WG4: State of Art

COSMIC WISPers in the Dark Universe: Theory, astrophysics and experiments

WG4: State of Art

Experiment

- **Introduction**
- **CAST Legacy**
- **Current efforts**
- **Prospects**

WG4: State of Art
Experiment

- **Introduction**
- **CAST Legacy**
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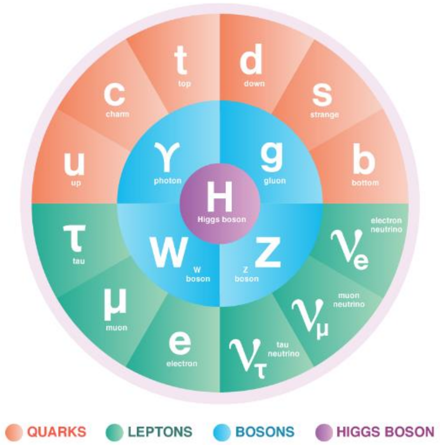
- **Prospects**

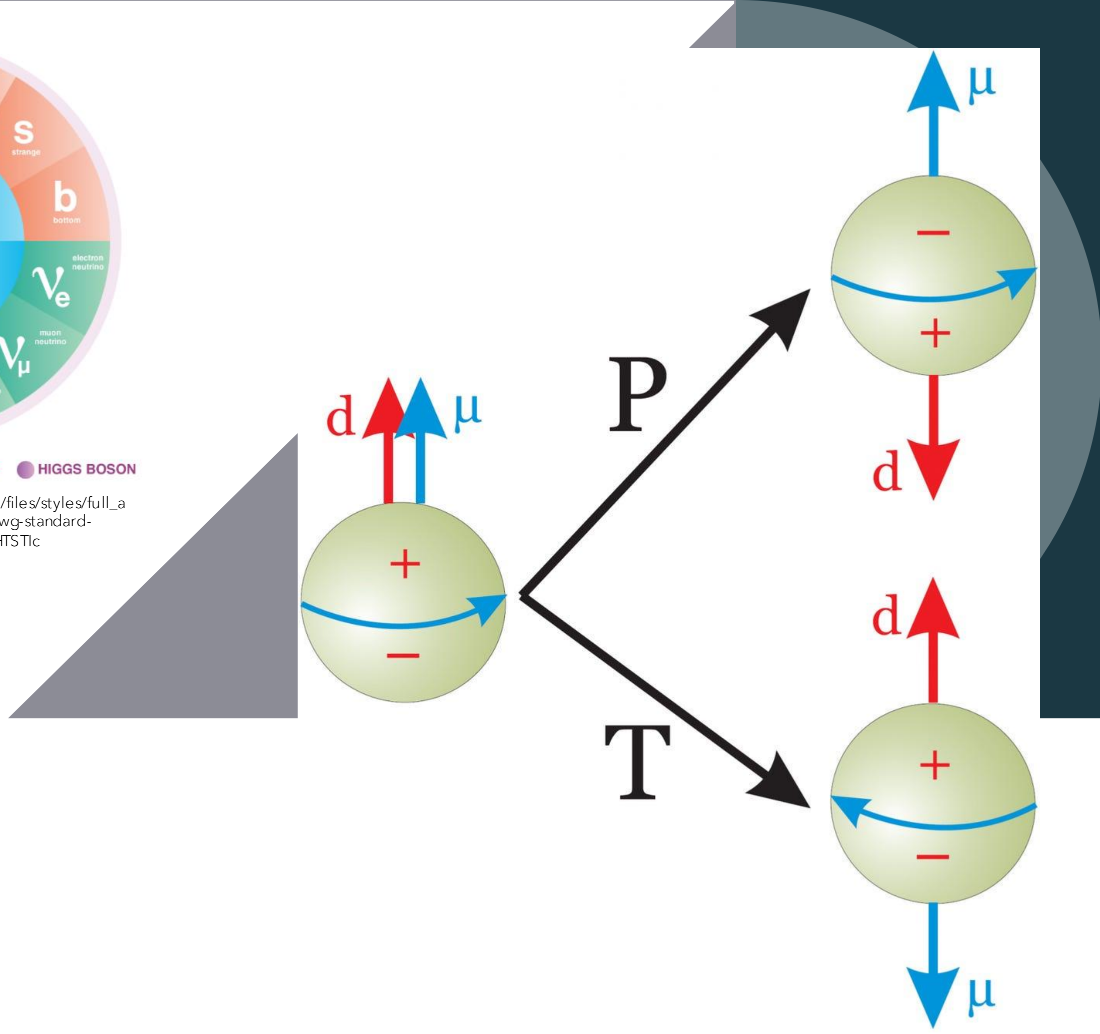
https://cdn.searchenginejournal.com/wp-content/uploads/2022/01/google-ads-experiments-61eeb097d573d-sej-760x400.webp

What is it all about?

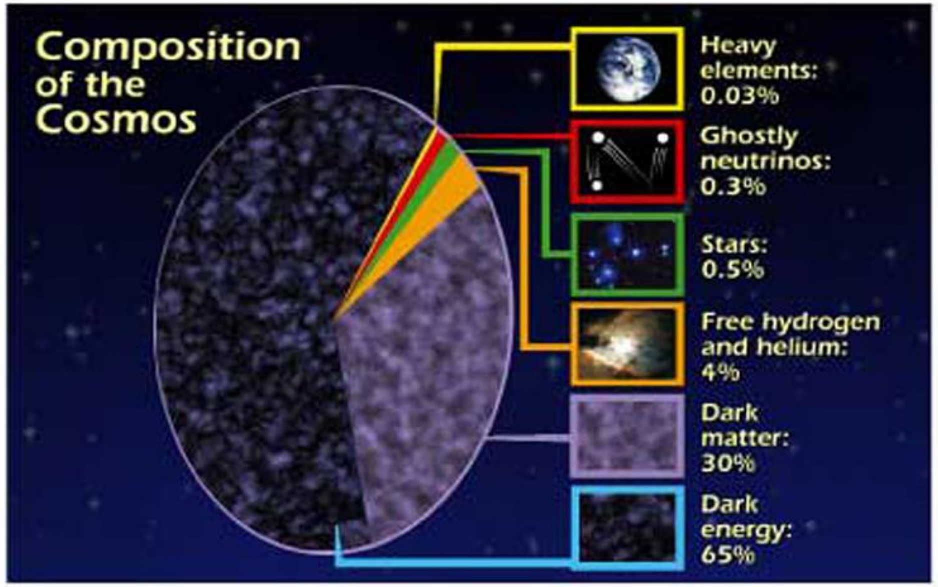
- **Strong CP problem**
- **Composition of the Universe**



https://www.energy.gov/sites/default/files/styles/full_article_width/public/2020/06/f75/gpawg-standard-model-particle-physics.png?itok=dZHTSTIc



In the Standard Model, the neutron's electric dipole moment is predicted to be a factor of ten billion larger than our observational limits show. The only explanation is that somehow, something beyond the Standard Model is protecting this CP symmetry in the strong interactions. We can demonstrate a lot of things in science, but proving that CP is conserved in the strong interactions can never be done. However, solving the strong CP problem may be closer on the horizon than almost anyone realizes. [-] PUBLIC DOMAIN WORK FROM ANDREAS KNECHT

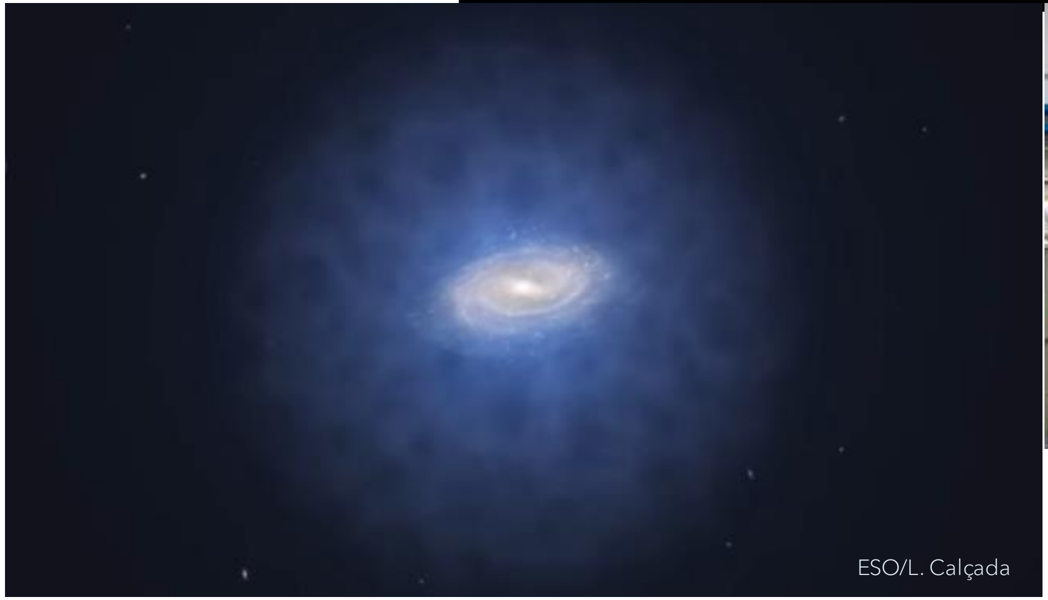


Ann Field (STScI)

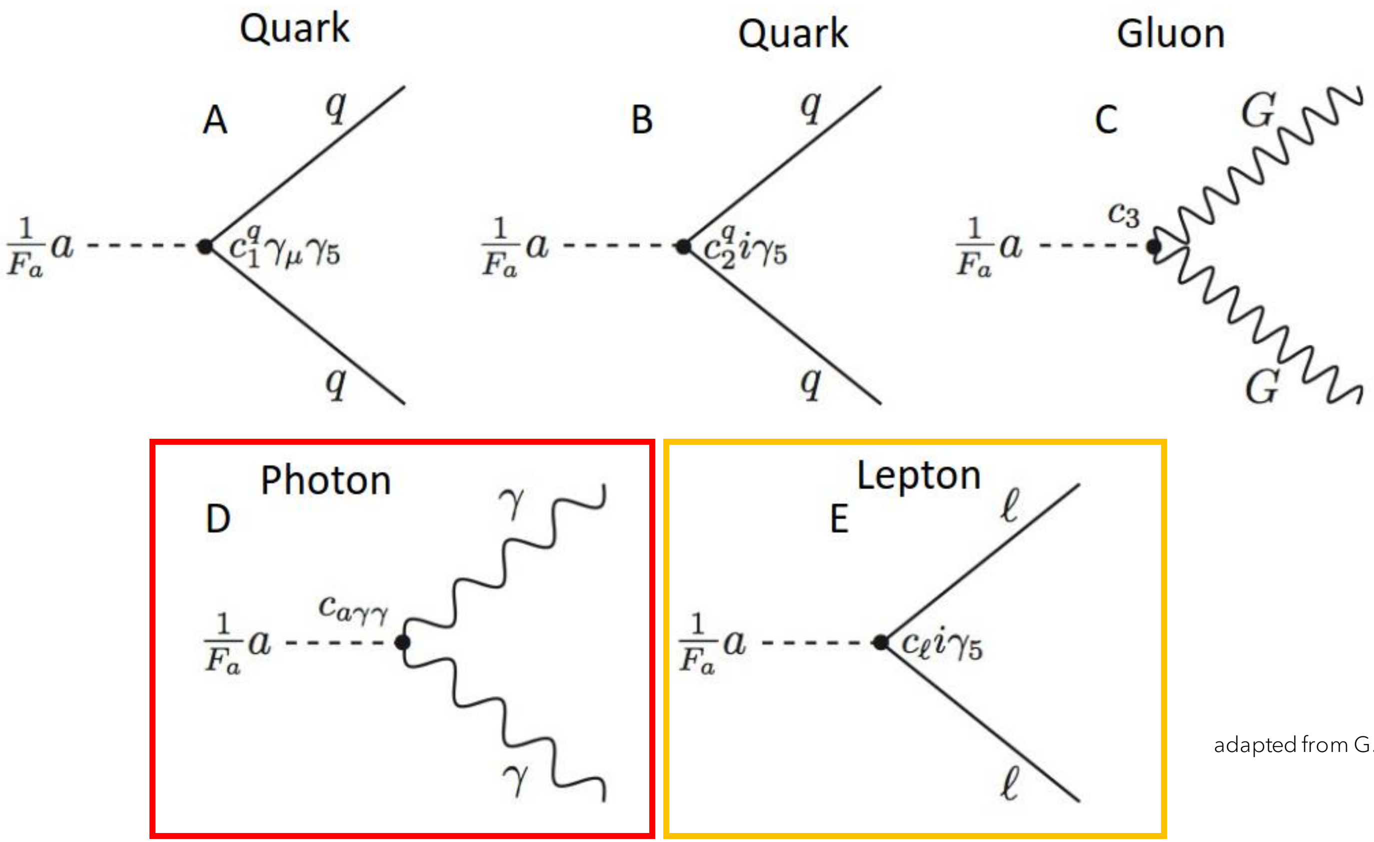
The answer?
New particle. Axion!

Strong CP problem
1977 Peccei and Quinn --> new global symmetry
--> spontaneusly broken
Wilczek and Weinberg --> new particle
pseudo-Nambu-Goldstone boson

Where find it?

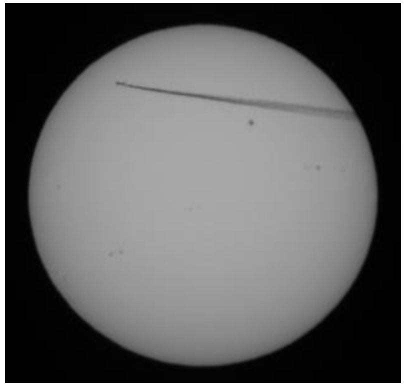


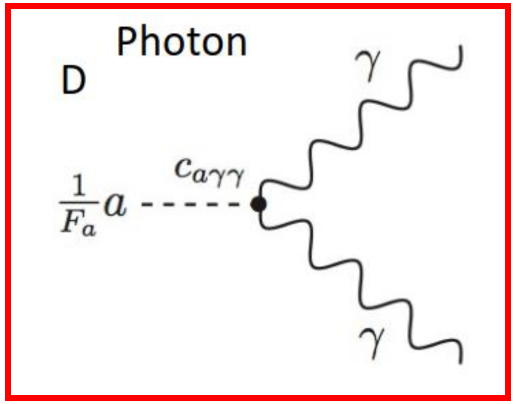
Strategy?



adapted from G. Ruoso

Most promising





Helioscopes
"*a la Sikivie*"
- CAST
- SUMICO
- BabyIAXO
- IAXO

See talk by J. Vogel

Haloscopes
- CAST
- GRAHAL
- ADMX
- CAPP
- MADMAX
- QUAX
- DM Radio
- ABRACADABRA
- ORPHEUS
- WISPDMX
- HAYSTAC
- FLASH

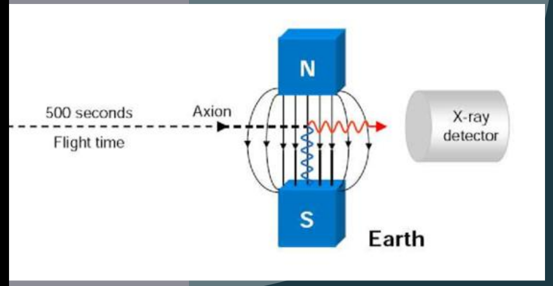
Laboratory

LSW
- ALPS
- OSQAR

Polarization
- PVLAS
- BFRT
- BMV
- OSQAR
- Q@A

CAST
- 20 years of running

P. Sikivie, PRL 51, 1415-14
(1983)



Sunset detectors
2 MicroMegas Detectors

Sunrise detectors
Up to 2013: MicroMegas, CCD & MPE XRT
Since 2014: MicroMegas & LLNL XRT, InGrid & MPE XRT , KWISP

CAST
- people

CAST

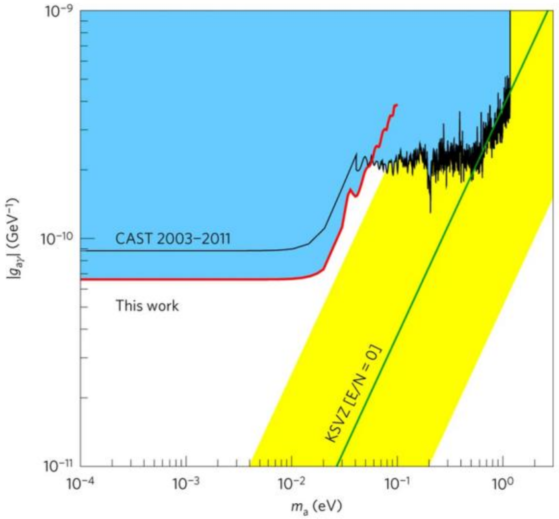
Results – helioscope, haloscope, chameleons, β_γ β_m

Open Access | Published: 01 May 2017

New CAST limit on the axion–photon interaction

CAST Collaboration

Nature Physics **13**, 584–590 (2017) | Cite this article



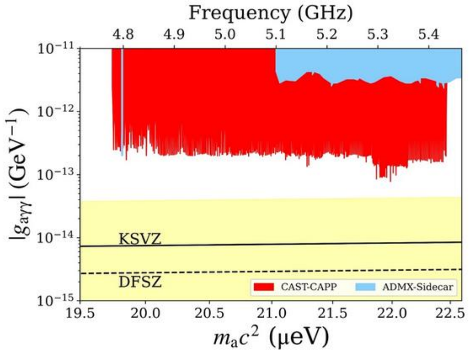
Article | Open Access | Published: 19 October 2022

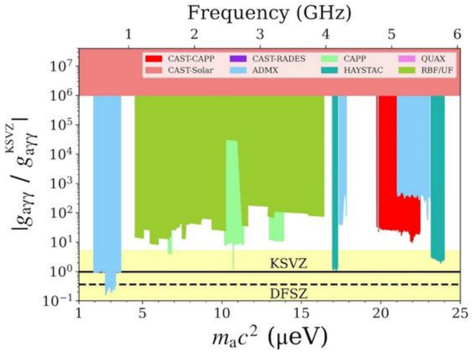
Search for Dark Matter Axions with CAST-CAPP

C. M. Adair, K. Altenmüller, V. Anastassopoulos, S. Arguedas Cuendis, J. Baier, K. Barth, A. Belov, D. Bozicevic, H. Bräuninger, G. Cantatore, F. Caspers, J. F. Castel, S. A. Çetin, W. Chung, H. Choi, J. Choi, T. Dafni, M. Davenport, A. Dermenev, K. Desch, B. Döbrich, H. Fischer, W. Funk, J. Galan, ... K. Zioutas

+ Show authors

Nature Communications **13**, Article number: 6180 (2022) | Cite this article





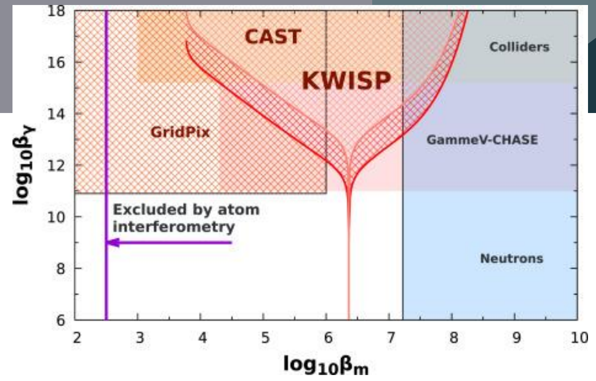
Physics of the Dark Universe

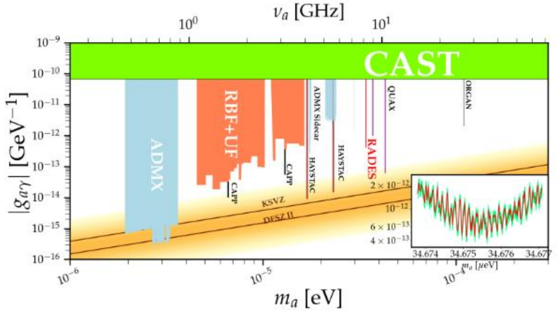
Volume 26, December 2019, 100367

ELSEVIER

First results on the search for chameleons with the KWISP detector at CAST

S. Arguedas Cuendis [g], J. Baier [e], K. Barth [g], S. Baum [p q], A. Bayirli [i 1], A. Belov [l], H. Bräuninger [f], G. Cantatore [r s], J.M. Carmona [h], J.F. Castel [v], S.A. Cetin [i], T. Dafni [v], M. Davenport [g], A. Dermenev [l], K. Desch [a], B. Döbrich [g], H. Fischer [e], W. Funk [g], J.A. García [v 2], A. Gardikiotis [m]...K. Zioutas [m g]





Regular Article - Experimental Physics | Open Access | Published: 08 October 2021

First results of the CAST-RADES haloscope search for axions at 34.67 μeV

A. Álvarez Melcón, S. Arguedas Cuendis, J. Baier, K. Barth, H. Bräuninger, S. Calatroni, G. Cantatore, F. Caspers, J. F. Castel, S. A. Cetin, C. Cogollos, T. Dafni, M. Davenport, A. Dermenev, K. Desch, A. Díaz-Morcillo, B. Döbrich, H. Fischer, W. Funk, J. D. Gallego, J. M. García Barceló, A. Gardikiotis, J. G. Garza, B. Gimeno, ... K. Zioutas + Show authors

Journal of High Energy Physics **2021**, Article number: 75 (2021) | Cite this article

Physics Letters B

Volume 749, 7 October 2015, Pages 172-180

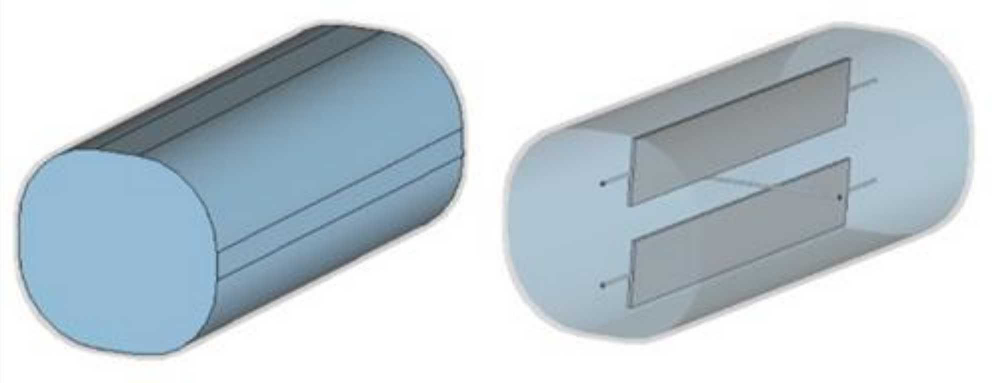
ELSEVIER

Search for chameleons with CAST

V. Anastassopoulos [a], M. Arik [b 1], S. Aune [c], K. Barth [d], A. Belov [e], H. Bräuninger [f], G. Cantatore [g], J.M. Carmona [h], S.A. Cetin [b], F. Christensen [i], J.I. Collar [j], T. Dafni [h], M. Davenport [d], K. Desch [k], A. Dermenev [e], C. Eleftheriadis [l], G. Fanourakis [m], E. Ferrer-Ribas [c], P. Friedrich [f], J. Galán [c]...A. Upadhye [z]

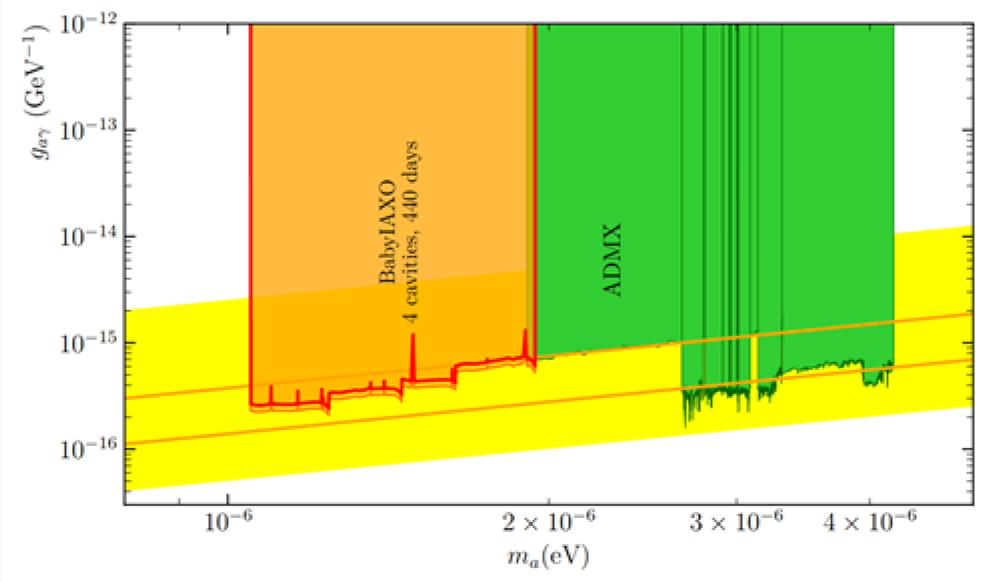
RADES (Relic Axion Detector Exploratory Setup)

Proposal for a haloscope setup in BabyIAXO:



Up to four quasi-cylindrical cavities of 5m with two rotating metallic plates each.
Placed inside the BabyIAXO bore.

Sensitivity prospect

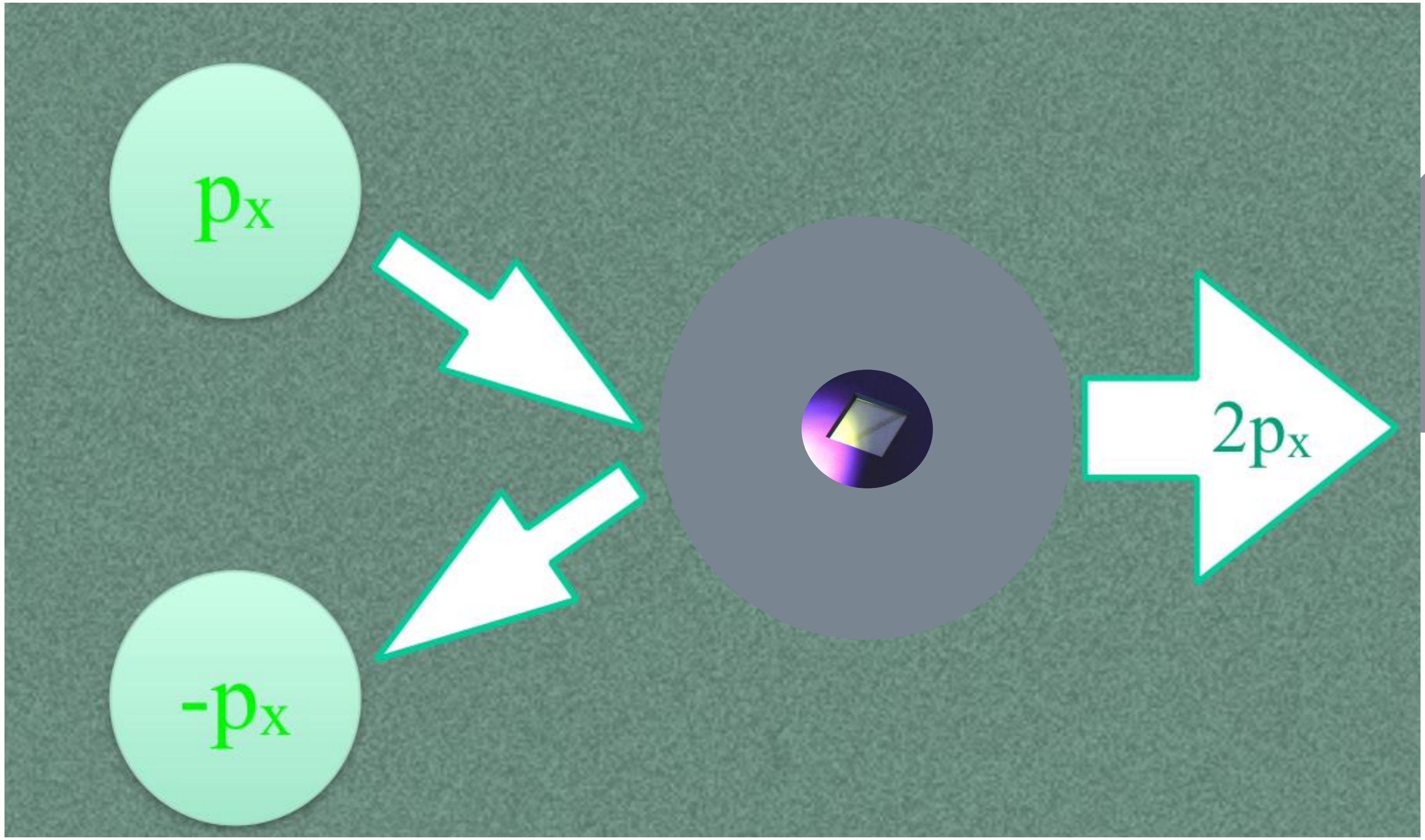


Worldwide collaboration:

Open Postdoc position for an experimental physicist at the Max Planck Institute for Physics in Munich!
https://inspirehep.net/jobs/2611376

Universidad Zaragoza · ICCUB · Universitat de Barcelona · Max-Planck-Gesellschaft · IFIC Institut de Física Corpuscular · CERN · LSC Laboratorio Subterráneo Canfranc

KWISP



Coherent Scattering of Low Mass Dark Matter from Optically Trapped Sensors

Gadi Afek, Daniel Carney, and David C. Moore

Phys. Rev. Lett. **128**, 101301 – Published 9 March 2022

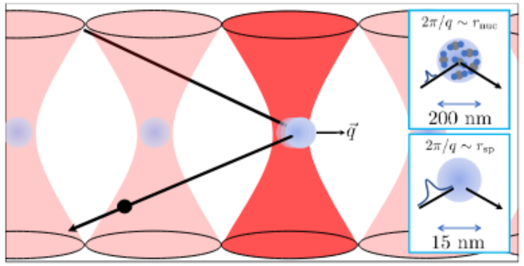


FIG. 1. As a dark matter particle scatters from a levitated optomechanical sensor (possibly part of a large array), it transfers to it momentum $\vec{q}$. For "large" sensors (upper inset) the interaction is coherent over a single nucleus. For "small" enough sensors, such that the inverse transferred momentum $2\pi/q$ of the dark matter particle is comparable to the size of the sensor, the interaction is coherent over the entire sensor, leading to a large increase in scattering cross-section.

Develop a radiation pressure detector!

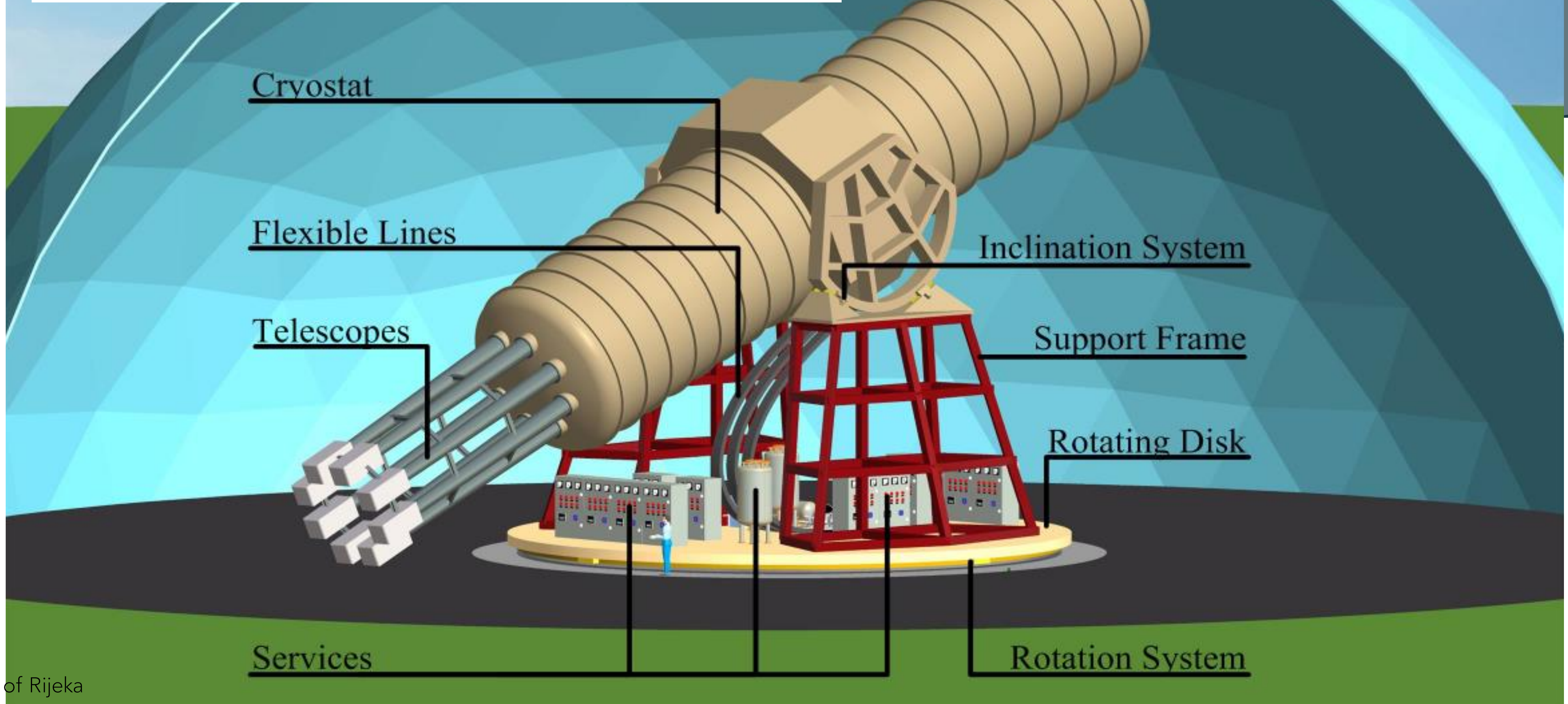
-measure momentum transfer

- high sensitivty

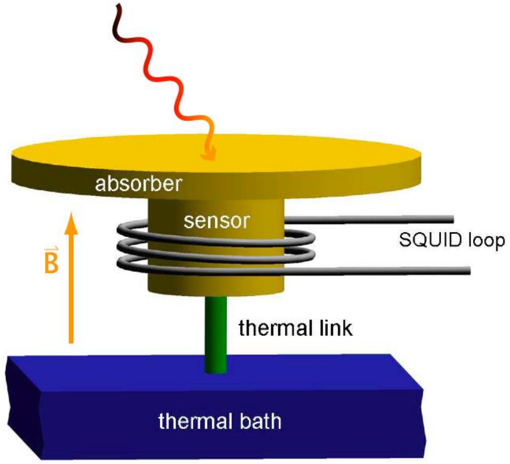
The International AXion Observatory

- **Large toroidal 8-coil magnet L ≃ 20 m**
- **8 bores: 60 cm diameter each**
- **8 x-ray telescopes + 8 detection systems**
- **Rotating platform with services**

Conceptual Design of the International Axion Observatory
Armengaud et al. *JINST* 9 T05002 (2014)



Low temperature metallic magnetic calorimeters (MMCs)



Fast risetime
Reduction un-resolved pile-up

Extremely good energy resolution
Reduced smearing in the end point region

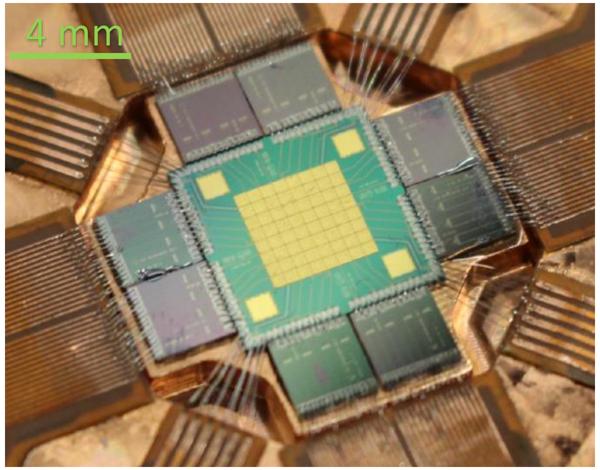
Excellent linearity
precise definition of the energy scale

40 m2 Cleanroom class 100
at Kirchhoff Institute for Physics

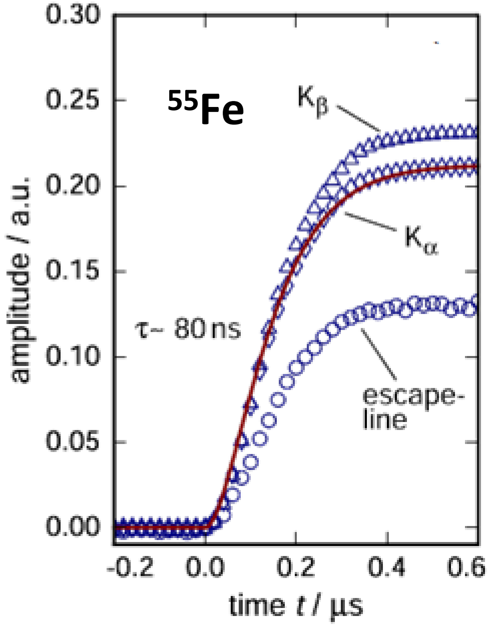
A.Fleischmann, C. Enss and G. M. Seidel,
Topics in Applied Physics **99** (2005) 63

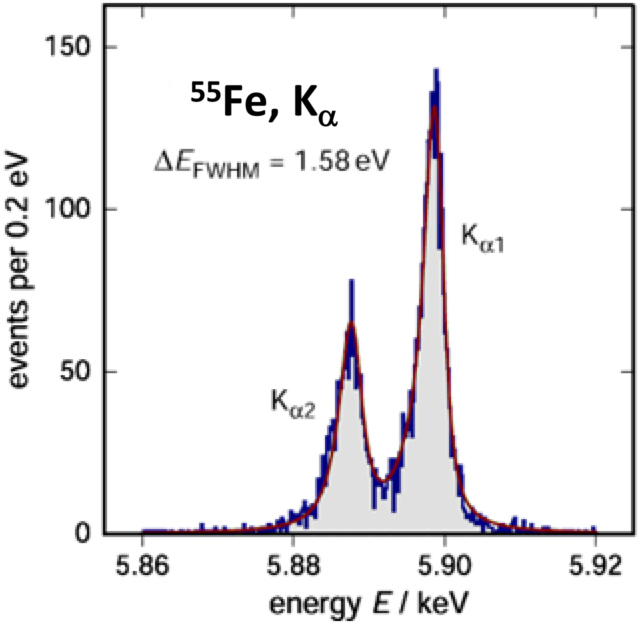
A.Fleischmann et al.,
AIP Conf. Proc. **1185** (2009) 571

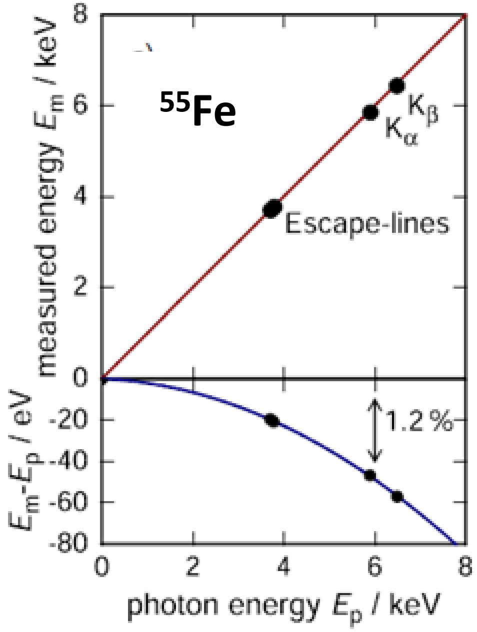
L. Gastaldo et al.,
Nucl. *Inst. Meth. A*, **711** (2013) 1

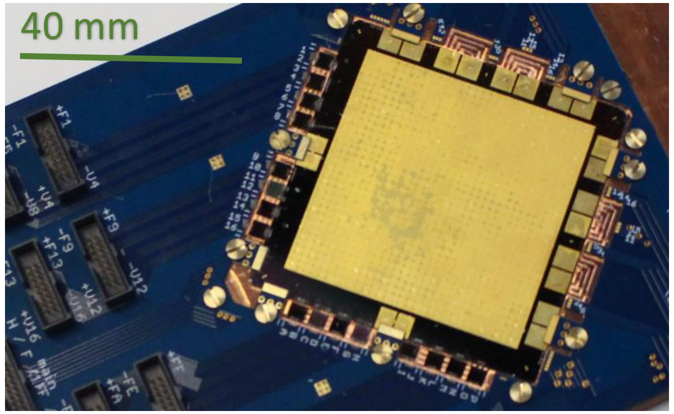


Focal plane detector for IAXO 64 pixels





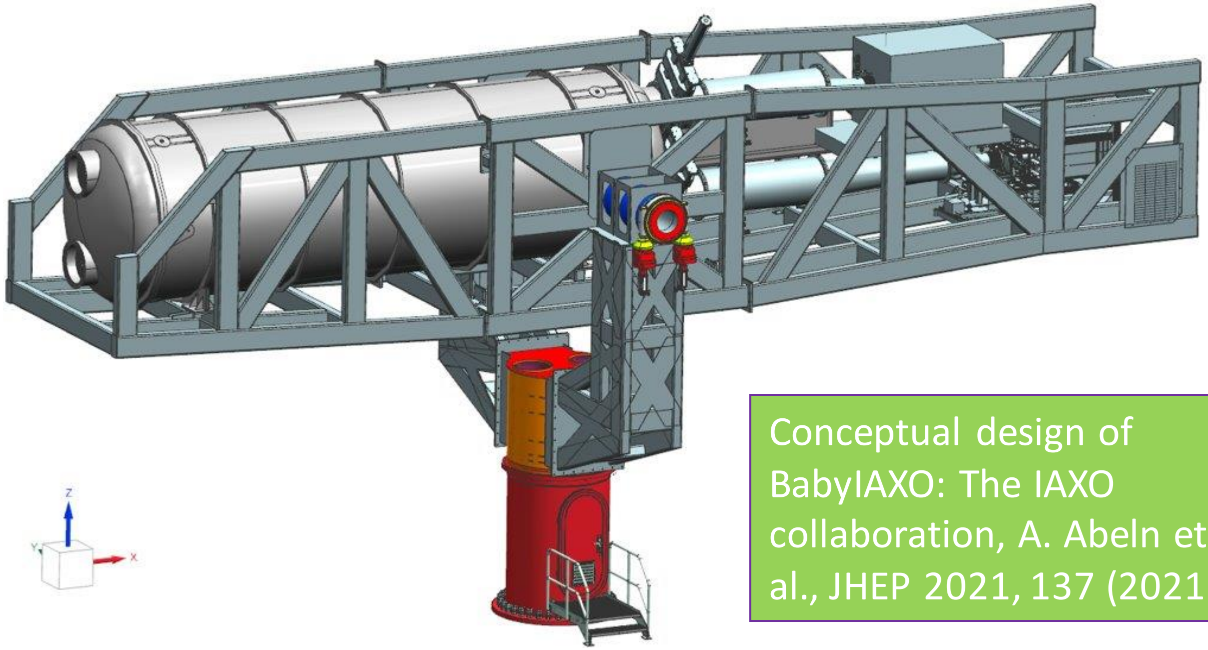




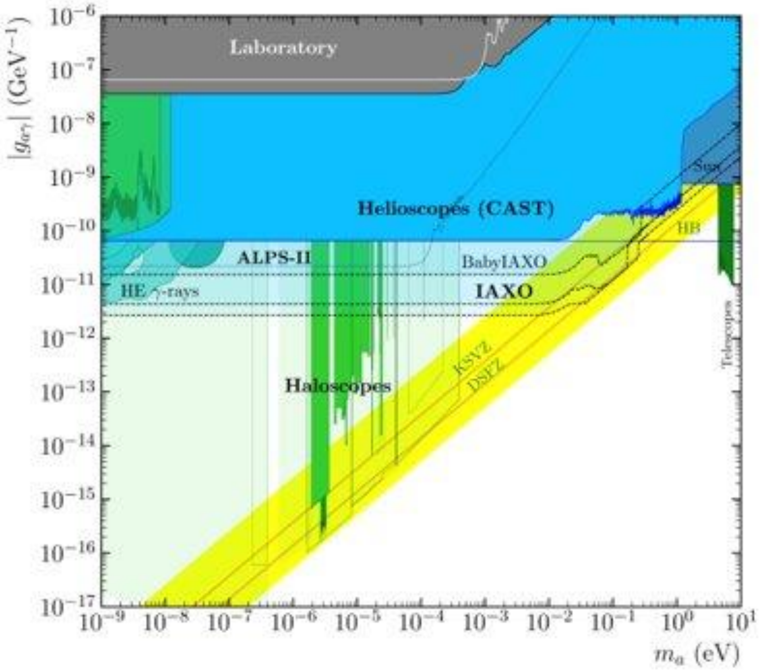
MOCCA system for
mass spectrometry @CSR
4096 pixels

CA21106

The International AXion Observatory



Conceptual design of BabyIAXO: The IAXO collaboration, A. Abeln et al., JHEP 2021, 137 (2021)



- Technological prototype with only two magnet bores (10 m, ⌀ 70 cm)
- 2 detection lines with one x-ray telescope and one ultra-low background detector each
- Moving platform to track the Sun

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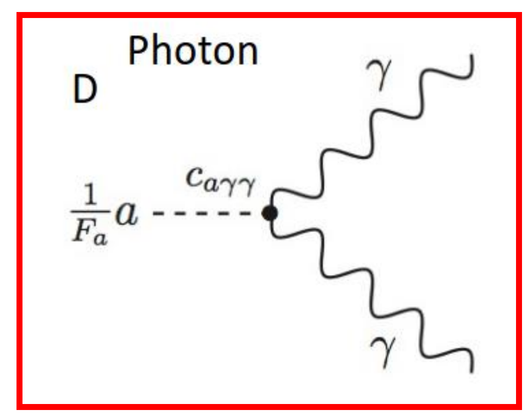
Back on track



Haloscopes

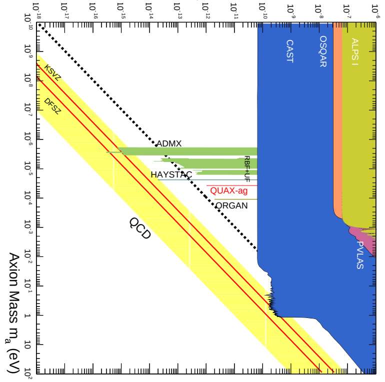
- CAST
- GRAHAL
- ADMX
- CAPP
- MADMAX
- QUAX
- DM Radio
- ABRACADABRA
- ORPHEUS
- WISPDMX
- HAYSTAC
- FLASH

QUAX-aγ Result with Superconductive Resonant Cavity at m_a = 37.5 meV, Phys. Rev. D **99**, 101101(R) (2019).

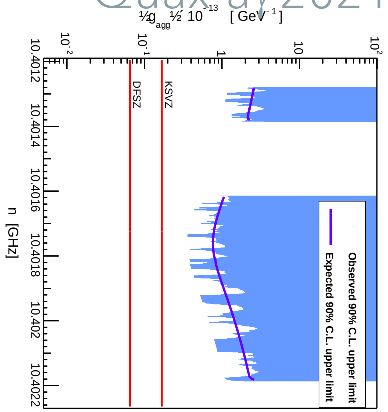
Search for Invisible Axion Dark Matter of mass m_a = 43 meV with the QUAX-ag Experiment, Phys. Rev. D 103, 102004 (2021).

Search for Galactic Axions with high-Q Dielectric Cavity, Phys. Rev. D 106, 052007 (2022).

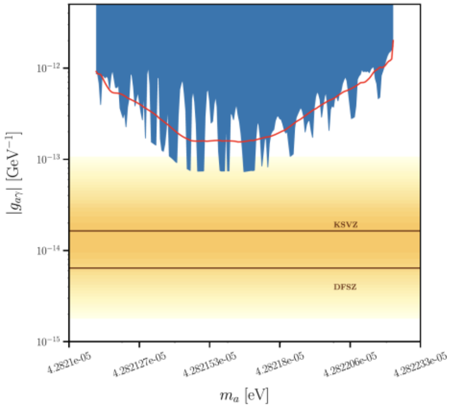
Quax-aγ 2019



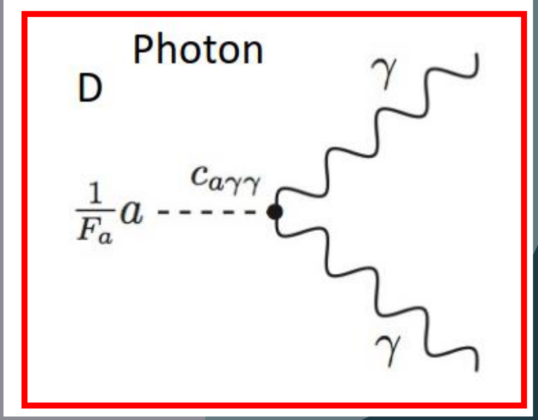
Quax-aγ 2021



Quax-aγ 2022



Back on track



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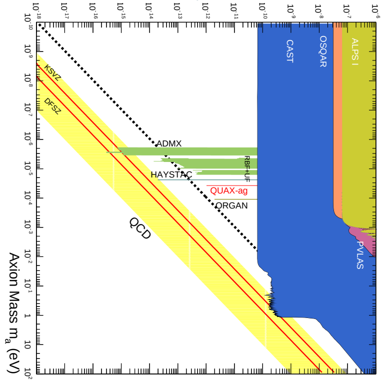
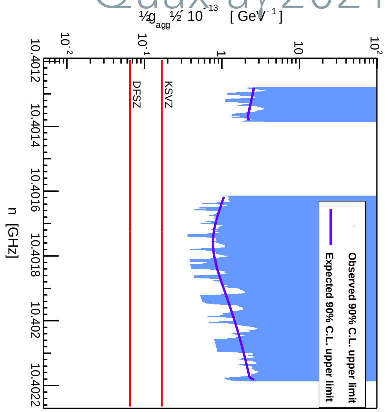
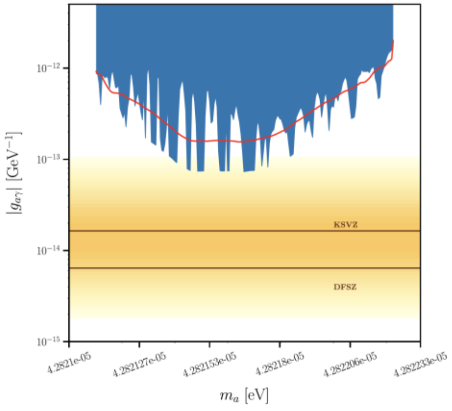
Quax-aγ 2019



Quax-aγ 2021



Quax-aγ 2022



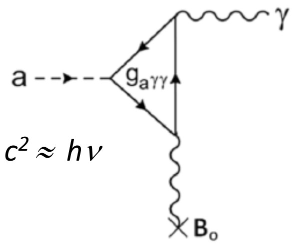
GrAHal - QUAX - CAPP

Grenoble Axion Haloscopes

Contact: pierre.pugnat@lncmi.cnrs.fr

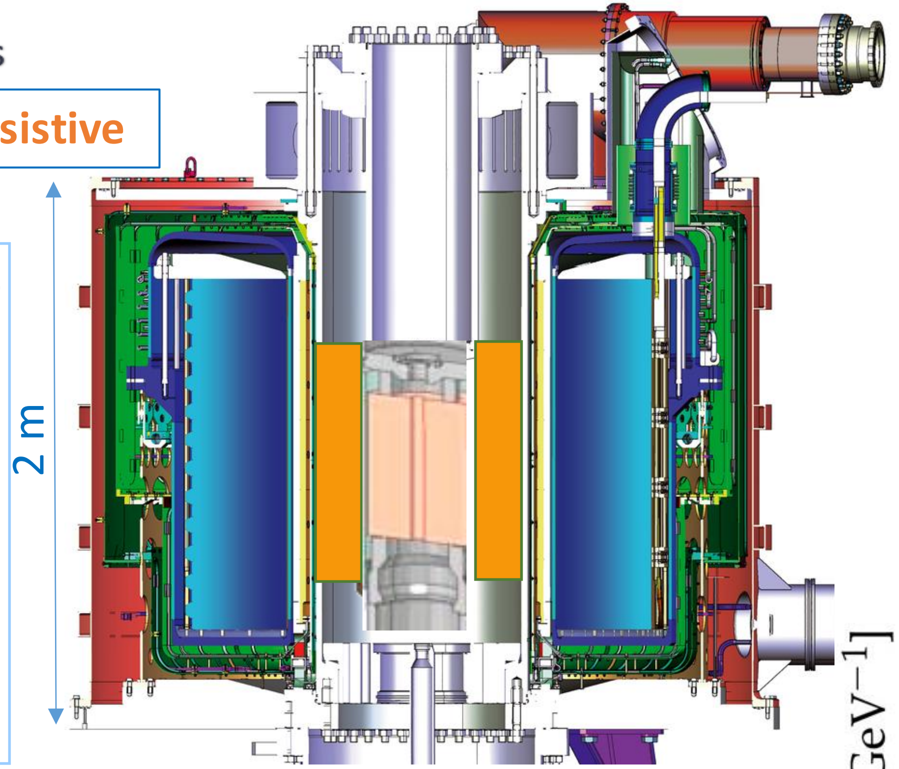
Hybrid Magnet = Sc + Resistive

Inverse Primakoff Effect



Sikivie's haloscope i.e. with RF cavity

$P \;\alpha\; g_{a\gamma\gamma}^2 B_0^2 V < 10^{-21}$ W

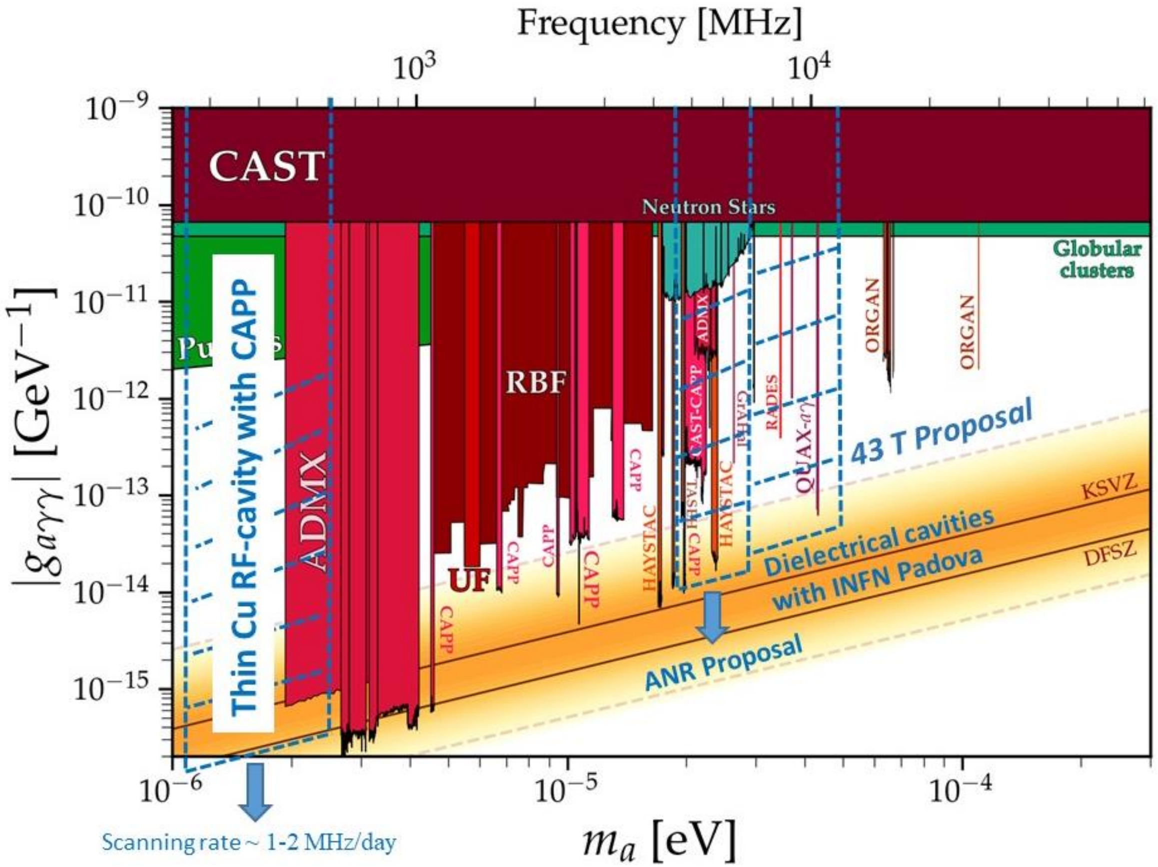


Grenoble Hybrid Magnet is in the commissioning phase, operation foresees in 2024

► *See Talk of P. Pugnat this Friday afternoon*

GrAHal first results in a 14 T superconducting magnet

https://arxiv.org/abs/2110.14406



Adapted from https://github.com/cajohare/AxionLimits/

Scientific case within the European Strategy of Particles Physics (ESPP)
https://www.nature.com/articles/s41567-020-0838-4

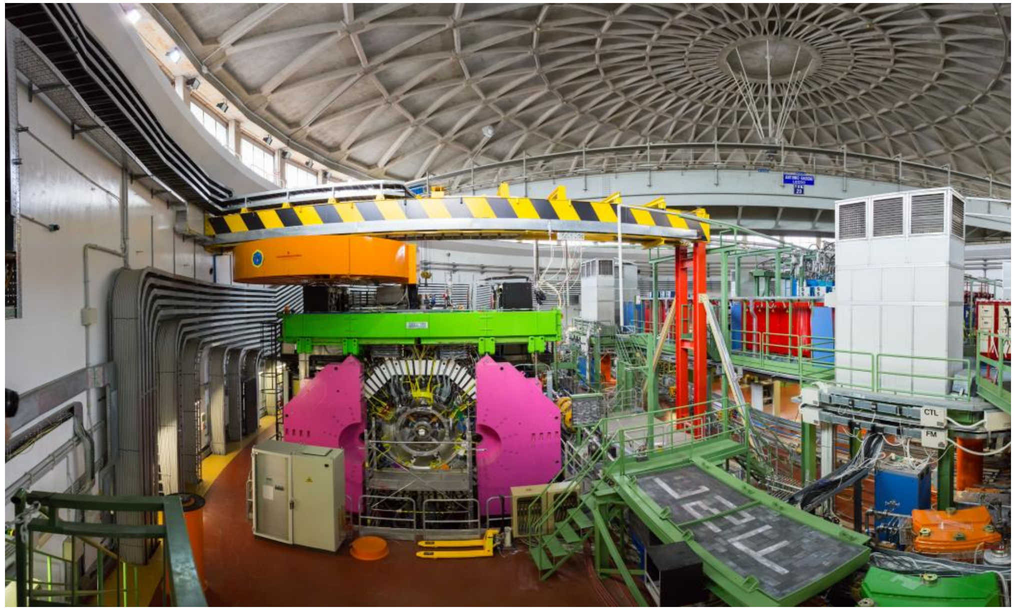
Field	Warm dia.	RF-cavity dia.	Freq. TM010	Axion mass
43 T	34 mm	20 mm	11.5 GHz	47.2 µeV
40 T	50 mm	34 mm	6.76 GHz	27.8 µeV
27 T	170 mm	86 mm	2.67 GHz	11 µeV
17.5 T	375 mm	291 mm	0.79 GHz	3.2 µeV
9.5 T	812 mm	700 mm	0.33 GHz	1.4 µeV

LNCMI

NÉEL institut

FLASH (previously KLASH): Finuda Magnet for Light Axion SearcH at 100-300 MHz

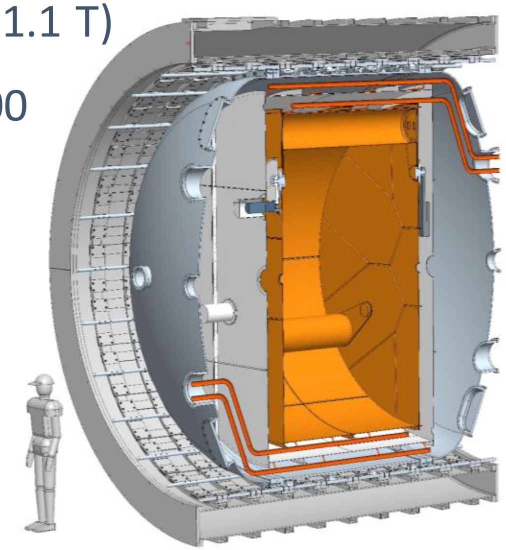
Recycling of the 1.1T, 3 m diameter, magnet of FINUDA experiment for a haloscope operating at 100 to 300 MHz



Magnet test foreseen in 2023

- Search of galactic axions in the mass range 0.5-1.5 μeV
- Large volume RF Cavity (4 m^3)
- Moderate magnetic field (1.1 T)
- Copper rf cavity Q~500,000
- T 4.5 K

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati



KLASH CDR arxiv:1911.02427

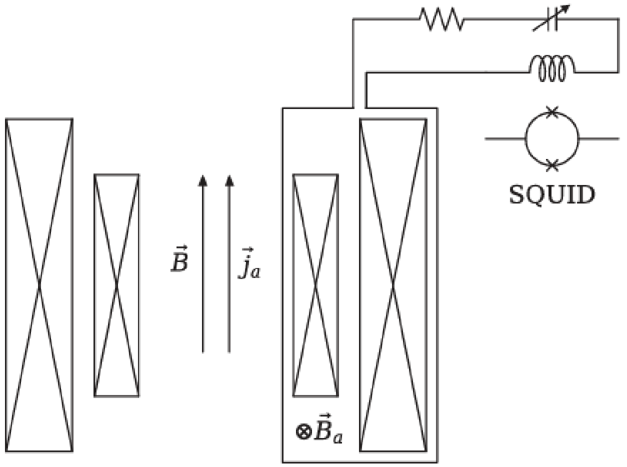
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

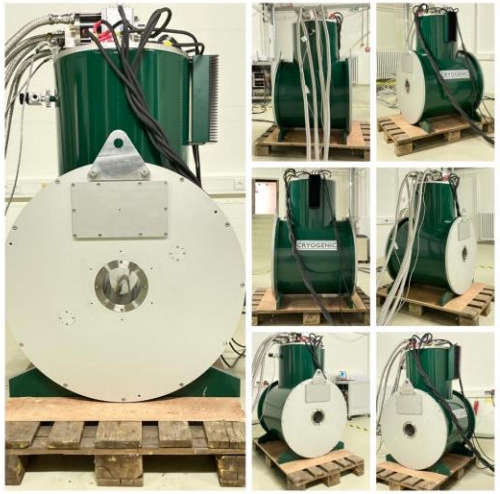
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

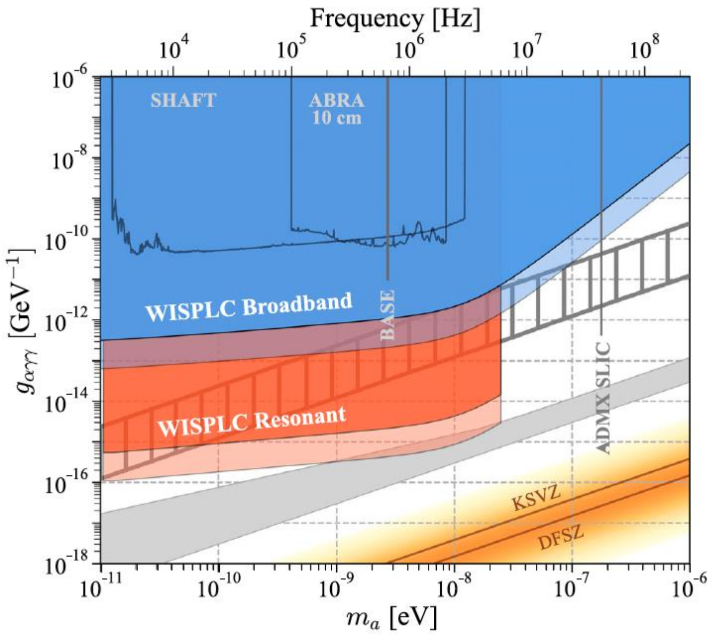
Dark Matter searches with WISPLC experiment

- External magnetic field from a 14 T solenoid magnet generates an axion-induced oscillating displacement current $\mathbf{j_a}$.
- This induces a toroidal magnetic field $\mathbf{B_a} \perp \mathbf{j_a}$ which creates an alternating EMF in a pickup loop.
- The EMF induced current can be pumped up by an LC circuit and picked up by a SQUID magnetometer.





- ➢ Broadband and resonant detection through a tunable LC circuit with a $Q \sim 10^4$.
- ➢ $g_{a\gamma\gamma} \sim 10^{-15}\mathrm{GeV}^{-1}$ for axion mass between 10^{-11} and 10^{-6} eV.
- ➢ Additional Gravitational Wave sensitivity (https://doi.org/10.1103/PhysRevLett.129.041101)



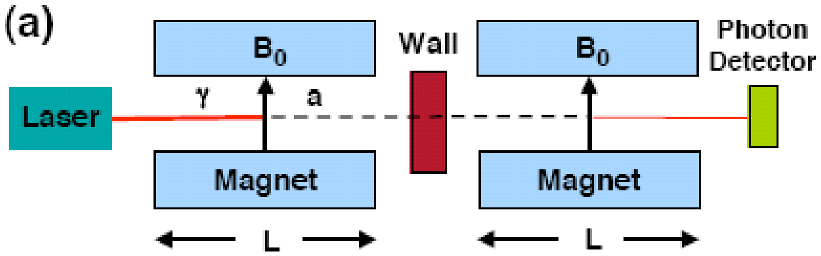
https://doi.org/10.1103/PhysRevD.106.023003

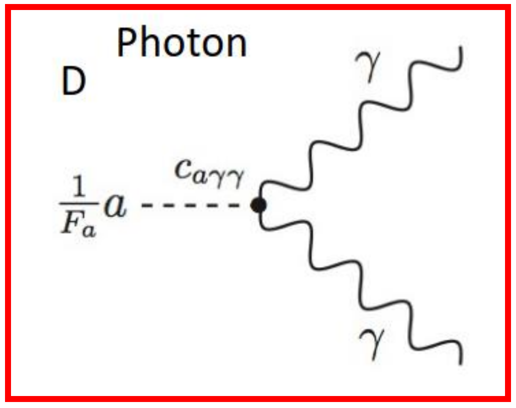
Laboratory

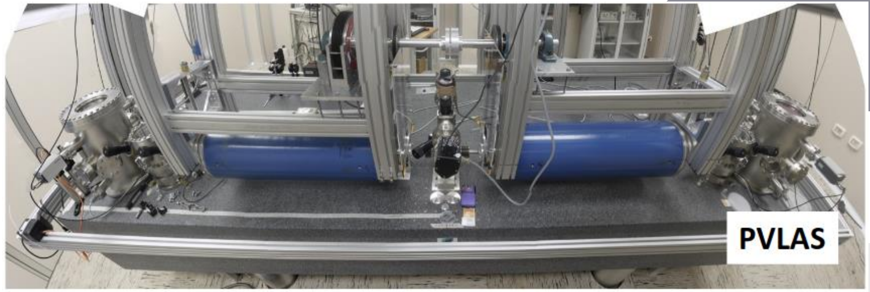
LSW
- ALPS
- OSQAR

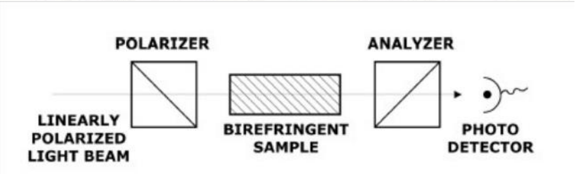
Polarization
- PVLAS
- BFRT
- BMV
- OSQAR
- Q@A

It's between these last two magnets where light is supposed to shine through the wall when ALPS II goes into operation.
Credit: DESY / Heiner Müller-Elsner

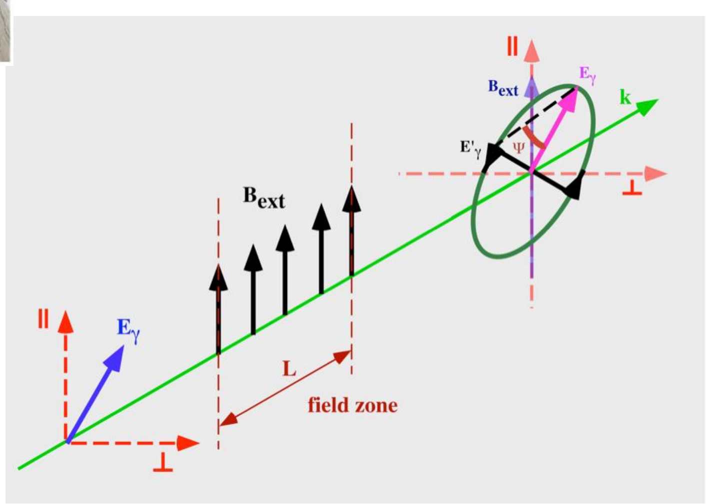








L.Maiani, R. Petronzio, E. Zavattini, Phys. Lett B, Vol. 173, no.3 1986

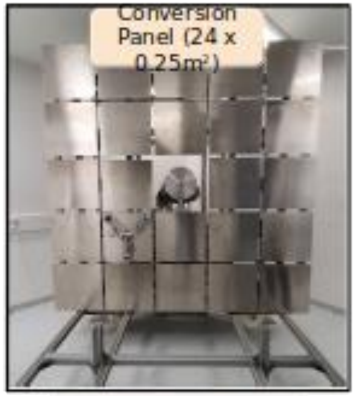


BRASS-p Experiment

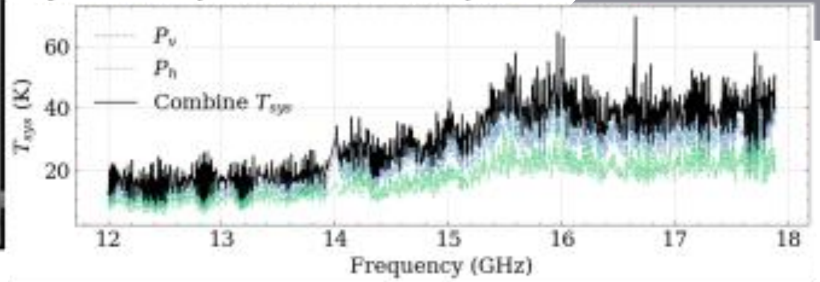
Collaboration between University of Hamburg[1] and MPI for Radioastronomy[2]

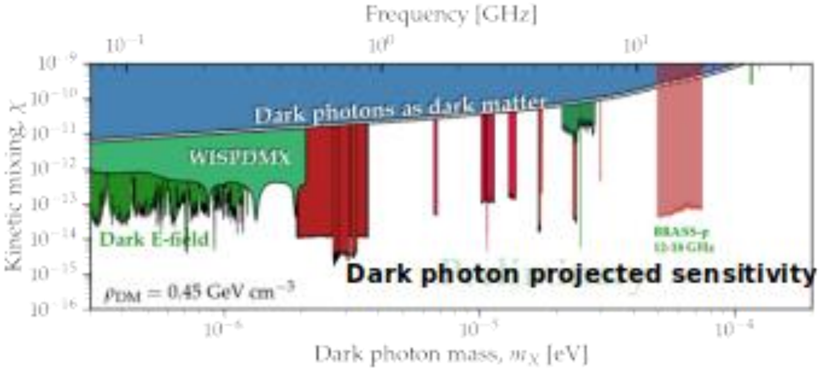
Le Hoang Nguyen[1], Dieter Horns[1], Andrei Lobanov[2]

- **Broadband dish antenna experiment (A = 4.7 m²)**
- **Receiver and digital backend technology from radioastronomy**
- **Open experiment with cryogenic frontend** $T_{sys} \approx 10-40\,\mathrm{K}$
- **Sensitive frequency from 12-18 GHz**
- **Permanent magnet panel for axion search** $B = 0.8\,\mathrm{Tesla}$

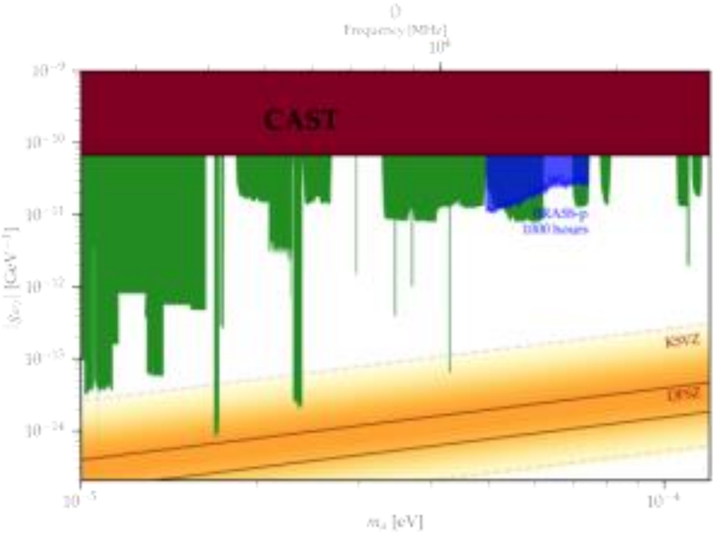


System temperature from two polarizations





Dark photon projected sensitivity



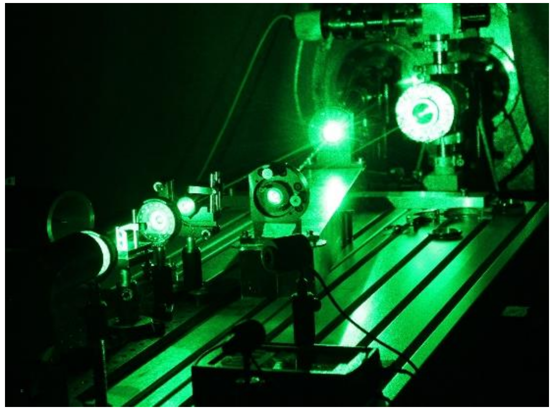
Axion/Alps projected sensitivity

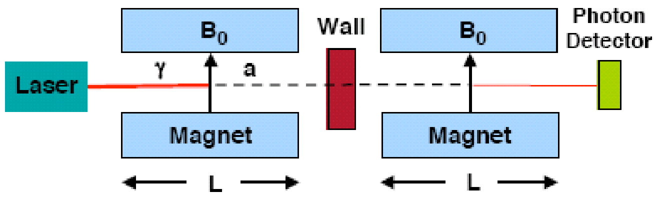
OSQAR – LSW (Light Shinning through Wall)

ALPs search from laser based experiment

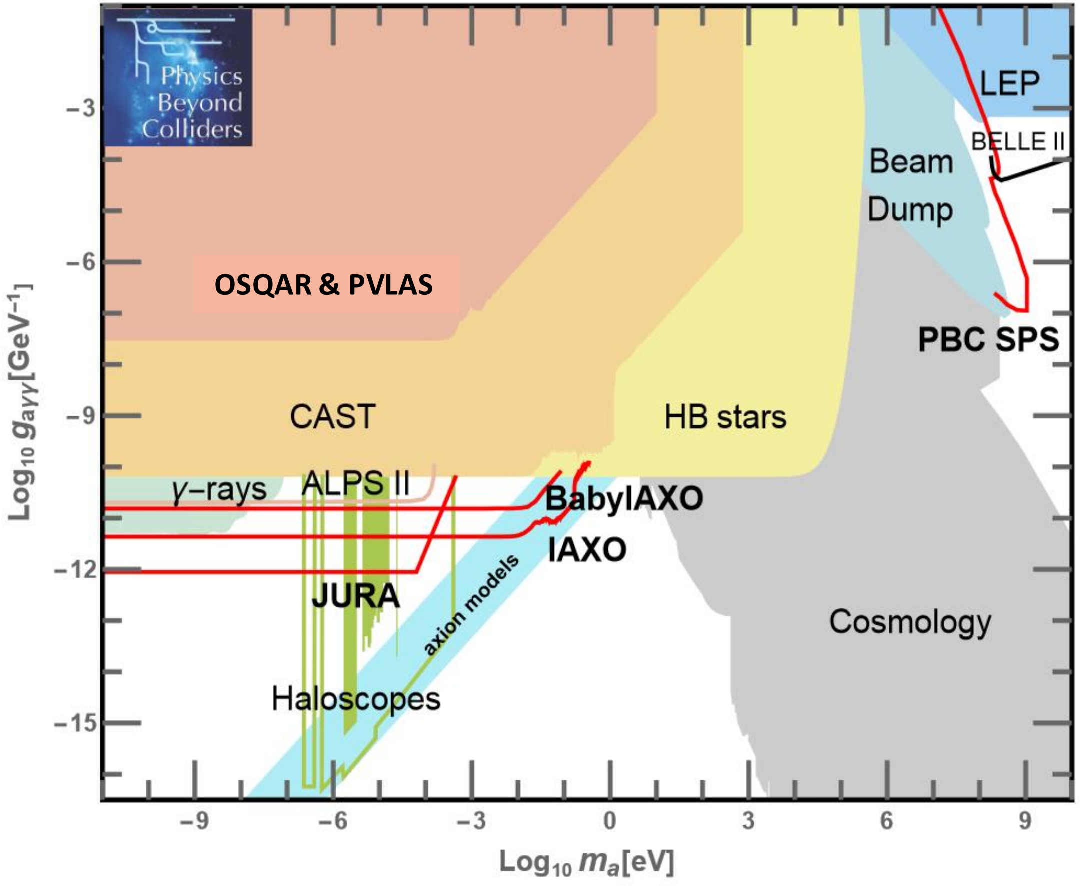
Contact: pierre.pugnat@lncmi.cnrs.fr

- Present reference results for laser experiment based on the use at CERN of 2 LHC dipoles powered to 9 T





Phys. Rev. D 92, 092002 (2015)



https://arxiv.org/pdf/1902.00260.pdf

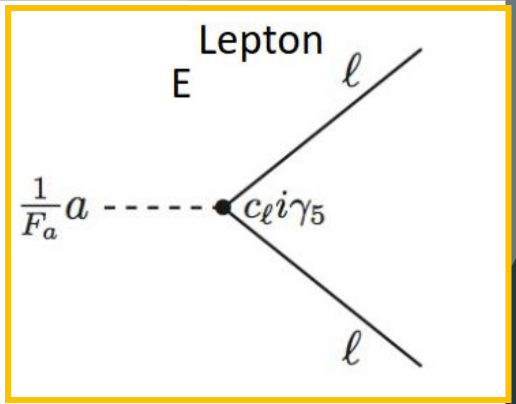
- OSQAR will be soon overpassed by ALPS II at DESY

- Futur within JURA (Join Undertaking Research of Axion)
  - OSQAR+ within the framework of Baby-JURA (under consideration with more than 2 LHC dipoles)

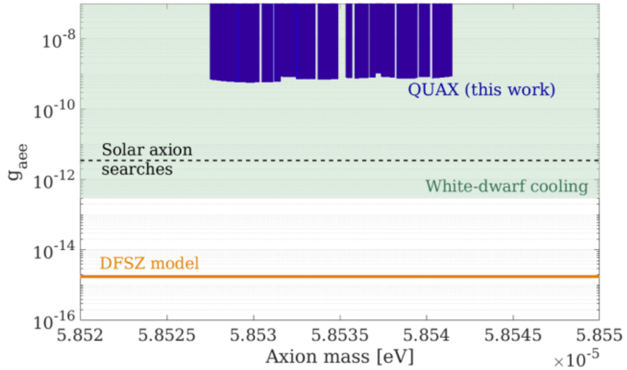
QUAX

QUAX-ae result with Ferromagnetic Axion Haloscope at m_a = 58 meV, EPJC (2018) 78:703.

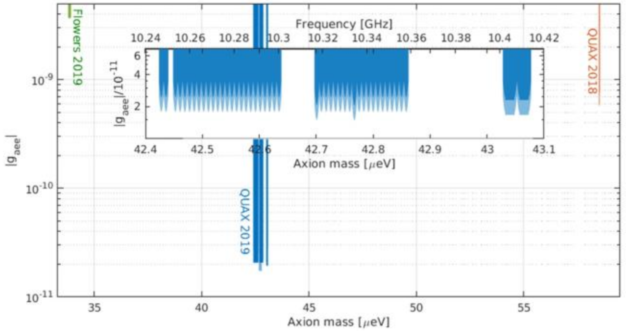
QUAX-ae with Quantum-Limited Ferromagnetic Haloscope, Phys. Rev. Lett. **124**, 171801 (2020).



Quax-ae 2018



Quax-ae 2020



QUAX

INFN PADOVA Istituto Nazionale di Fisica Nucleare Sezione di Padova

TIFPA Trento Institute for Fundamental Physics and Applications

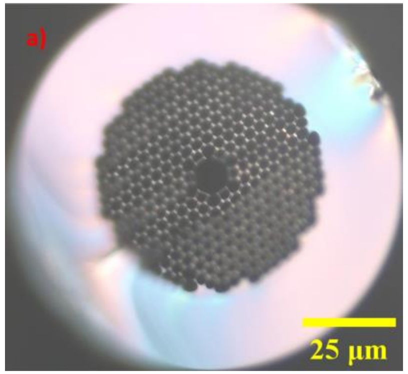
INFN Gruppo Collegato di Salerno Sezione di Napoli Istituto Nazionale di Fisica Nucleare

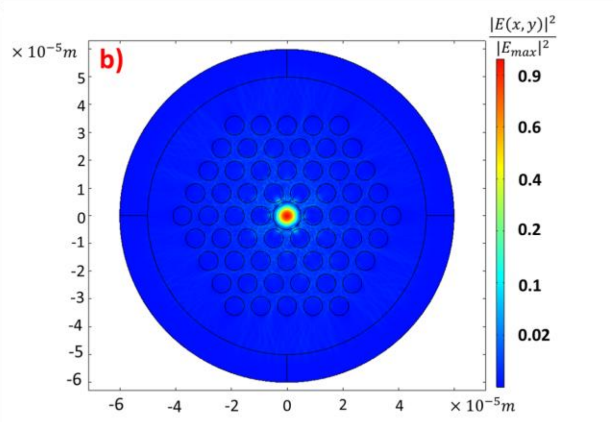
UNIVERSITY OF BIRMINGHAM

And new collaborations with SQMS, SUPERGALAX, NÉEL institut

WISP Searches on a Fiber Interferometer (WISPFI)

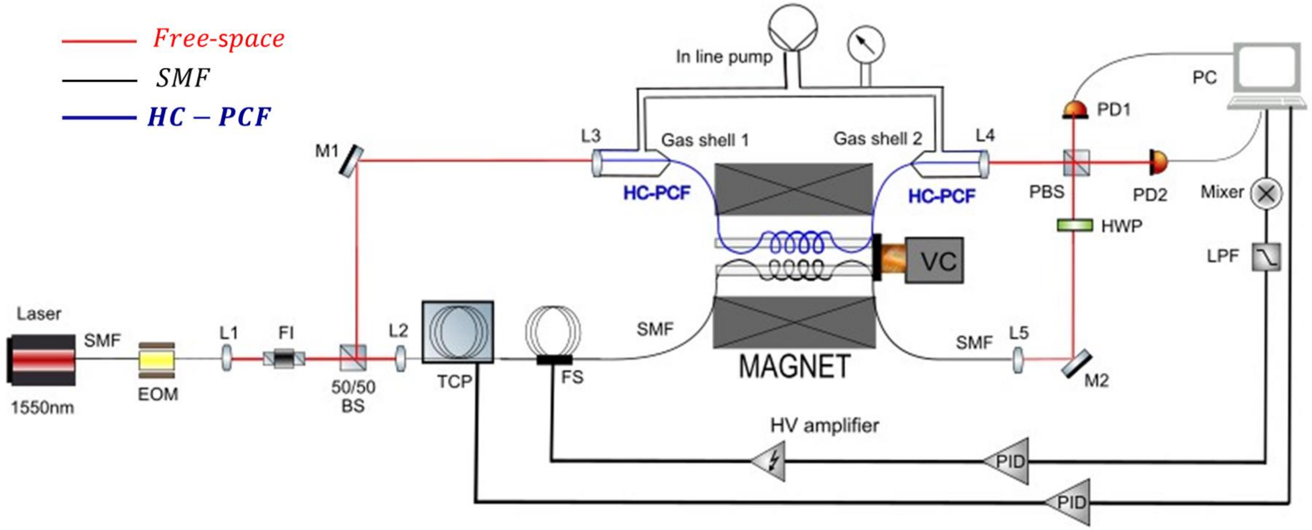
- Table-top experiment independent on local Dark Matter density.
- Partial free-space Mach-Zhender Interferometer.
- Use of a superconducting solenoid 14 T magnet for photon – axion conversion.
- Use of HC-PCF for axion detection at resonant mixing.





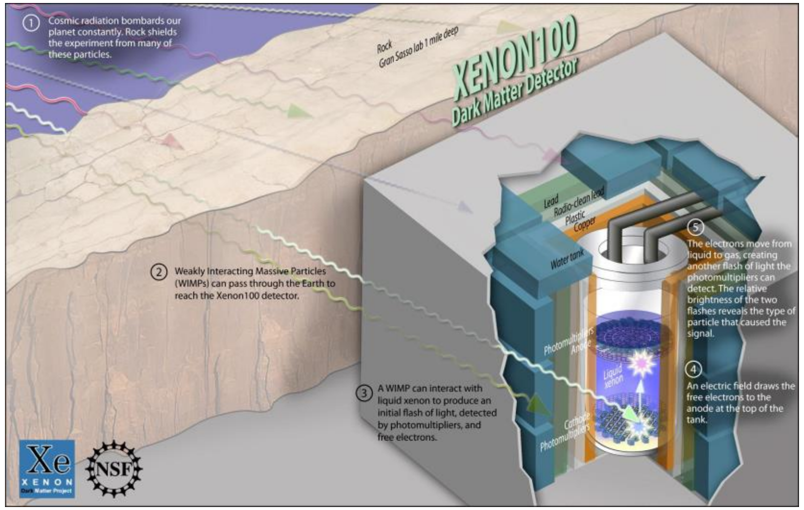
Comsol Multiphysics

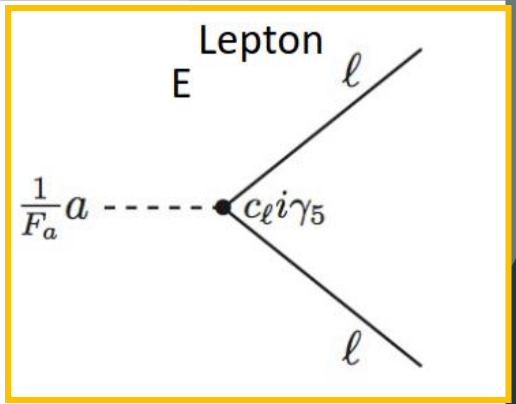
- ➢ γ → a conversion introduces a **phase-shift** and an **amplitude reduction**.
- ➢ Conversion probability: $P_{\gamma \to a} \propto g_{a\gamma\gamma}^2 \left(BL_{\text{fib}}\right)^2$
- ➢ Tuning in a *wide* range of axion masses (0-120 meV) by changing the effective mode index inside the fiber through pressurization: $m_a = \omega\sqrt{1 - n_{eff}^2(\lambda, p, T, R_c)}$



Marin Karuza, University of Rijeka

NOT ONLY





First axion results from the XENON100 experiment

E. Aprile *et al.* (XENON100 Collaboration)

Phys. Rev. D **90**, 062009 – Published 9 September 2014; Erratum Phys. Rev. D **95**, 029904 (2017)

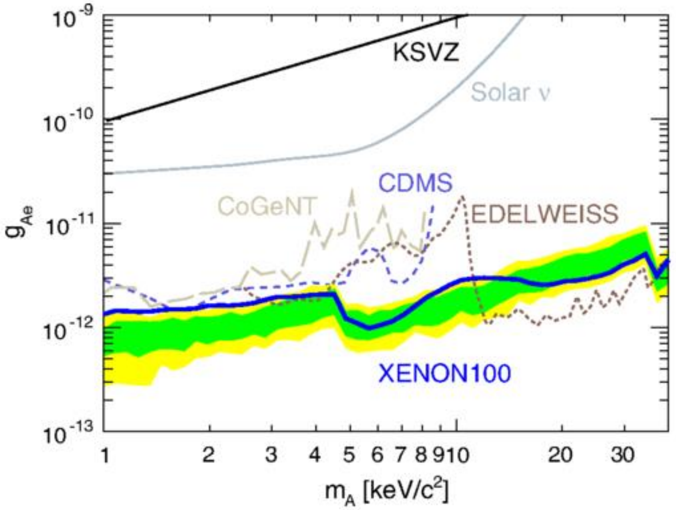
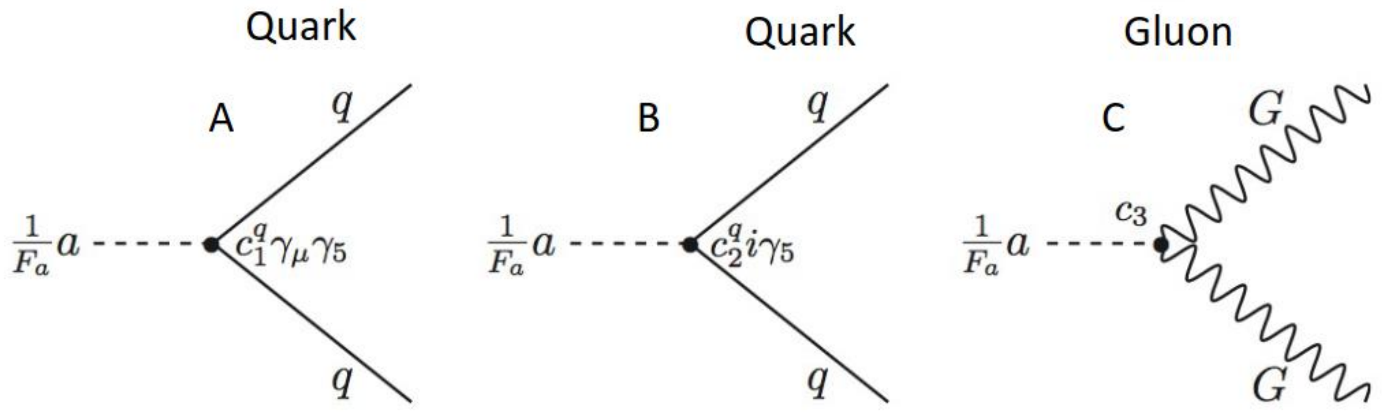


Figure 7

The XENON100 limits (90% C.L.) on ALP coupling to electrons as a function of the mass, under the assumption that ALPs constitute all of the dark matter in our galaxy (blue line). The expected sensitivity is shown by the green/yellow bands $1\sigma/2\sigma$. The other curves are constraints set by CoGeNT [39] (light brown dashed line), CDMS [40] (blue dashed line, more dotted), and EDELWEISS-II [31] (ochre dashed line, extending up to $40\ \mathrm{keV}/c^2$). Indirect astrophysical bound from solar neutrinos [34] is represented as a continuous light grey line. The benchmark KSVZ model is represented by a dark grey line [6, 7].

Reuse & Permissions

"Exotic"

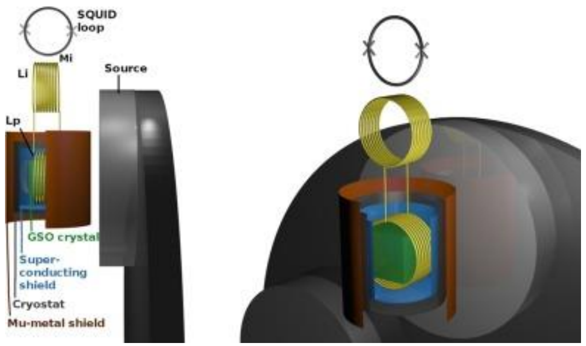


QUAX

Physics Letters B
Volume 773, 10 October 2017, Pages 677-680

Improved constraints on monopole–dipole interaction mediated by pseudo-scalar bosons

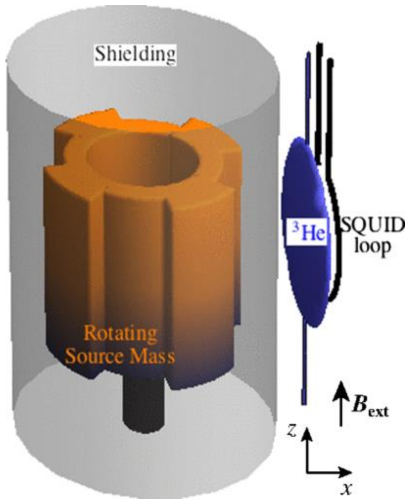
N. Crescini [a,b], C. Braggio [c], G. Carugno [c], P. Falferi [d], A. Ortolan [b], G. Ruoso [b]



ARIADNE

Resonantly Detecting Axion-Mediated Forces with Nuclear Magnetic Resonance

Asimina Arvanitaki and Andrew A. Geraci
Phys. Rev. Lett. 113, 161801 – Published 14 October 2014



Regular Article - Theoretical Physics | Open Access | Published: 10 June 2020

Dark matter induced Brownian motion

Ting Cheng, Reinard Primulando & Martin Spinrath

The European Physical Journal C 80, Article number: 519 (2020) | Cite this article

Letter | Published: 25 August 2022

Experiments with levitated force sensor challenge theories of dark energy

Peiran Yin, Rui Li, Chengjiang Yin, Xiangyu Xu, Xiang Bian, Han Xie, Chang-Kui Duan, Pu Huang, Jian-hua He & Jiangfeng Du

Nature Physics 18, 1181–1185 (2022) | Cite this article

Physics of the Dark Universe
Volume 26, December 2019, 100367

First results on the search for chameleons with the KWISP detector at CAST

S. Arguedas Cuendis [g], J. Baier [e], K. Barth [g], S. Baum [p,q], A. Bayirli [i,1], A. Belov [l], H. Bräuninger [f], G. Cantatore [r,s], J.M. Carmona [v], J.F. Castel [v], S.A. Cetin [i], T. Dafni [v], M. Davenport [g], A. Dermenev [l], K. Desch [a], B. Döbrich [g], H. Fischer [e], W. Funk [g], J.A. García [v,2], A. Gardikiotis [m]...K. Zioutas [m,g]

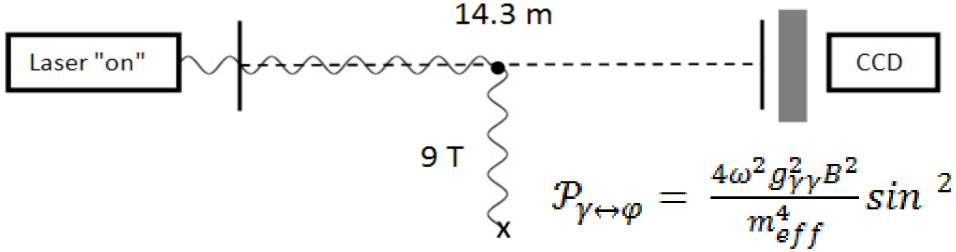
OSQAR – CHASE (CHAmeleon Search Experiment)

Chameleon afterglow search from laser based experiment

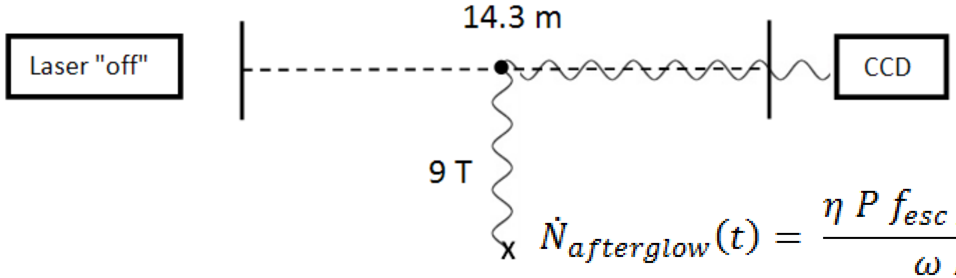
Contact: pierre.pugnat@lncmi.cnrs.fr

- Chameleon is an hypothetical scalar particle with mass dependent of the surrounding density, which could explain Dark Energy

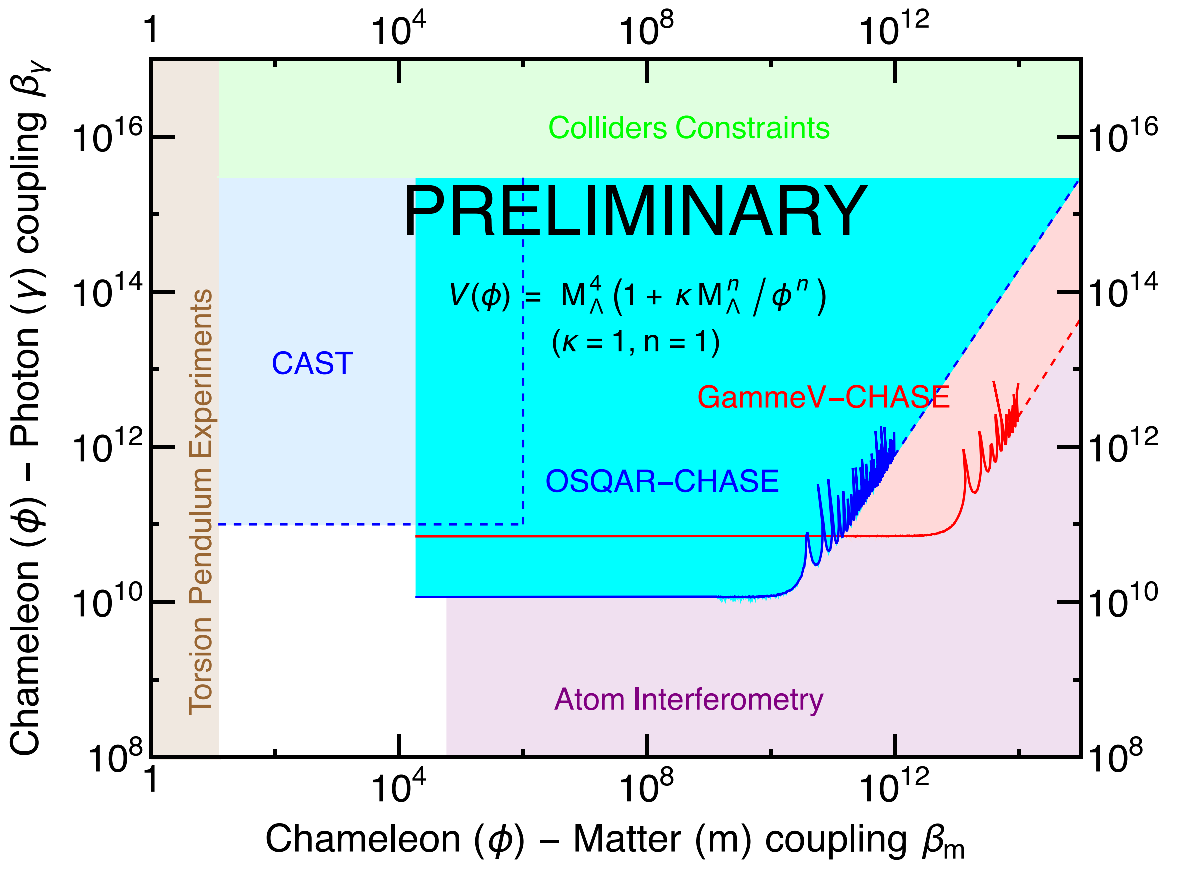
- Experiment in 2 steps



$$\mathcal{P}_{\gamma\leftrightarrow\varphi} = \frac{4\omega^2 g_{\gamma\gamma}^2 B^2}{m_{eff}^4} sin^2\left(\frac{m_{eff}^2 L}{4\omega}\right)$$



$$\dot{N}_{afterglow}(t) = \frac{\eta\ P\ f_{esc}\ f_{vol}\ \mathcal{P}_{\gamma\leftrightarrow\varphi}^{\ 2}\ c}{\omega\ \Gamma\ L_{total}}(1 - e^{-\Gamma\Delta t})e^{-\Gamma t}$$



A.S. Chou et al., Phys. Rev. Lett. **102** 030402 (2009)

NIMA 936 (2019) 187-188 & to be published

http://cds.cern.ch/record/2001850/files/SPSC-P-331-ADD-1.pdf

Conclusion

- The field is developing rapidly
- Different directions
    - bigger
    - more sensitive, SQL and beyond
- Lots of headache
- Interesting times ahead

- Thanks to everyone that contributed