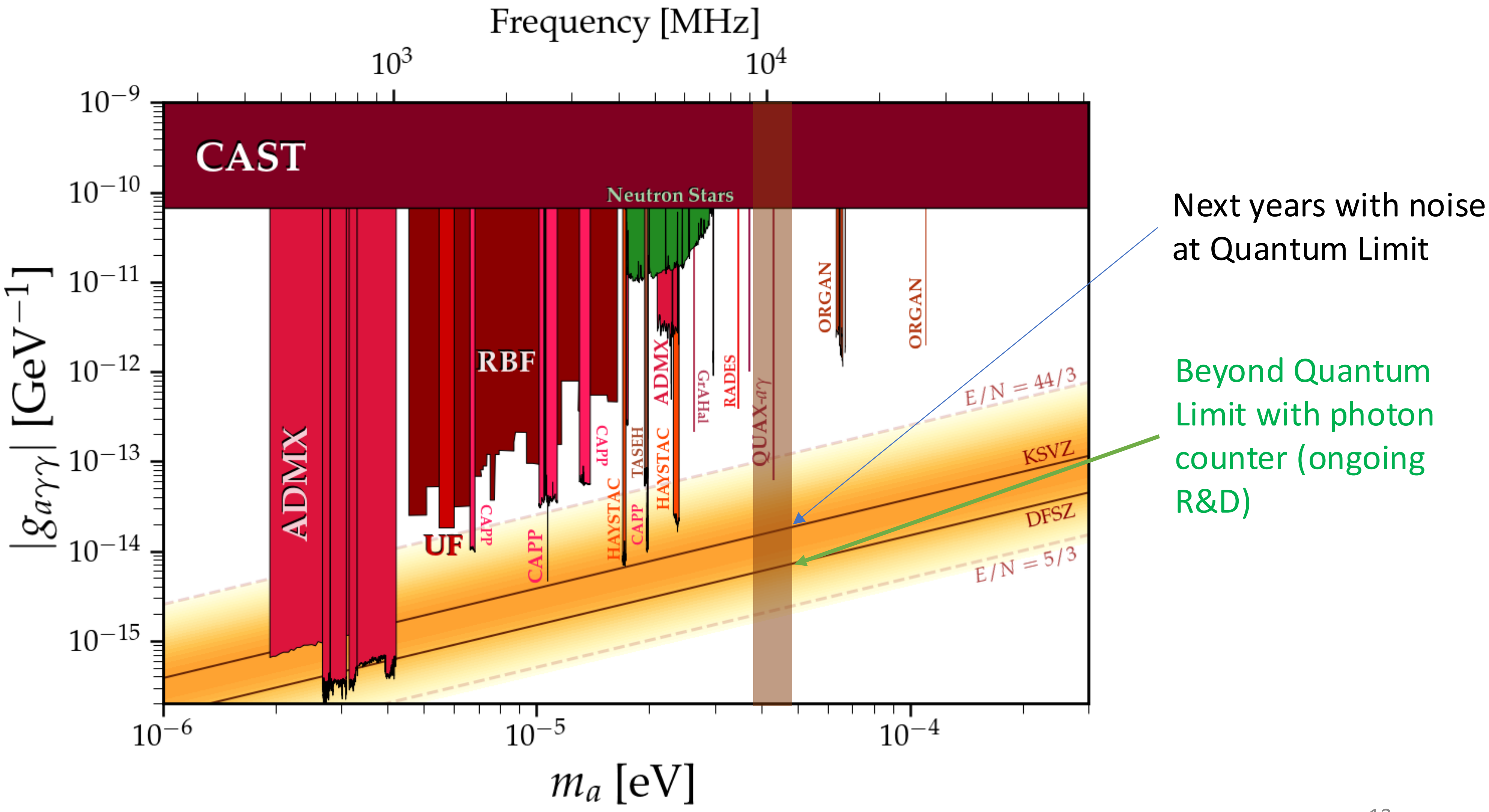
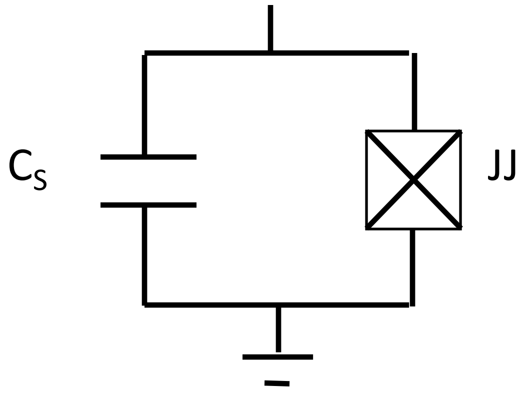
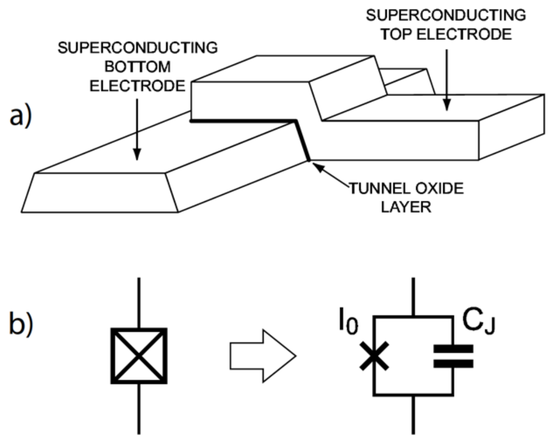
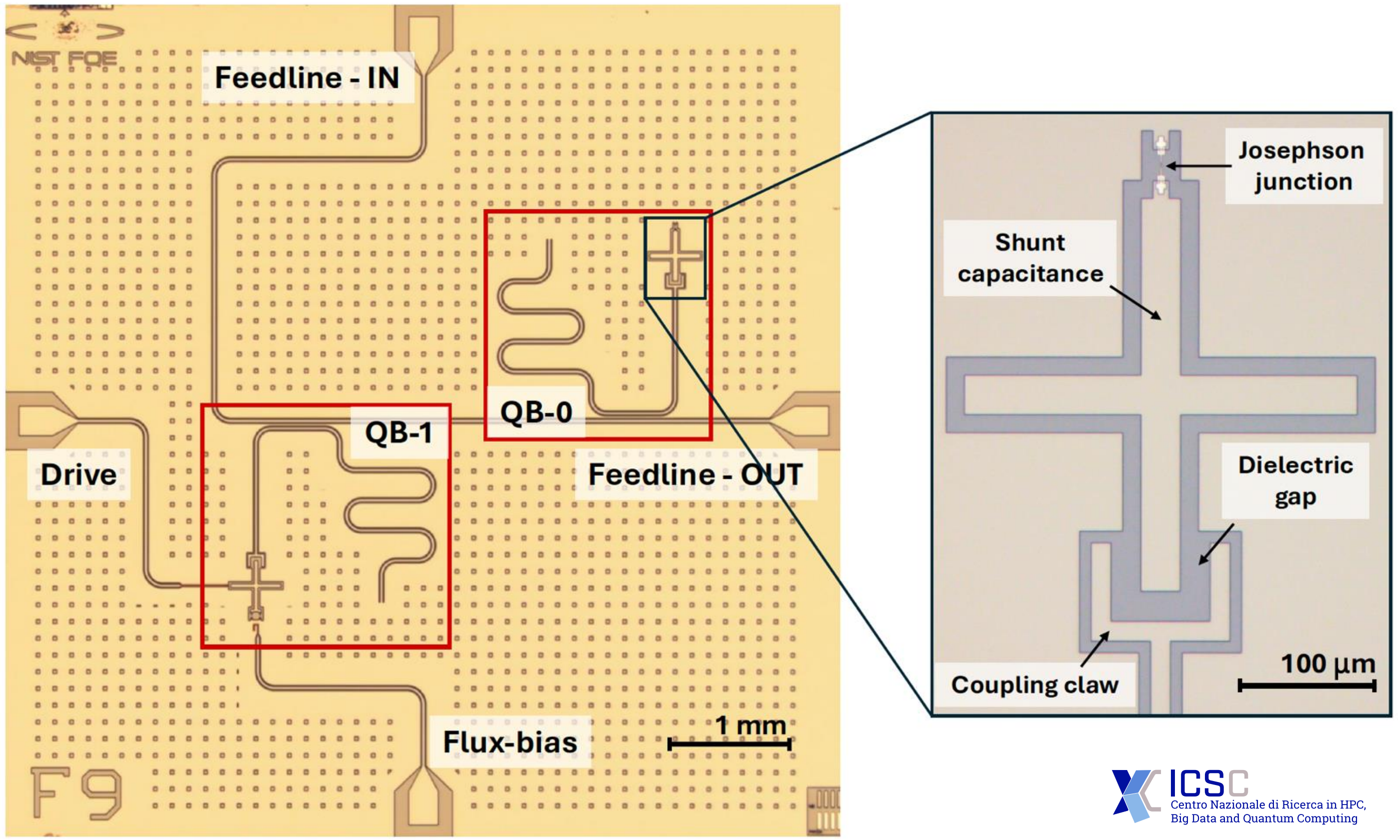


https://cajohare.github.io/AxionLimits/

Superconducting Qubits

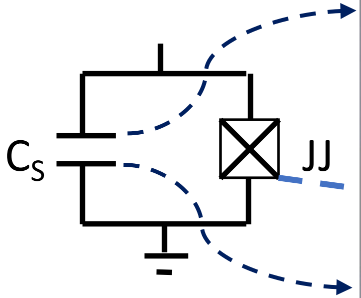


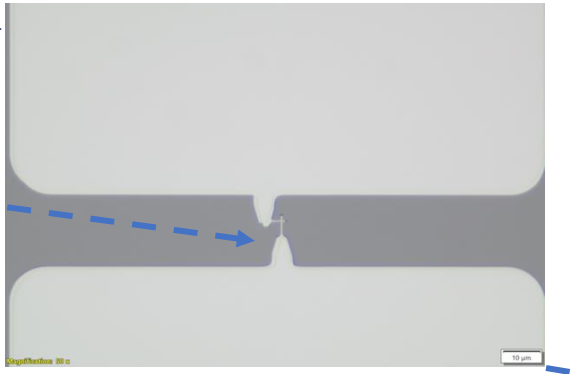


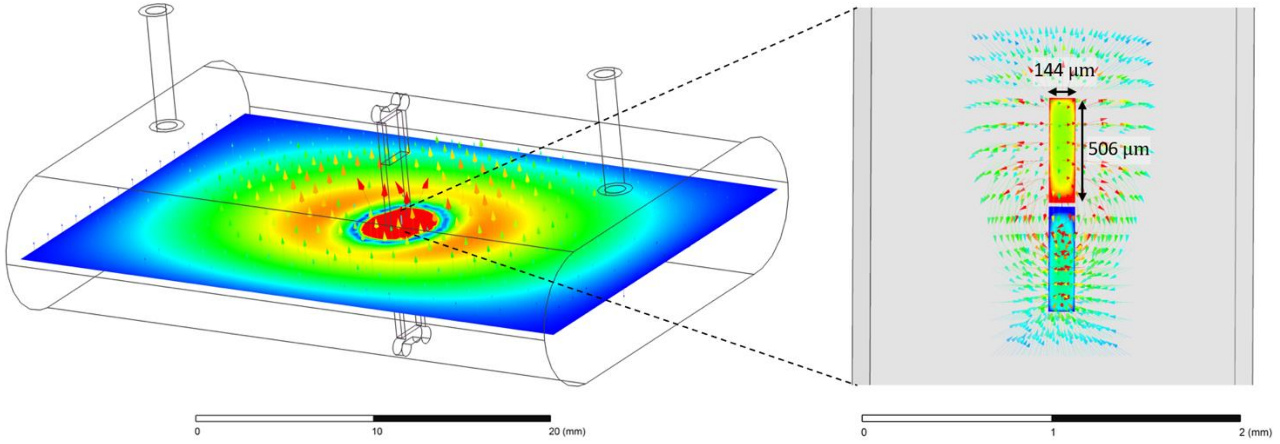


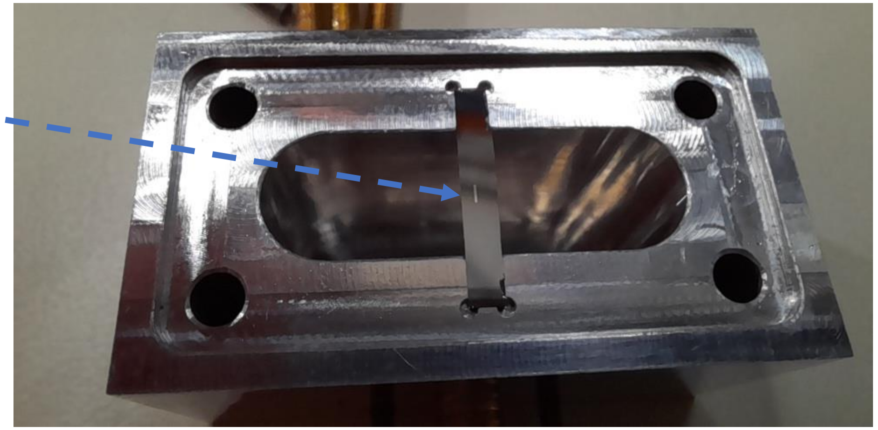
arXiv:2409.05988

Qubit in a 3D Resonator

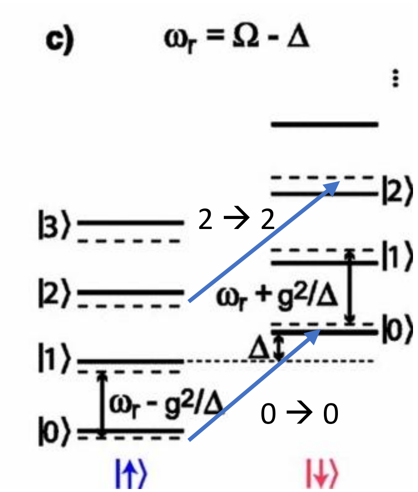






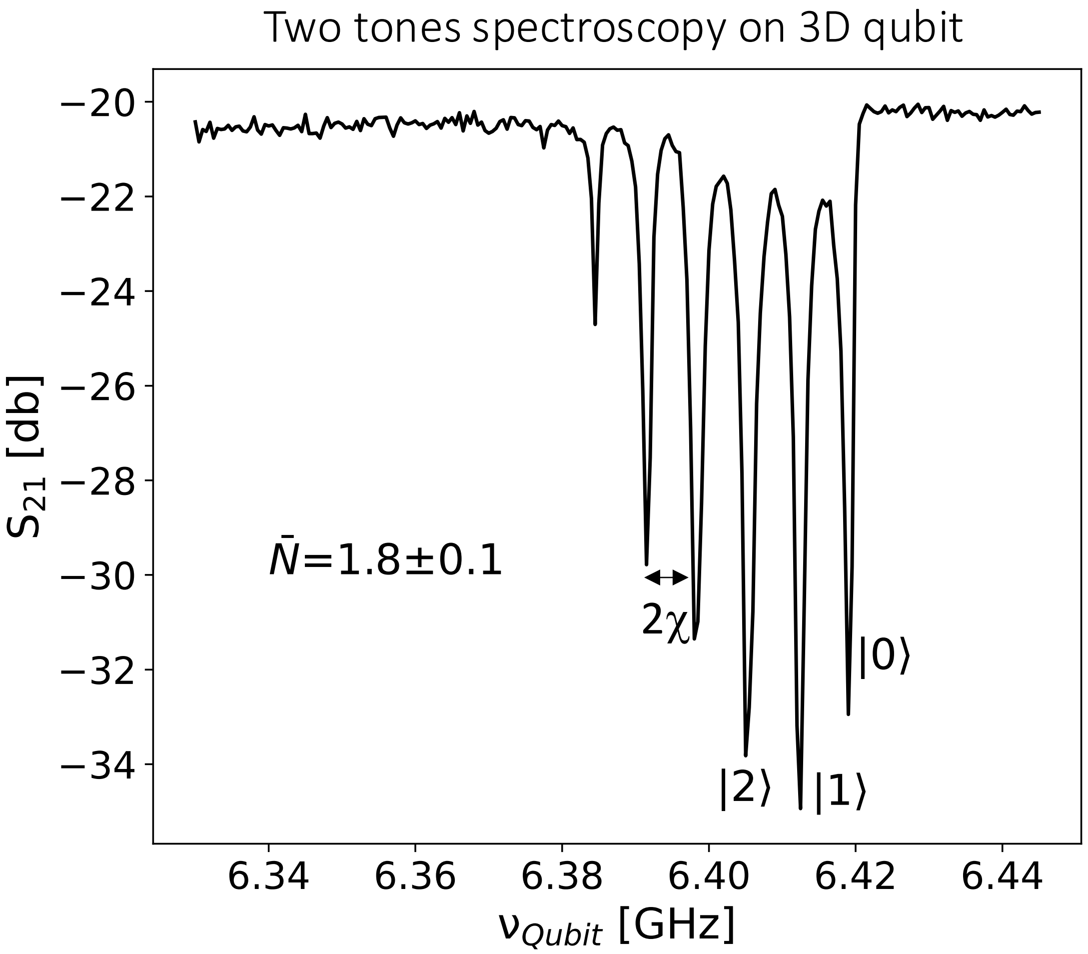


Quantum Sensing with SC Qubits



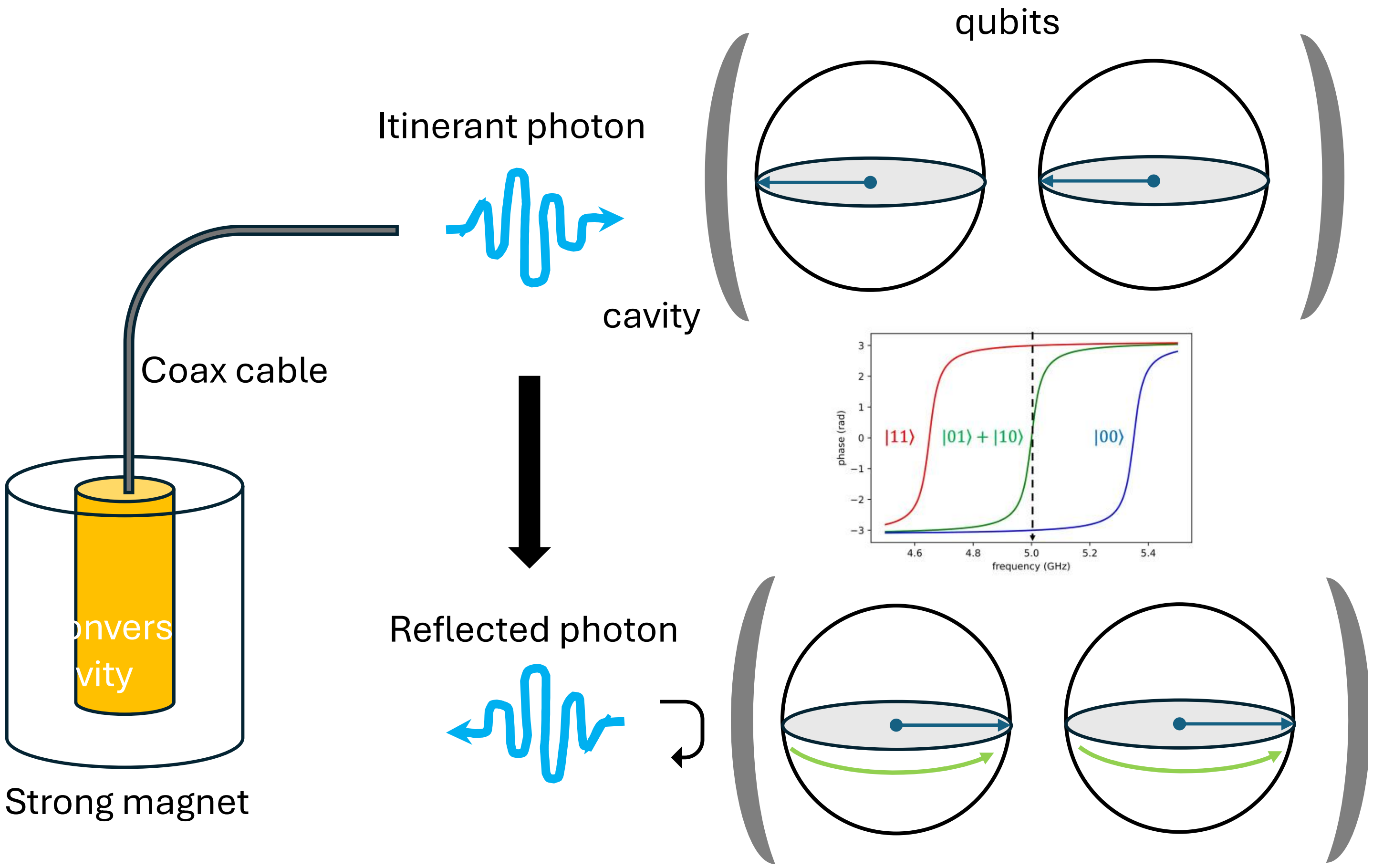
$$\omega'_q = \omega_q + 2n_\gamma\chi$$

Photon number in resonator



Appl. Sci. 2024, 14(4), 1478

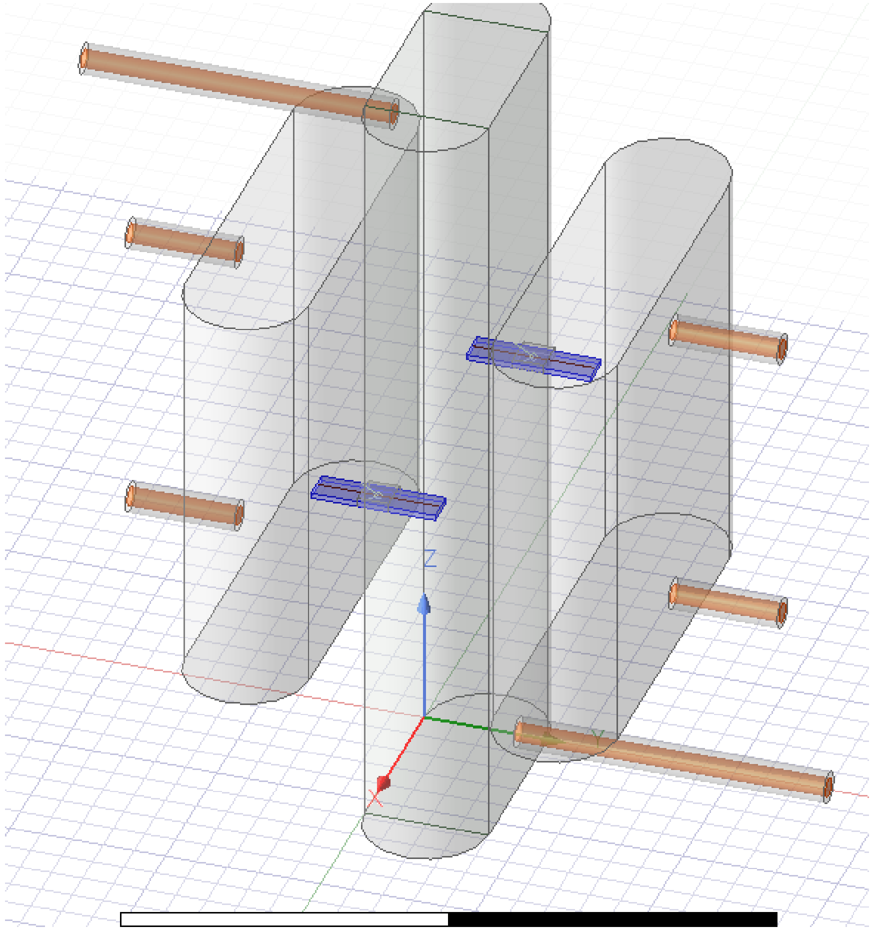
Two Qubits Detection Scheme

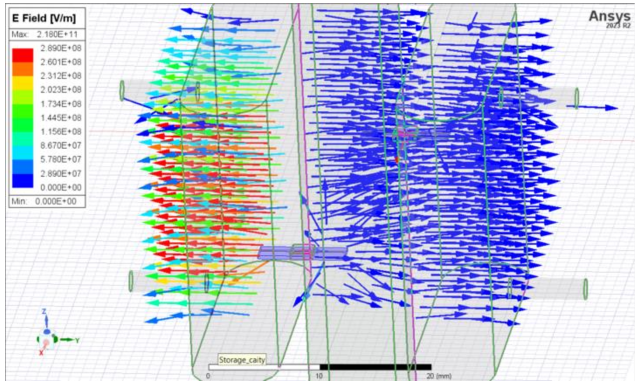


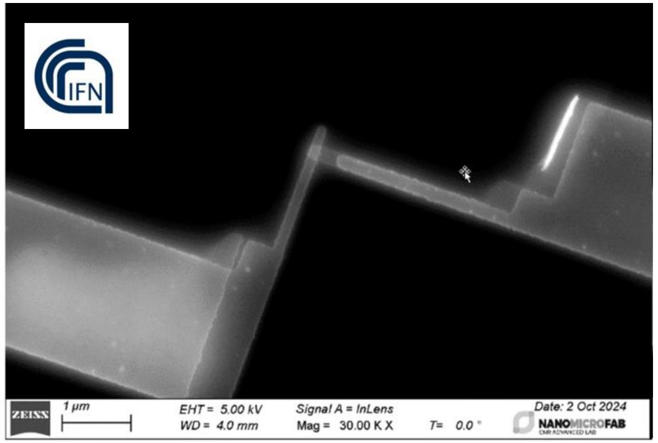
Kono et al. *Nature Phys* **14**, 546–549 (2018)

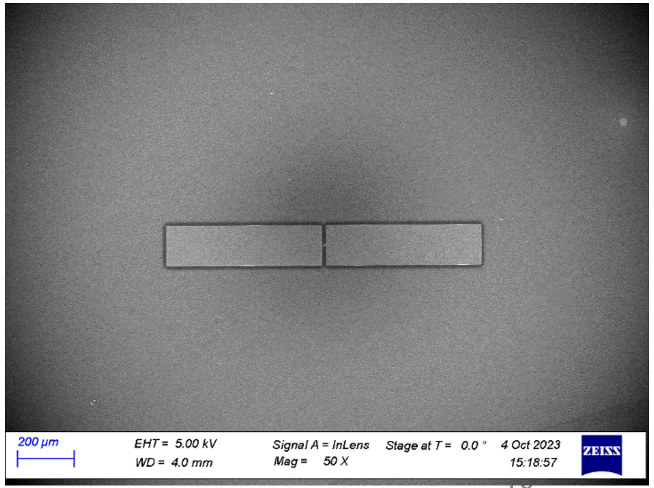
A D'Elia Appl. Sci. 2024, 14(4), 1478

Two Qubits Detection Scheme

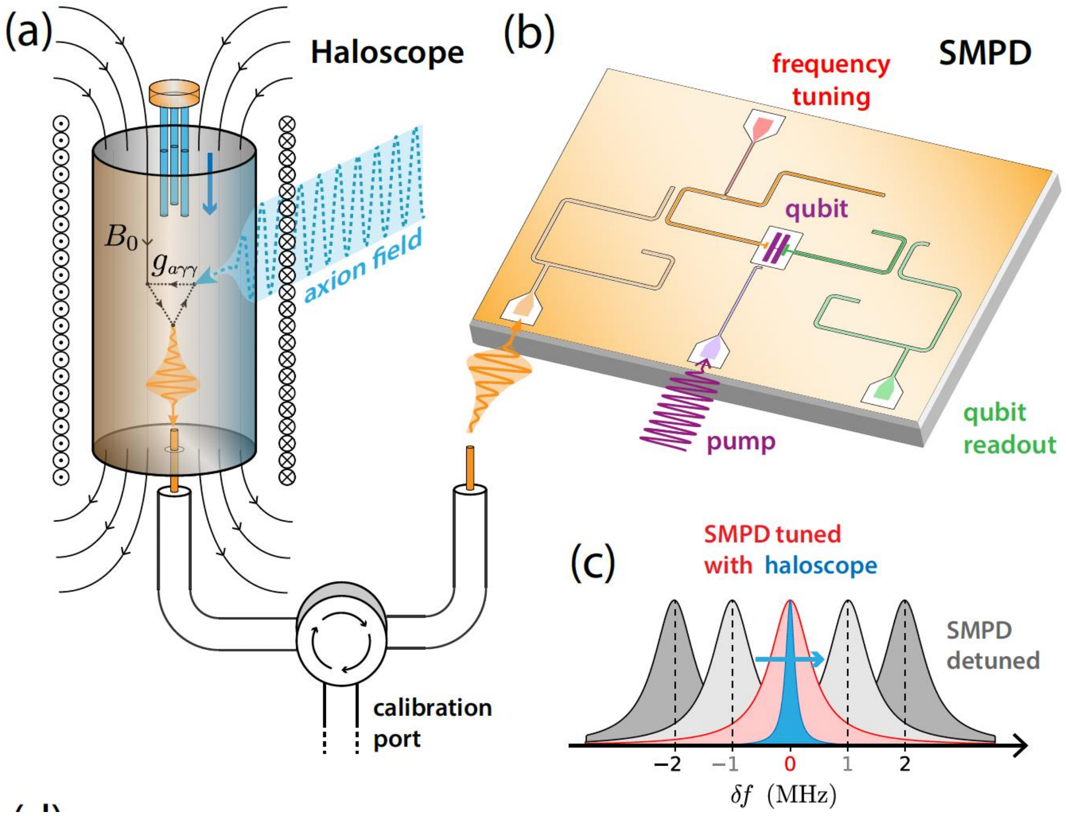


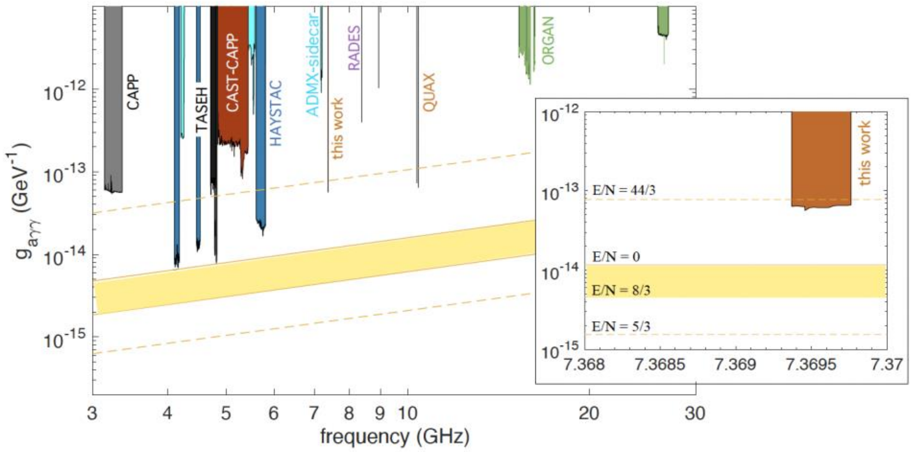






Quantum-enhanced sensing of axion dark matter with a transmon-based single microwave photon counter@LNL





QUAX-LNL+Saclay teams performed the first search for axion DM with a device developed in Saclay [R. Lescanne Physical Review X 10, 021038 (2020)]

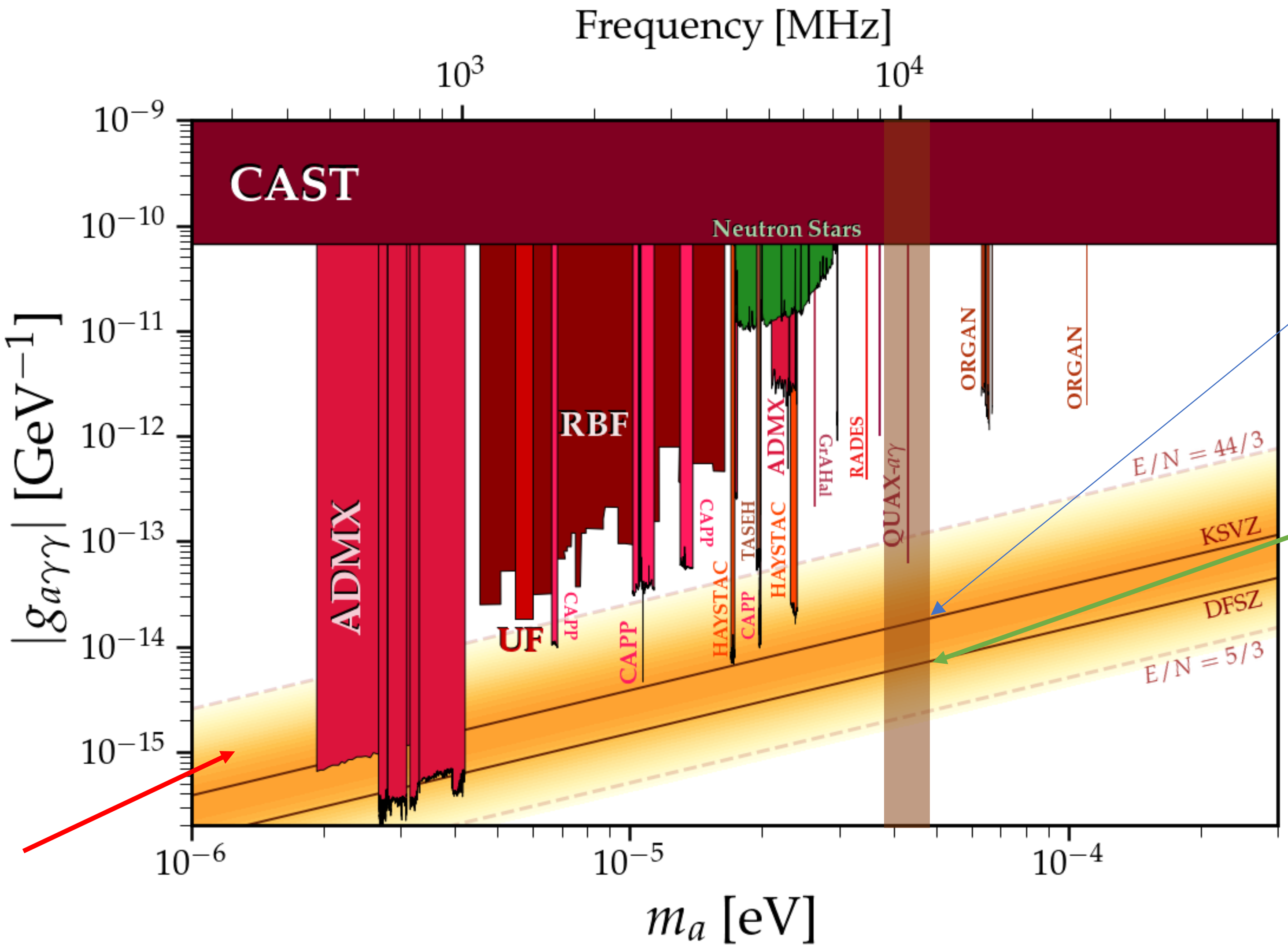
arXiv:2403.02321

QUAX LNF&LNL Next Years

LNF:
- Superconducting cavity $Q_0 > 2\times10^5$
- B=9T
- Multicavity

LNL:
- Dielectric cavity $Q_0 > 10^6$
- B=14 T
- Single cavity

What about the low mass limit?



Next years with noise at Quantum Limit

Beyond Quantum Limit with photon counter (ongoing R&D)

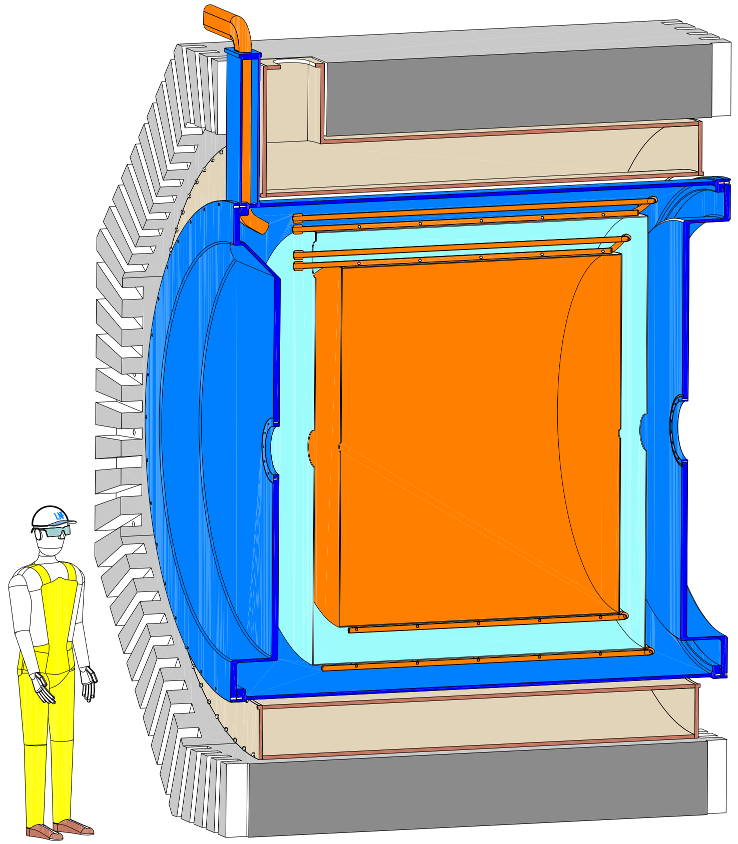
See arXiv:2403.02321 for LNL R&D on photon counter

https://cajohare.github.io/AxionLimits/

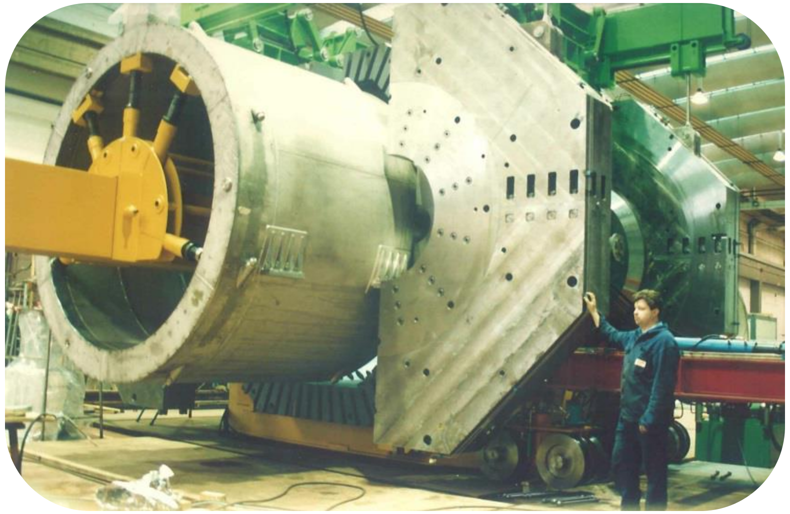
FLASH
Finuda magnet for Light Axion Search Haloscope

A large cryogenic resonant-cavity in a high static magnetic field which is planned to probe new physics in the form of dark matter (DM) axions, scalar fields, chameleons, hidden photons, as well as high frequency gravitational waves (GWs) in the frequency range (100–300) MHz.

The experiment will make use of the cryogenic plant and magnet of the FINUDA experiment at INFN-LNF.



"The future search for low-frequency axions and new physics with the FLASH resonant cavity experiment at Frascati National Laboratories"
Physics of the Dark Universe 42 (2023) 101370



FINUDA

Fisica Nucleare a DAFNE

B(T)	1.1
I(A)	2845
R(m)	1.4
L(m)	2.2

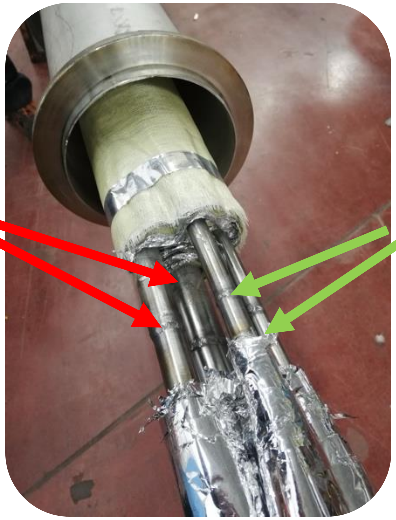
INFN
LNF
Istituto Nazionale di Fisica Nucleare

Commissioning of the FINUDA Magnet at LNF

Last Operated in 2007

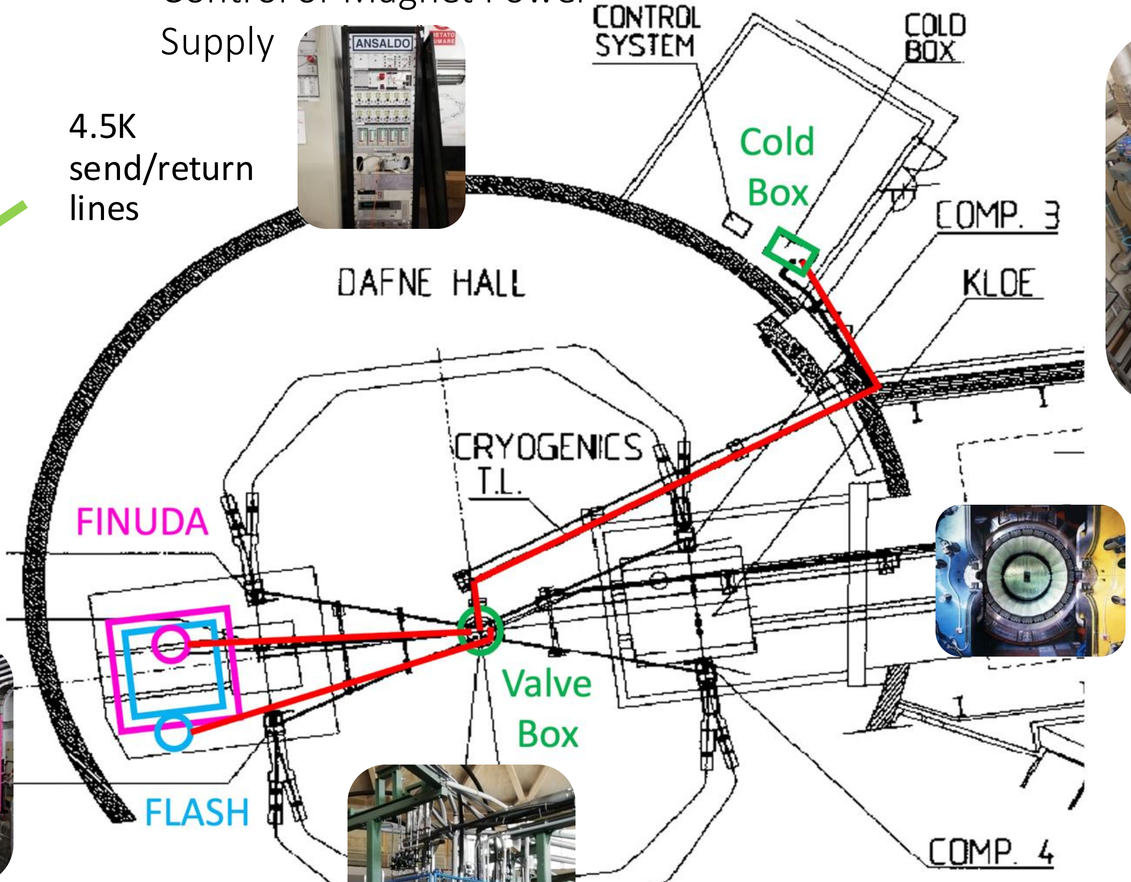
70K send/return lines

4.5K send/return lines



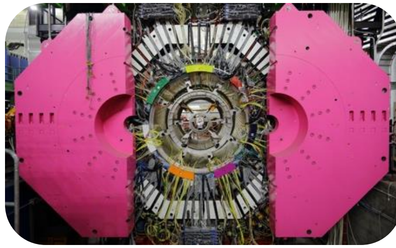
Reconnection of He transfer line

Control of Magnet Power Supply

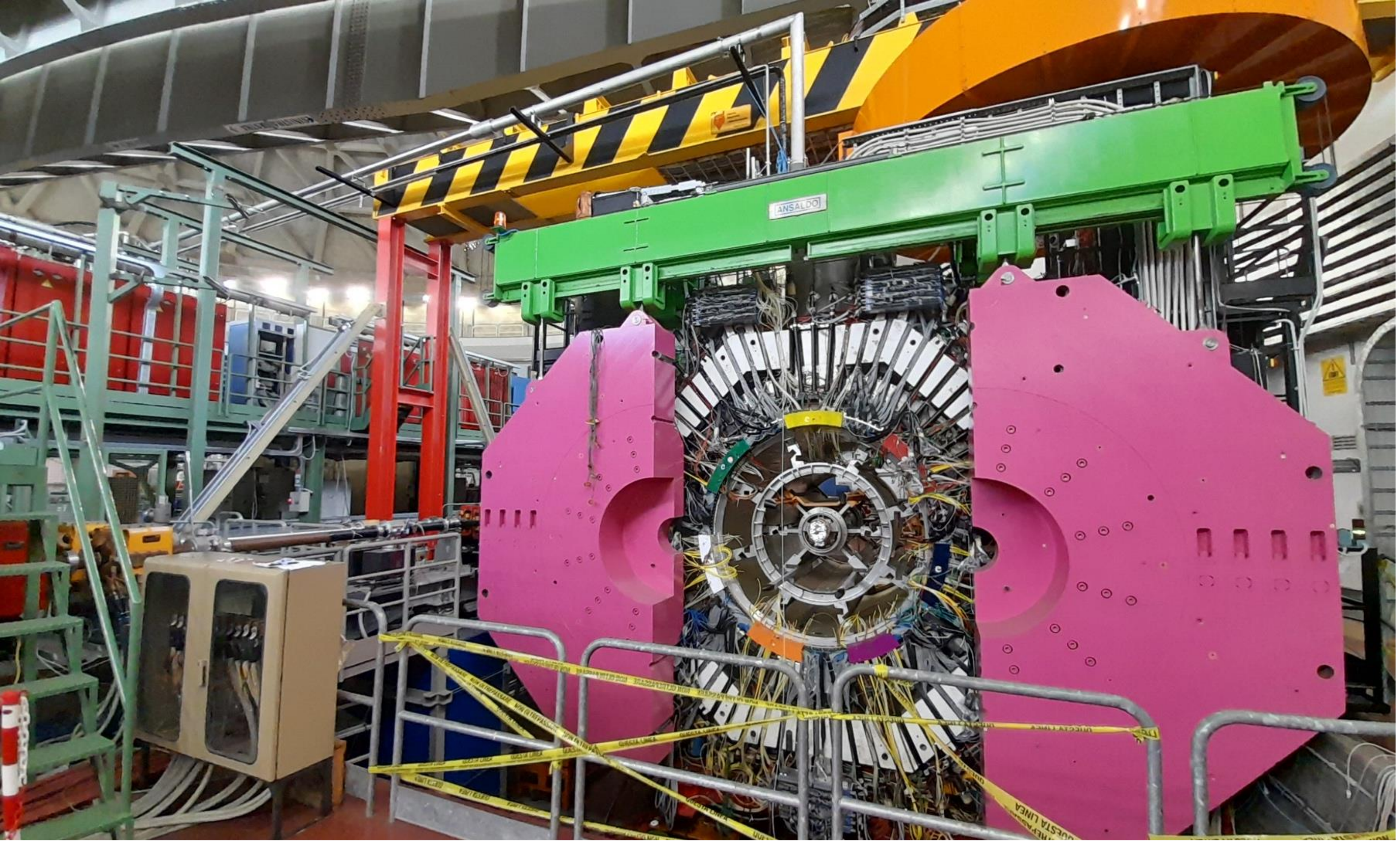


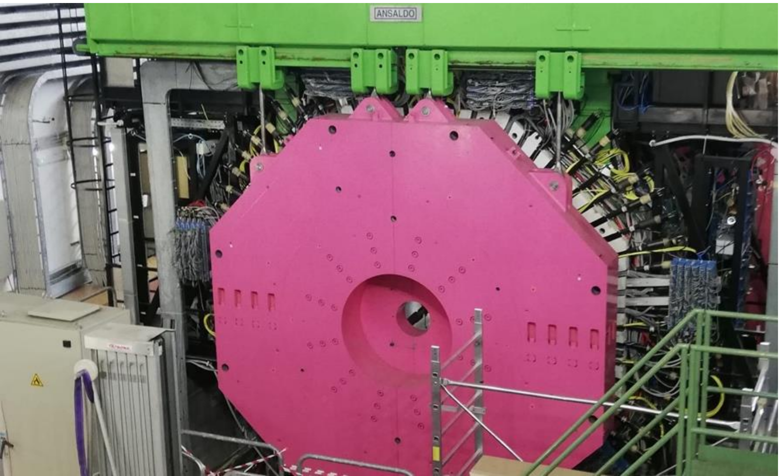
Cryogenic plant

KLOE

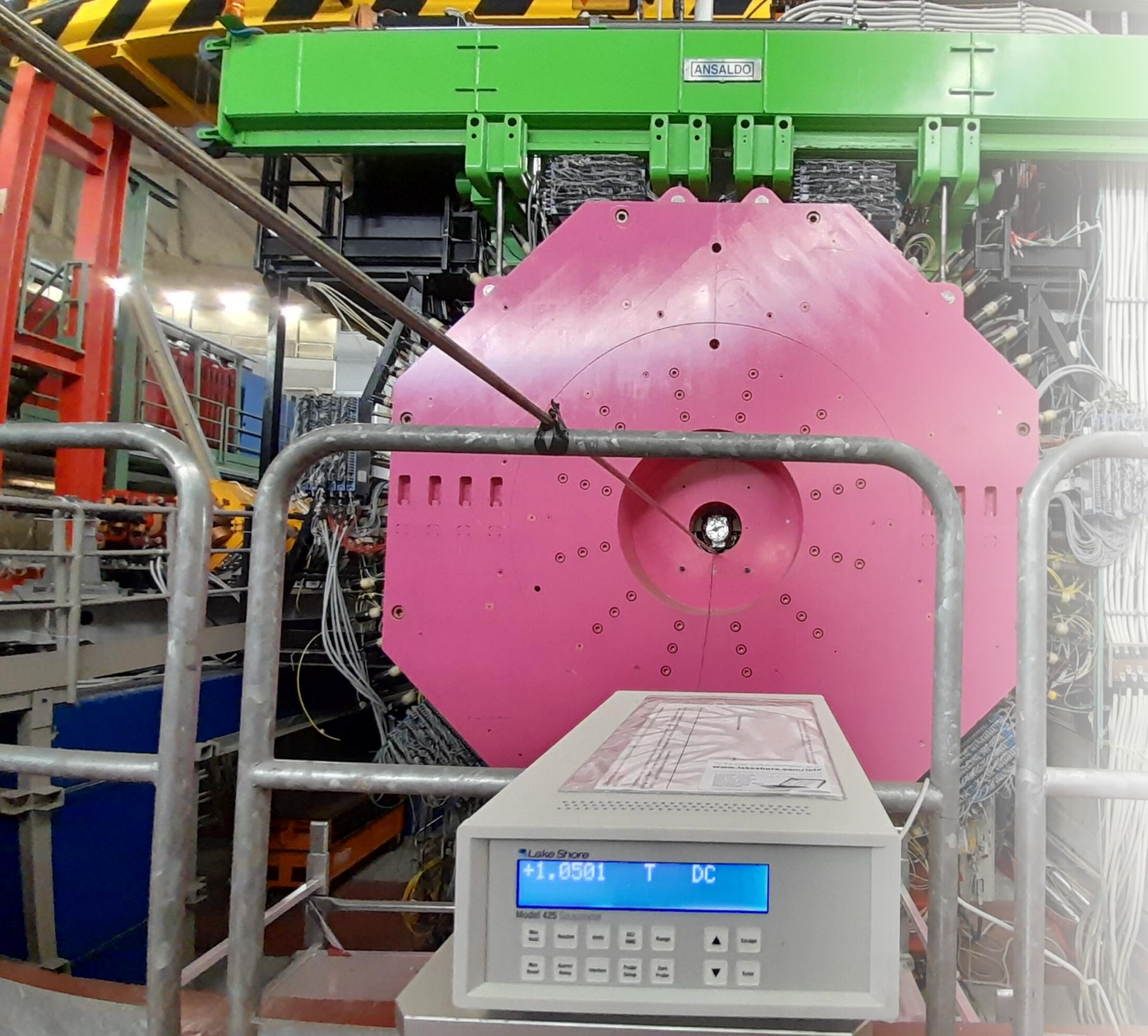


FINUDA/FLASH


ANSALDO



ANSALDO

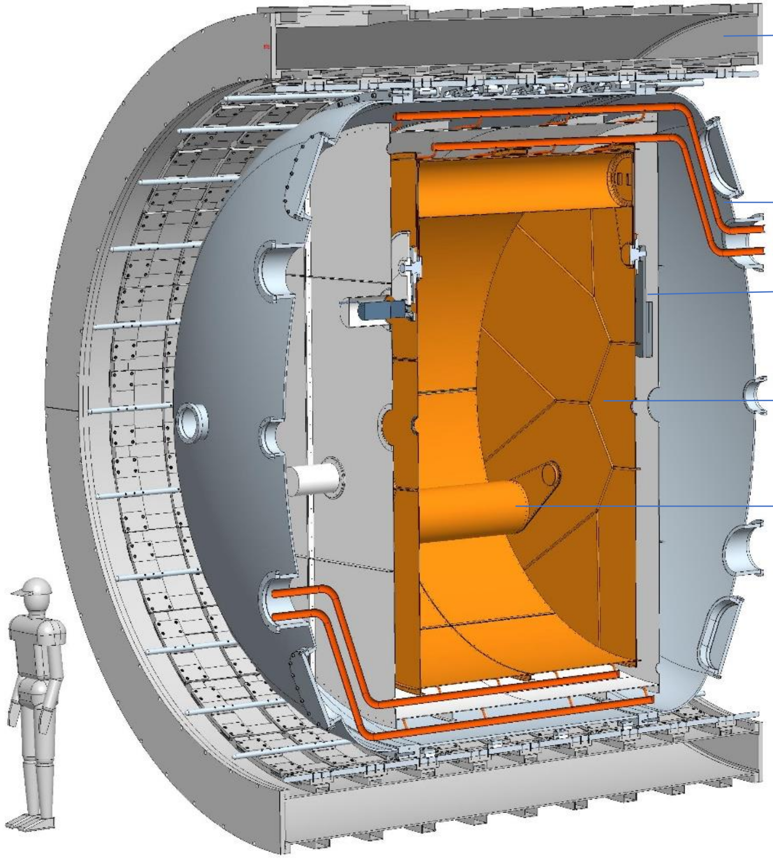

CV01
CV02
CV07
FIC1 (-)
FIC2 (+)
CV04
CV12
CV20
CV06
CV03
CV09



Successful Test of the FINUDA Magnet

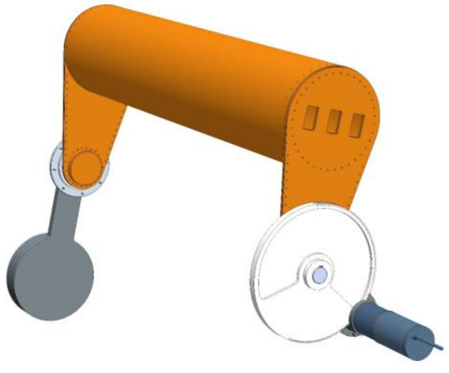
- After a series of operations, the cryogenic plant was finally put back into operation. On Jan the 19th 2024, FINUDA was cooled down to 4 K and energized with a current of 2706 A, generating a magnetic field of 1.05 T.

THE FLASH Cryostat and Resonant Cavity



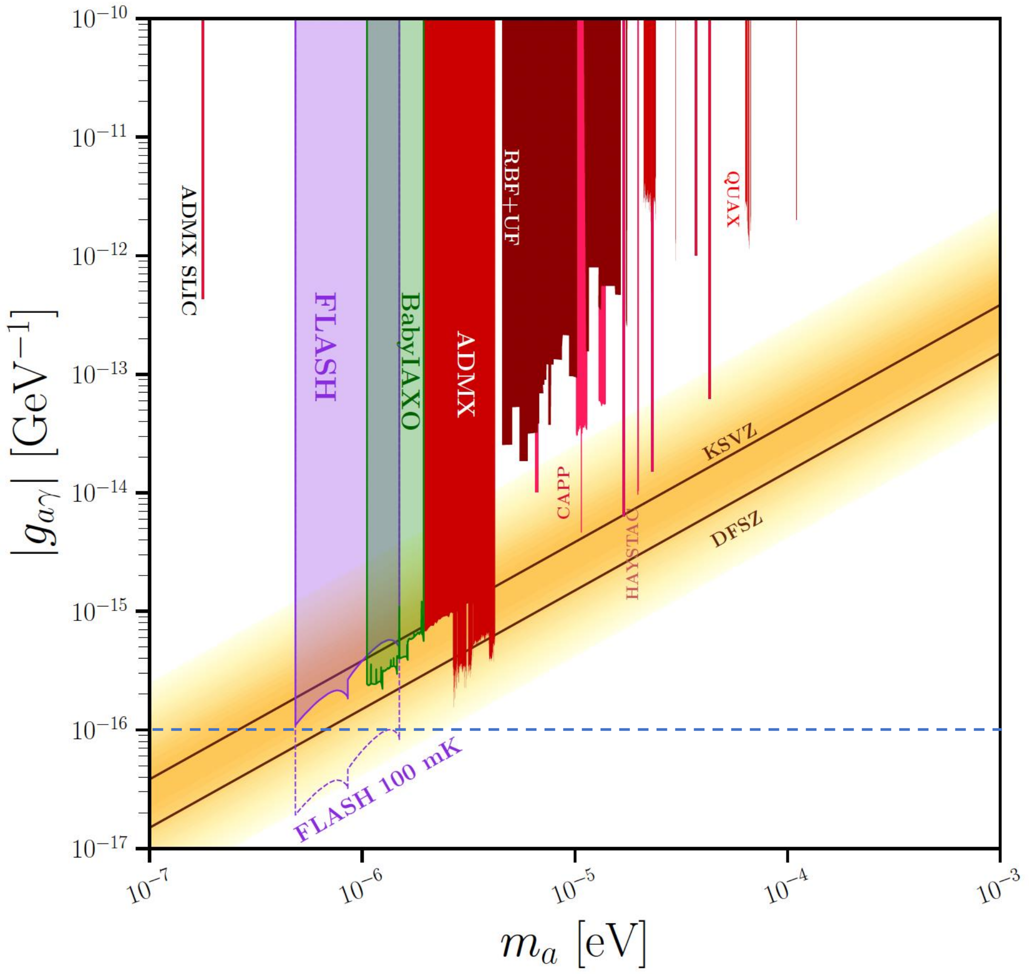
- KLOE/FINUDA Magnet
- Vacuum vessel made by a-magnetic stainless steel
- Shield in aluminum alloy, to be cooled to 70 K by gaseous Helium
- OFHC Cu resonant cavity, cooled to 4.6 K by saturated liquid Helium
- 3 OFHC Cu tuning bars mounted on eccentric cranks with reduction gearboxes

Design by FANTINI Sud Mechanical Div.



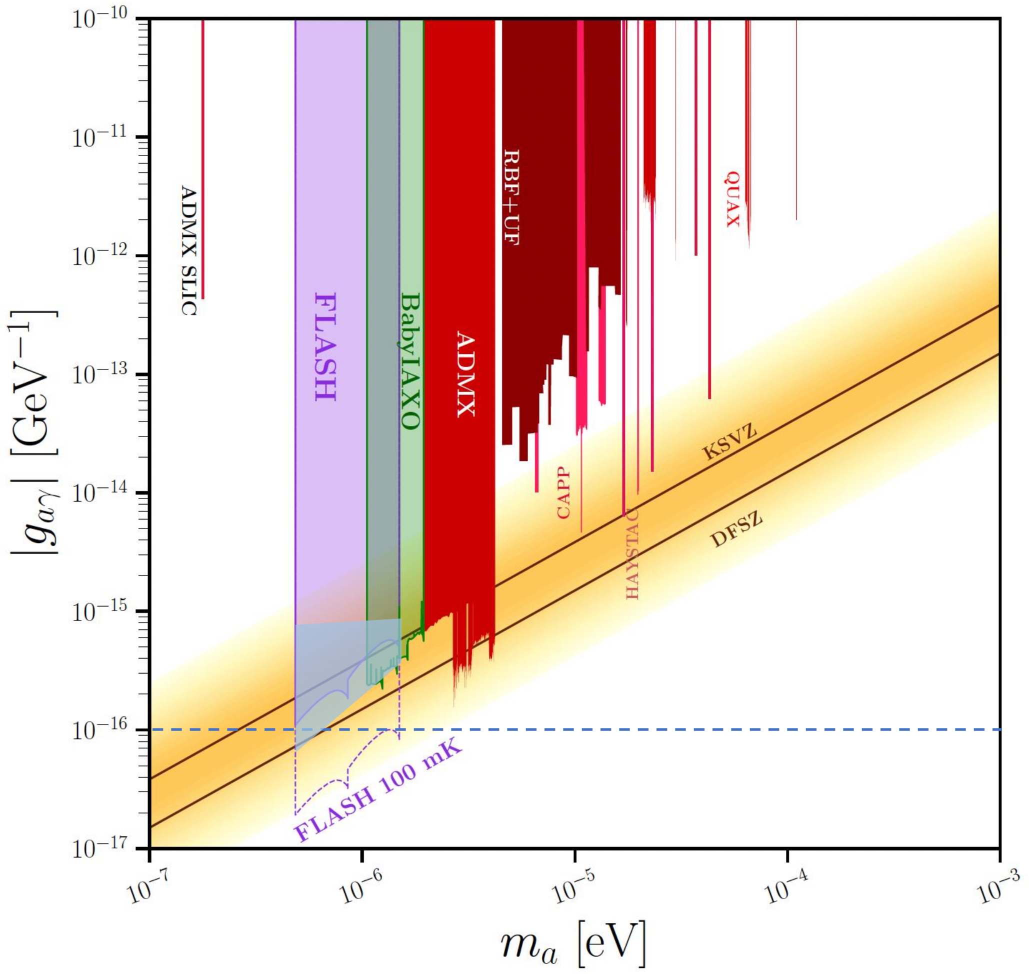
FLASH Physics Reach

With Cu cavity at 4.5 K



Parameter	Value
ν_c [MHz]	150
m_a [μeV]	0.62
$g_{a\gamma\gamma}^{\mathrm{KSVZ}}$ [GeV^{-1}]	2.45×10^{-16}
Q_L	1.4×10^5
C_{010}	0.53
$B_{\max}$ [T]	1.1
β	2
τ [min]	5
T_{sys} [K]	4.9
P_{sig} [W]	0.9×10^{-22}
Scan rate [Hz s^{-1}]	8
m_a [μeV]	0.49 - 1.49
$g_{a\gamma\gamma}$ 90% c.l. [GeV^{-1}]	$(1.25 - 6.06) \times 10^{-16}$

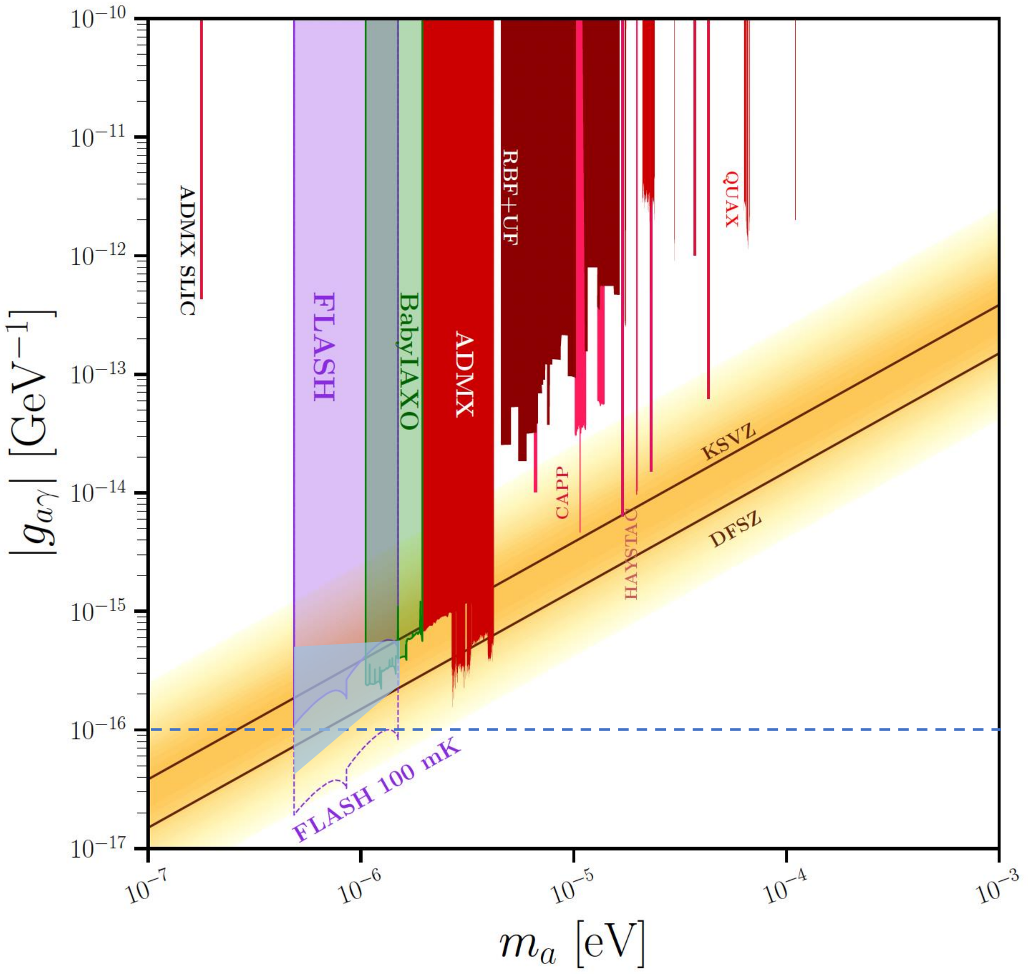
FLASH Physics Reach



With Cu cavity at 1.9 K

Parameter	Value
ν_c [MHz]	150
m_a [μeV]	0.62
$g_{a\gamma\gamma}^{\mathrm{KSVZ}}$ [GeV^{-1}]	2.45×10^{-16}
Q_L	1.4×10^5
C_{010}	0.53
B_{max} [T]	1.1
β	2
τ [min]	5
T_{sys} [K]	4.9
P_{sig} [W]	0.9×10^{-22}
Scan rate [Hz s^{-1}]	8
m_a [μeV]	0.49 - 1.49
$g_{a\gamma\gamma}$ 90% c.l. [GeV^{-1}]	(0.8- 3.96) $\times 10^{-16}$

FLASH Physics Reach

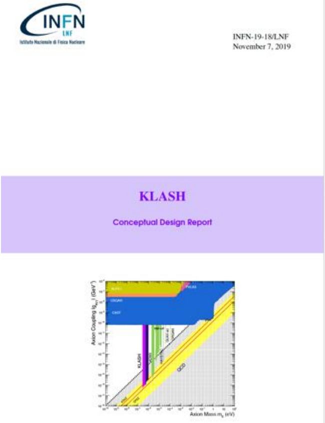


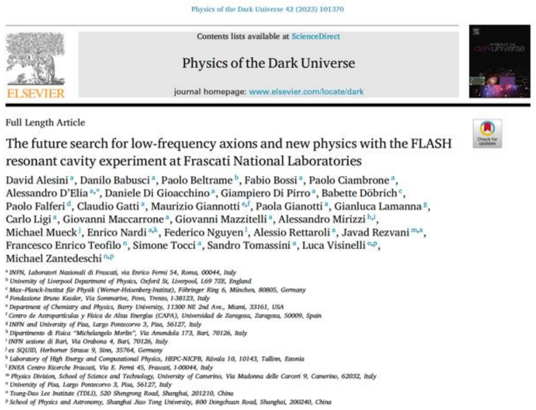
With NbTi cavity at 1.9 K

Parameter	Value
ν_c [MHz]	150
m_a [μeV]	0.62
$g_{a\gamma\gamma}^{\mathrm{KSVZ}}$ [GeV^{-1}]	2.45×10^{-16}
Q_L	6.7×10^5
C_{010}	0.53
B_{max} [T]	1.1
β	2
τ [min]	5
T_{sys} [K]	4.9
P_{sig} [W]	0.9×10^{-22}
Scan rate [Hz s^{-1}]	8
m_a [μeV]	0.49 - 1.49
$g_{a\gamma\gamma}$ 90% c.l. [GeV^{-1}]	$(0.37\text{-}1.8) \times 10^{-16}$

FLASH Approved by INFN


Laboratori Nazionali di Frascati
INFN-18-09-LNF
September 18, 2018
The KLASH – Letter of Intent
D.Alesini[1], D.Babusci[1], F.Bossi[1], P.Ciambrone[1], G.Corcella[1], D.Di Gioacchino[1], P.Falferi[2], C.Gatti[1], A.Ghigo[1], G.Lamanna[3], C.Ligi[1], G.Maccarrone[1], A.Mirizzi[4], D.Montanino[5], D.Moricciani[1], A.Mostacci[6], E.Nardi[1], A.Paoloni[1], L.Pellegrino[1], A.Rettaroli[1], R.Ricci[1], L.Sabbatini[1], S.Tocci[1].


INFN-19-18/LNF
November 7, 2019
KLASH
Conceptual Design Report


Physics of the Dark Universe 42 (2023) 101370
Contents lists available at ScienceDirect
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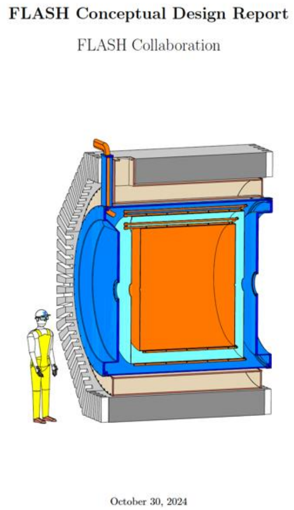
journal homepage: www.elsevier.com/locate/dark
Full Length Article
The future search for low-frequency axions and new physics with the FLASH resonant cavity experiment at Frascati National Laboratories


FLASH Conceptual Design Report
FLASH Collaboration
October 30, 2024

2018
Letter of intent for KLASH sent to INFN

2019
KLASH CDR published on arxiv

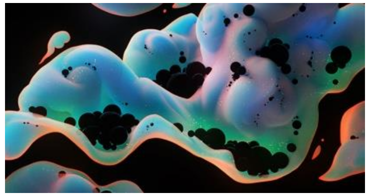
2023
New study with FINUDA magnet
KLASH→FLASH

2024
FLASH CDR sent to INFN and approved.

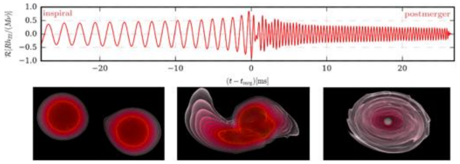
KLASH CDR arXiv:1911.02427
FLASH paper Phys. Dark Univ. 42 (2023)

High Frequency Gravitational Waves

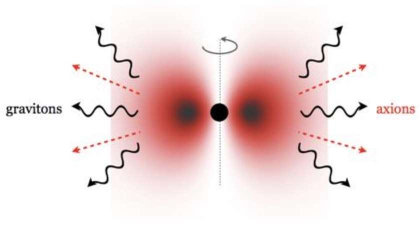
- The landscape of gravitational waves in the ultra-high frequency regime, above the kHz, is beyond the sensitivities of the present terrestrial experiments.
- HFGW could potentially be sourced by a collection of exotic physical phenomena originating both in the early and late Universe.
- Possibility to probe particle physics at very high energy scales



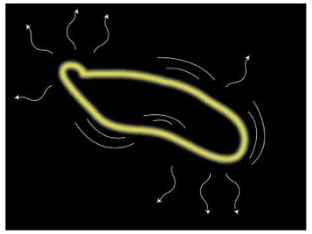
Primordial BH



Boson stars mergers



BH superradiance

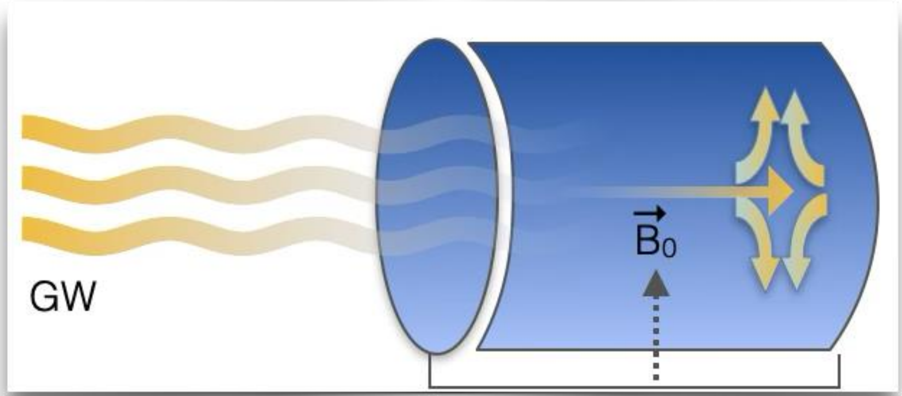


Cosmic strings

Aggarwal et al. Challenges and opportunities of gravitational-wave searches at MHz to GHz frequencies. Living Rev Relativ 24, 4 (2021).

How to Detect HFGW

Source



Strong static magnetic field

SOVIET PHYSICS JETP VOLUME 14, NUMBER 1 JANUARY, 1962

WAVE RESONANCE OF LIGHT AND GRAVITIONAL WAVES

M. E. GERTSENSHTEĬN

Submitted to JETP editor July 29, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 113-114 (July, 1961)

The energy of gravitational waves excited during the propagation of light in a constant magnetic or electric field is estimated.

Similar to Axion DM Detection

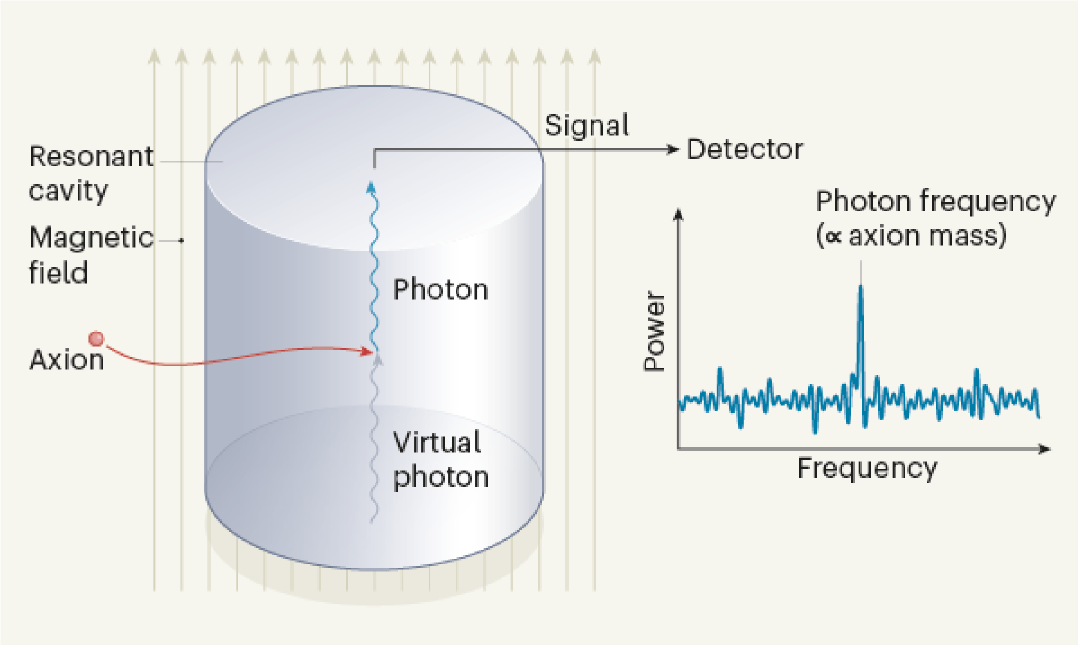
VOLUME 51, NUMBER 16 PHYSICAL REVIEW LETTERS 17 OCTOBER 1983

Experimental Tests of the "Invisible" Axion

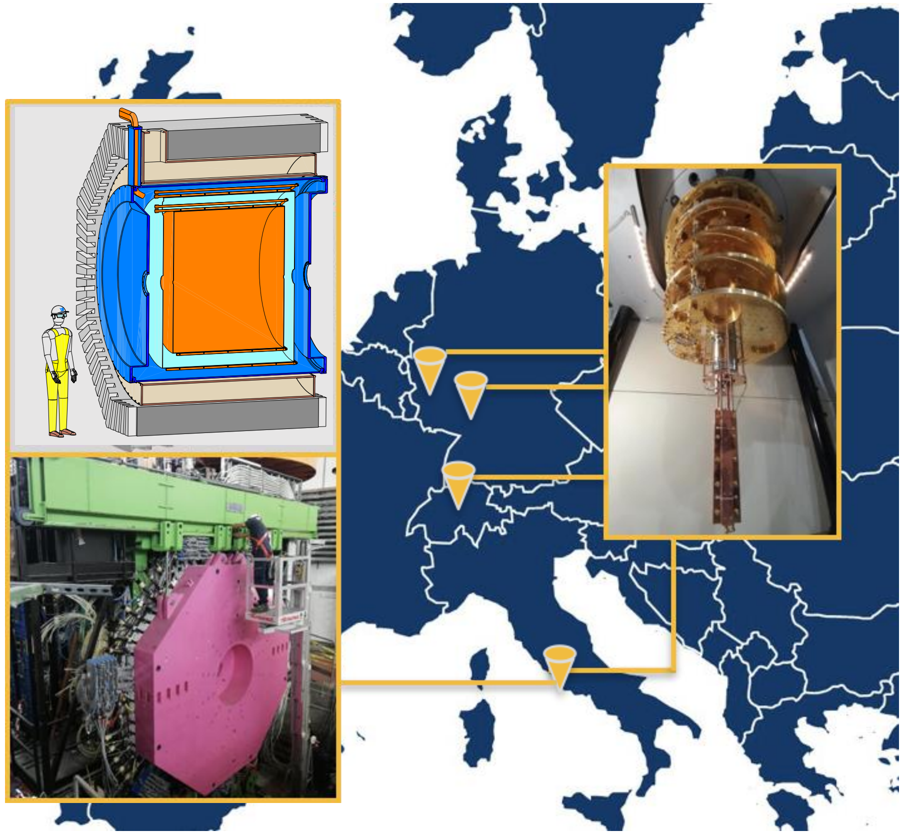
P. Sikivie
Physics Department, University of Florida, Gainesville, Florida 32611
(Received 13 July 1983)

Experiments are proposed which address the question of the existence of the "invisible" axion for the whole allowed range of the axion decay constant. These experiments exploit the coupling of the axion to the electromagnetic field, axion emission by the sun, and/or the cosmological abundance and presumed clustering of axions in the halo of our galaxy.

PACS numbers: 14.80.Gt, 11.30.Er, 95.30.Cq

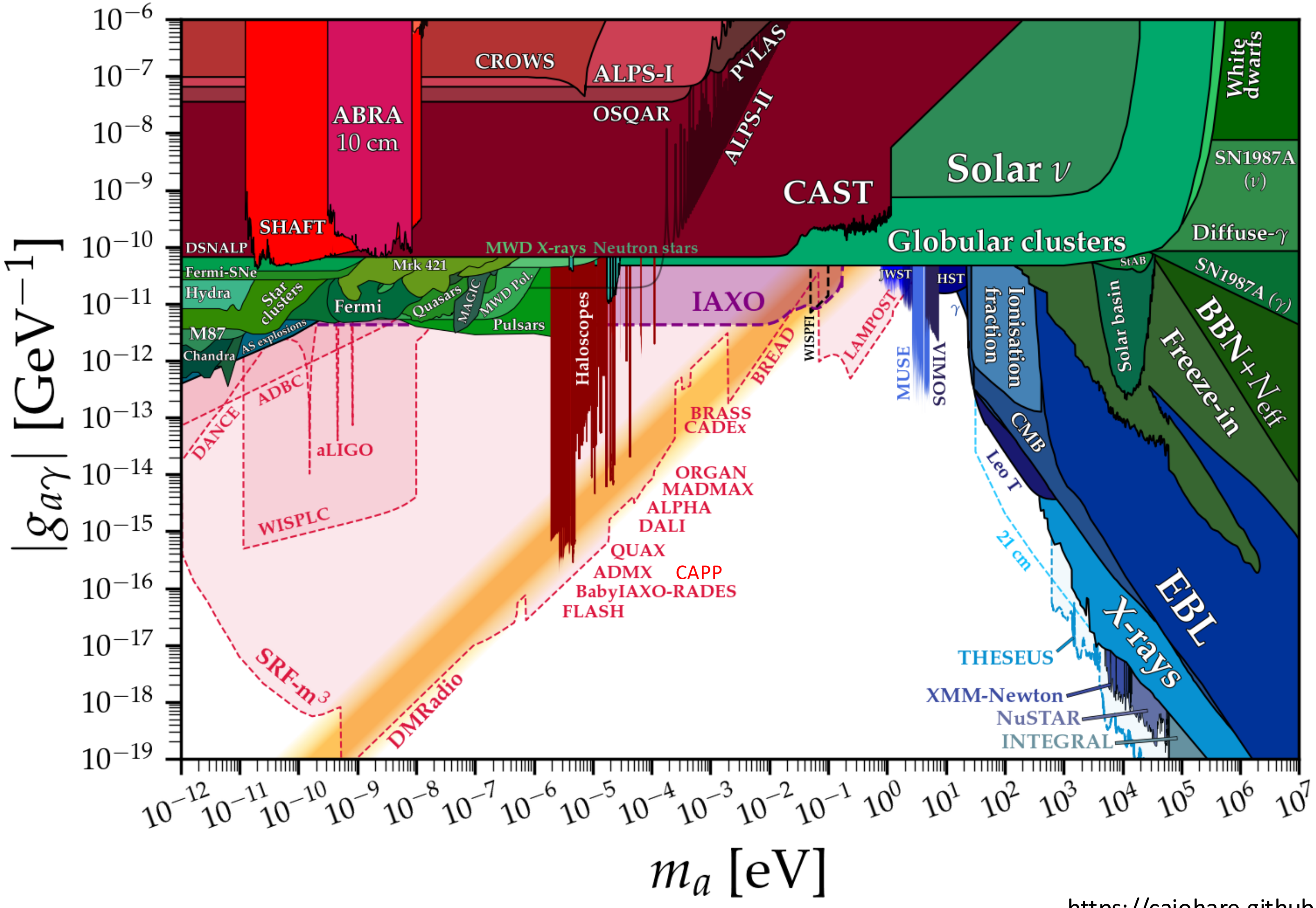


GravNet: A Global Network for the Search for High Frequency Gravitational Waves



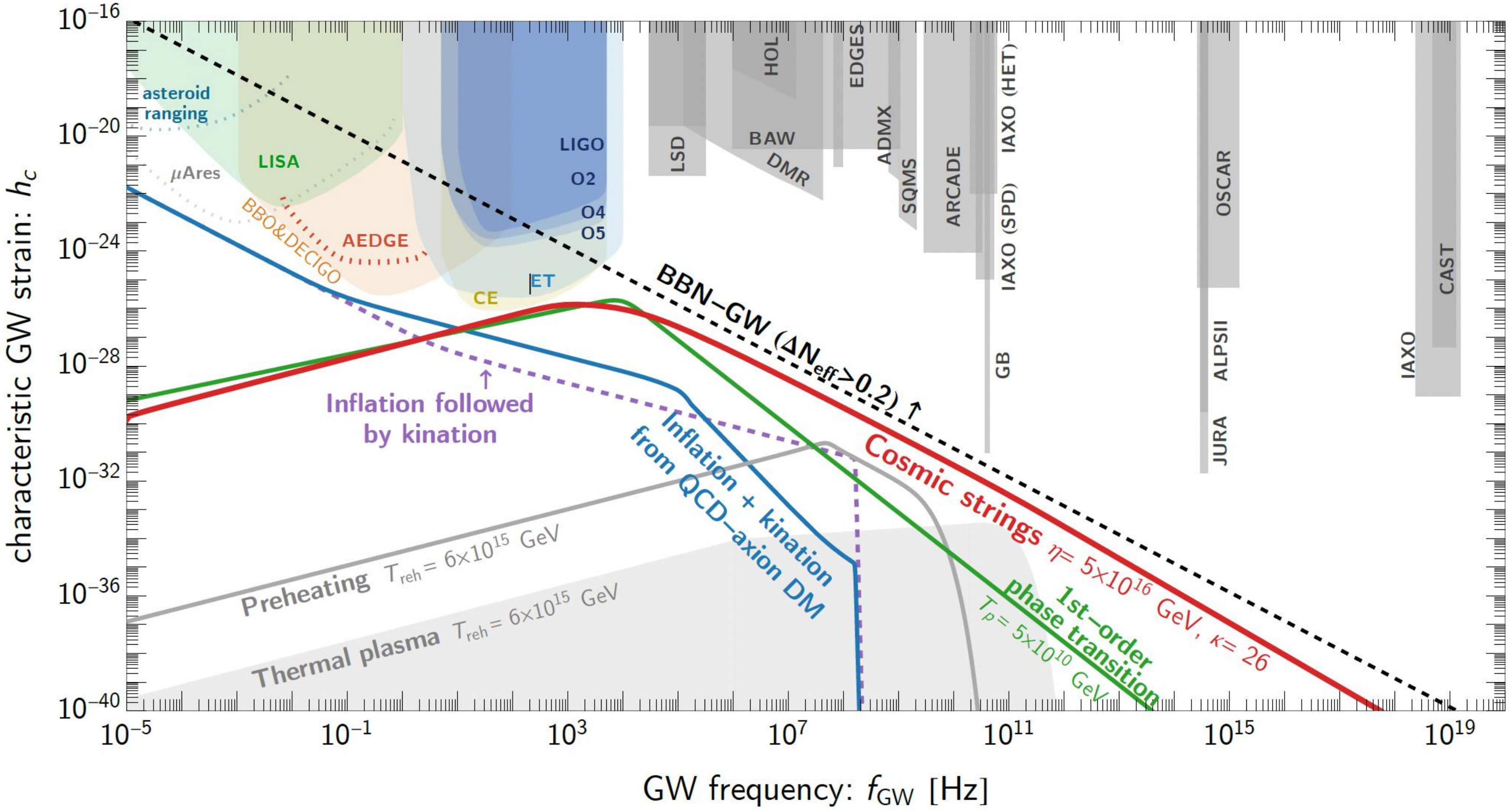
European Research Council
Established by the European Commission

Global Effort to Probe the Full QCD-Axion Band in the Next 10 Years

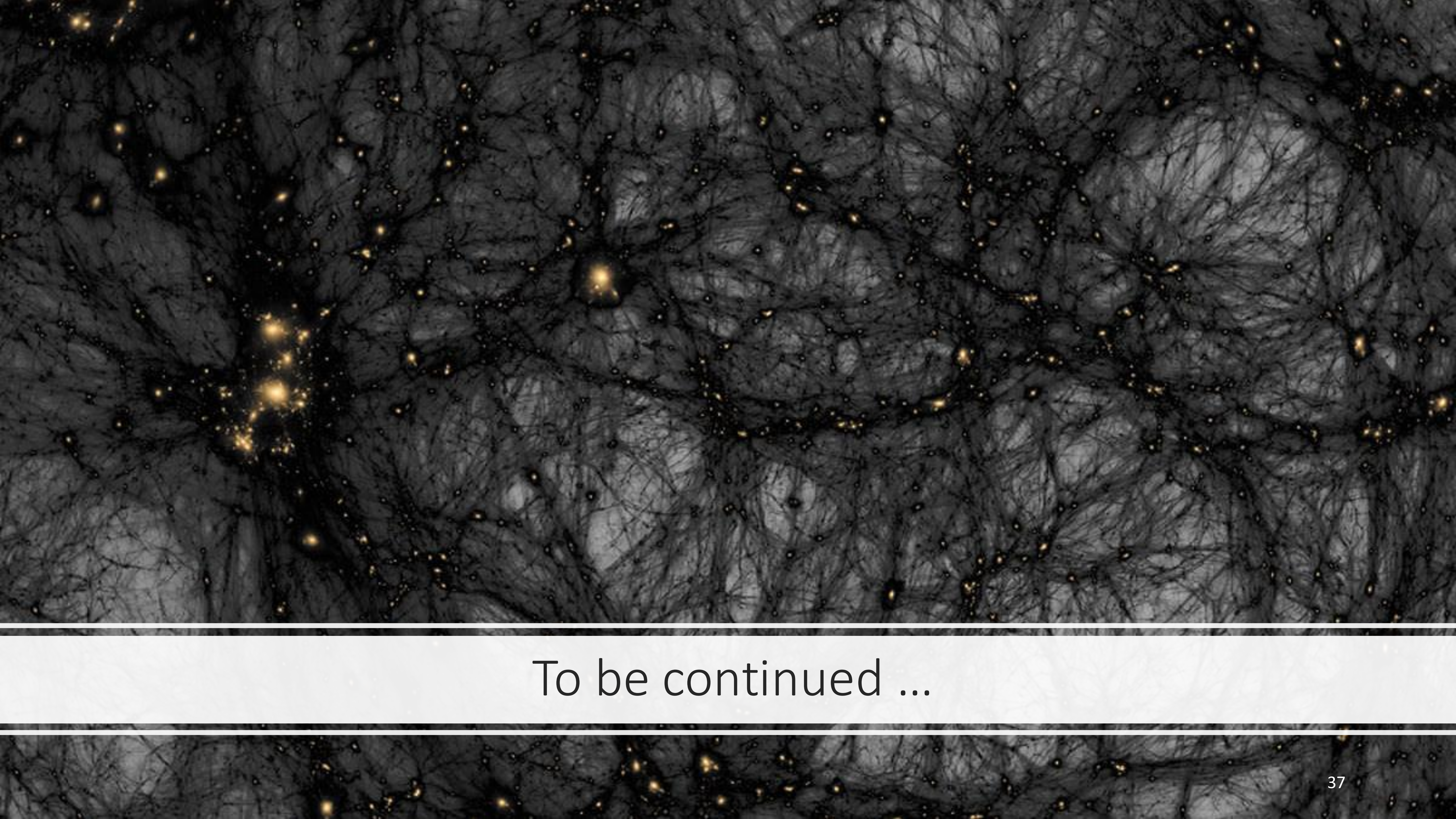


https://cajohare.github.io/AxionLimits/

Global Effort to Probe HFGW Band in the Next Years?



arXiv:2312.09281



To be continued ...