Current Status of Axion Searches and Future Prospects

Marin Karuza, University of Rijeka

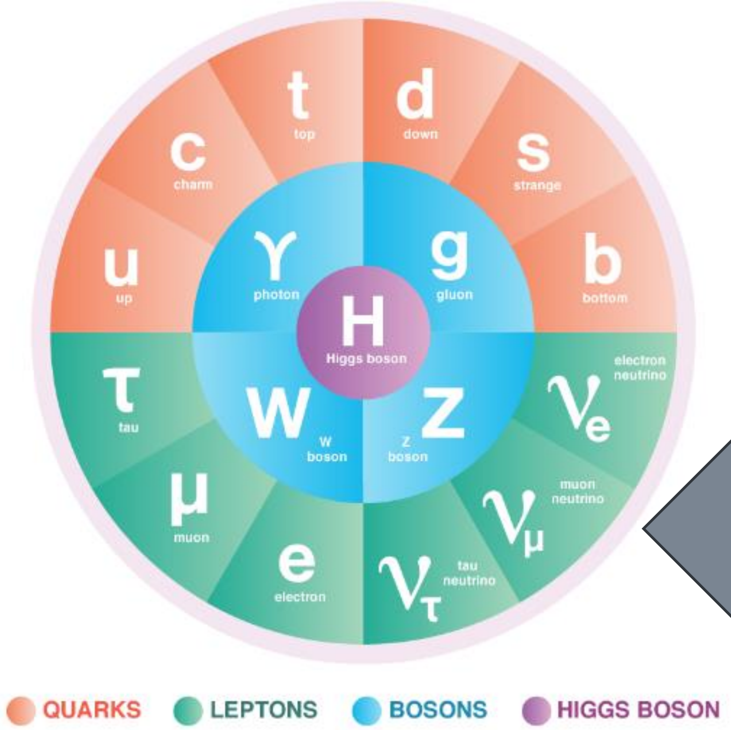
CA21106

AXION EXPERIMENTS

- Introduction
- Current efforts
- Prospects

What is it all about?

- Standard model

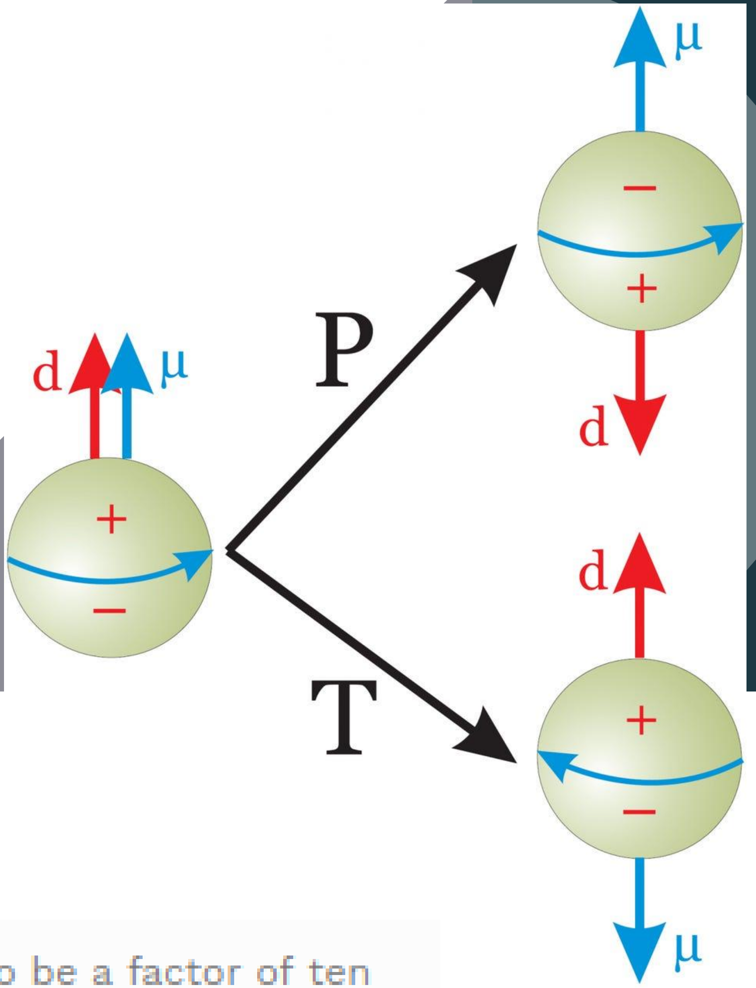


Yesterday
--> 2040

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

What is it all about?

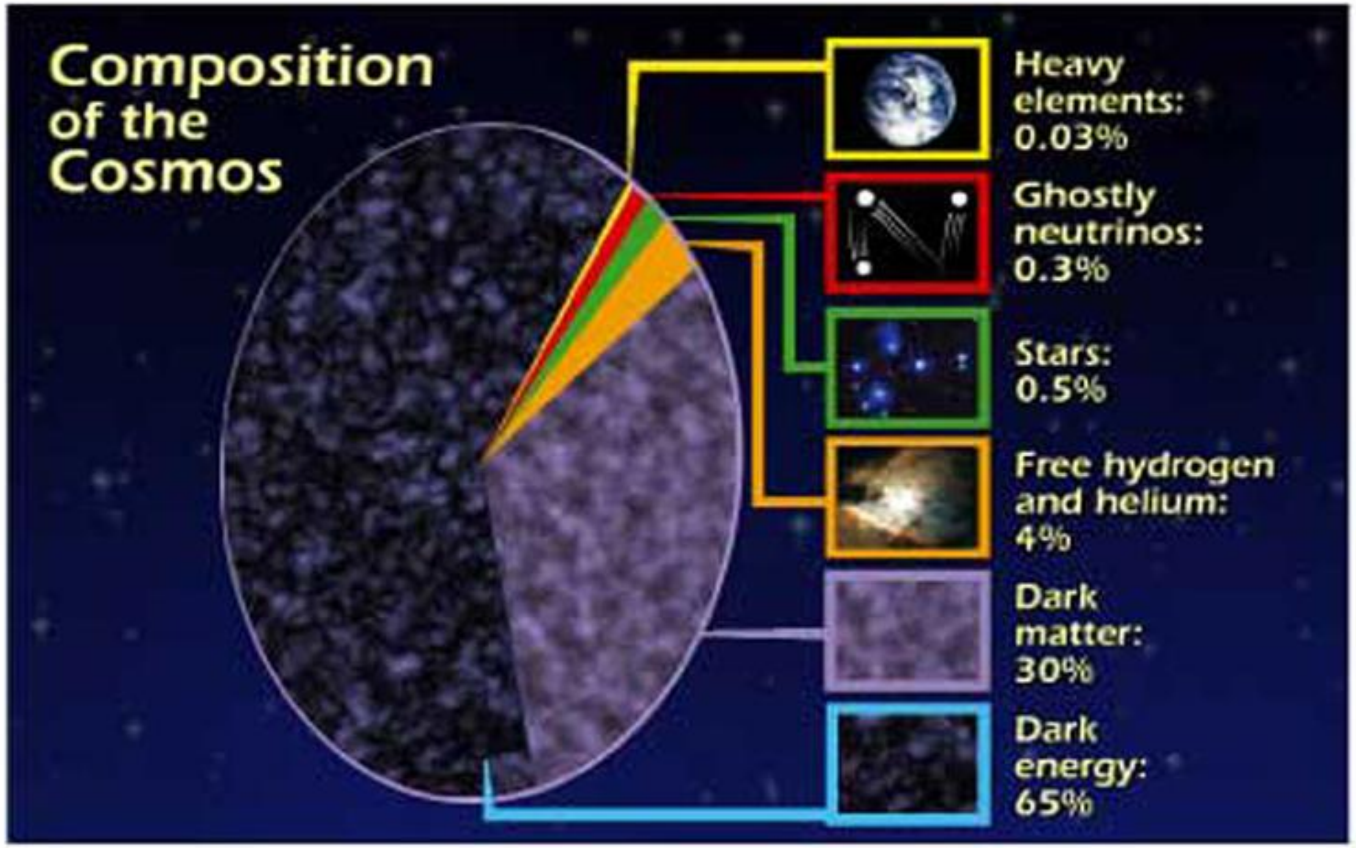
- Strong CP problem



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

What is it all about?

- Composition of the Universe



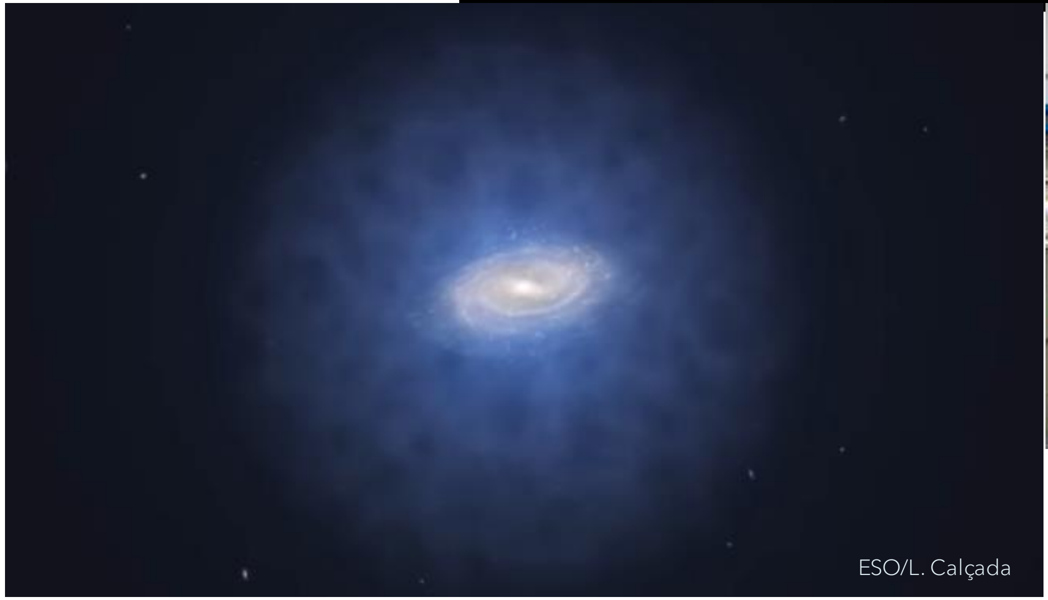
Ann Field (STScI)

The answer?
New particle. Axion!

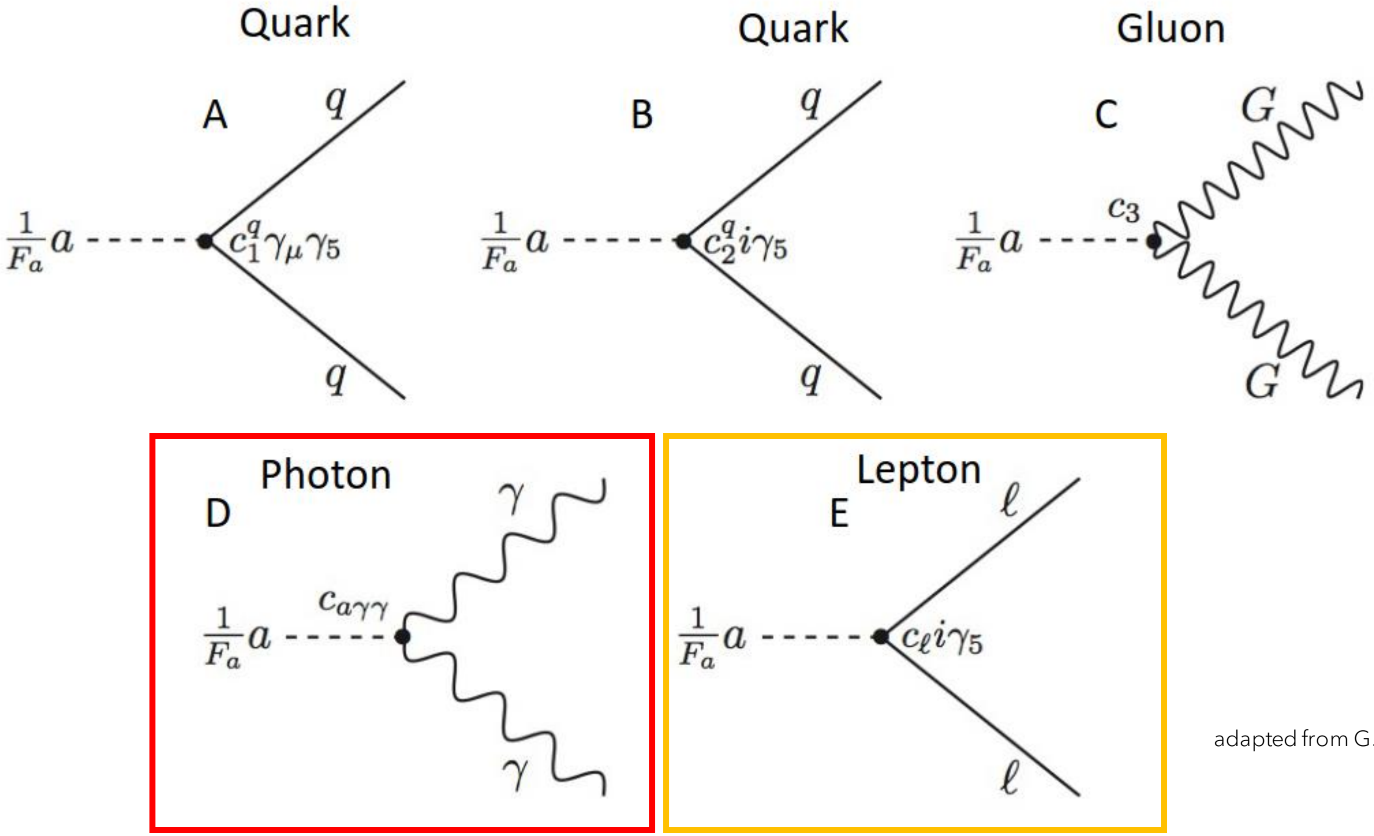
Strong CP problem
1977 Peccei and Quinn --> new global symmetry
--> spontaneusly broken
Wilczek and Weinberg --> new particle
pseudo-Nambu-Goldstone boson

COSMIC WISPERS
CA21106

Where find it?



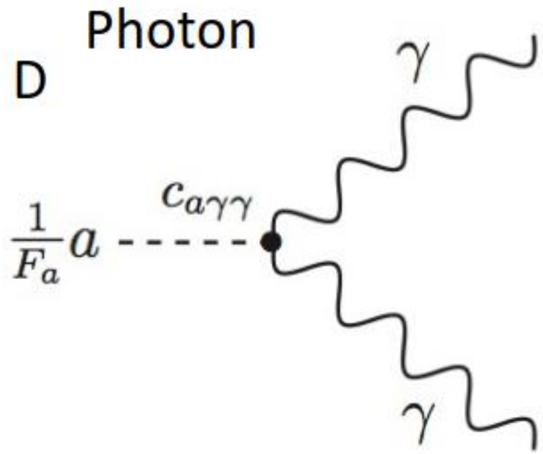
Strategy?

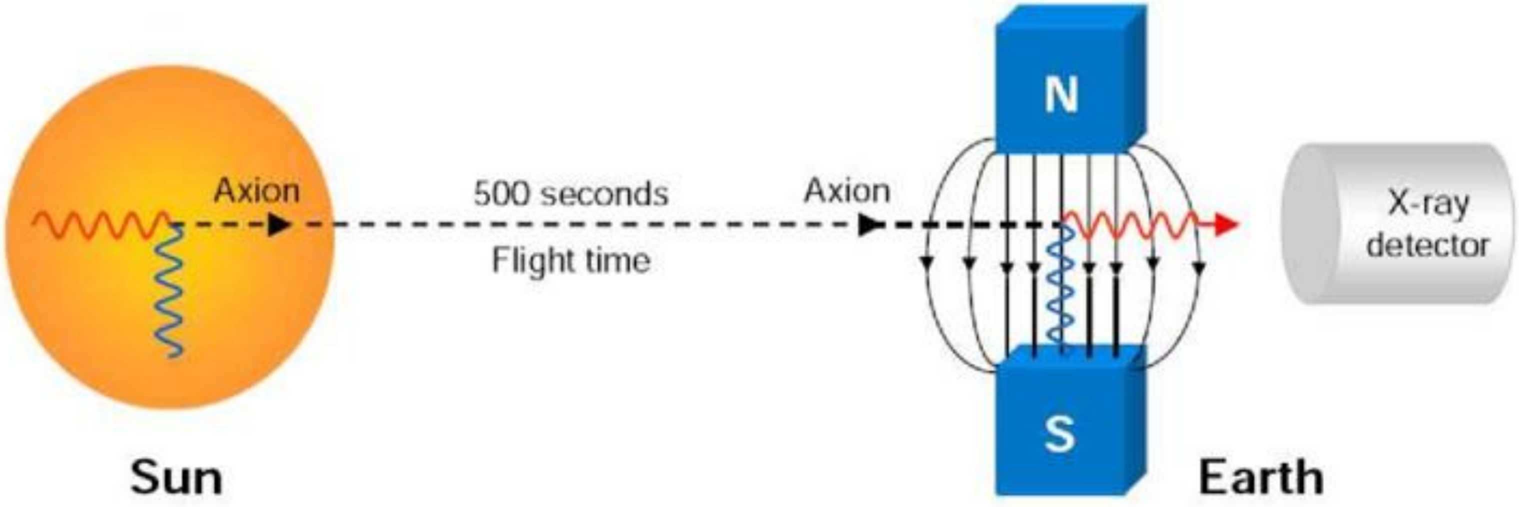


adapted from G. Ruoso

Detection strategy

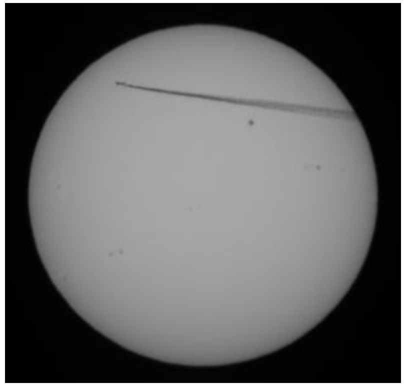
- **Sun --> plenty of photons**
- **and strong magnetic field**

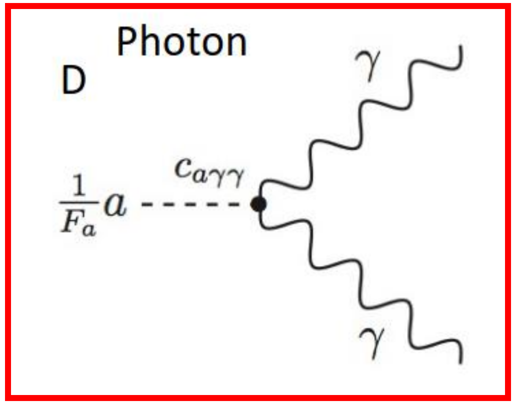




P. Sikivie, PRL 51, 1415-1417 (1983)

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

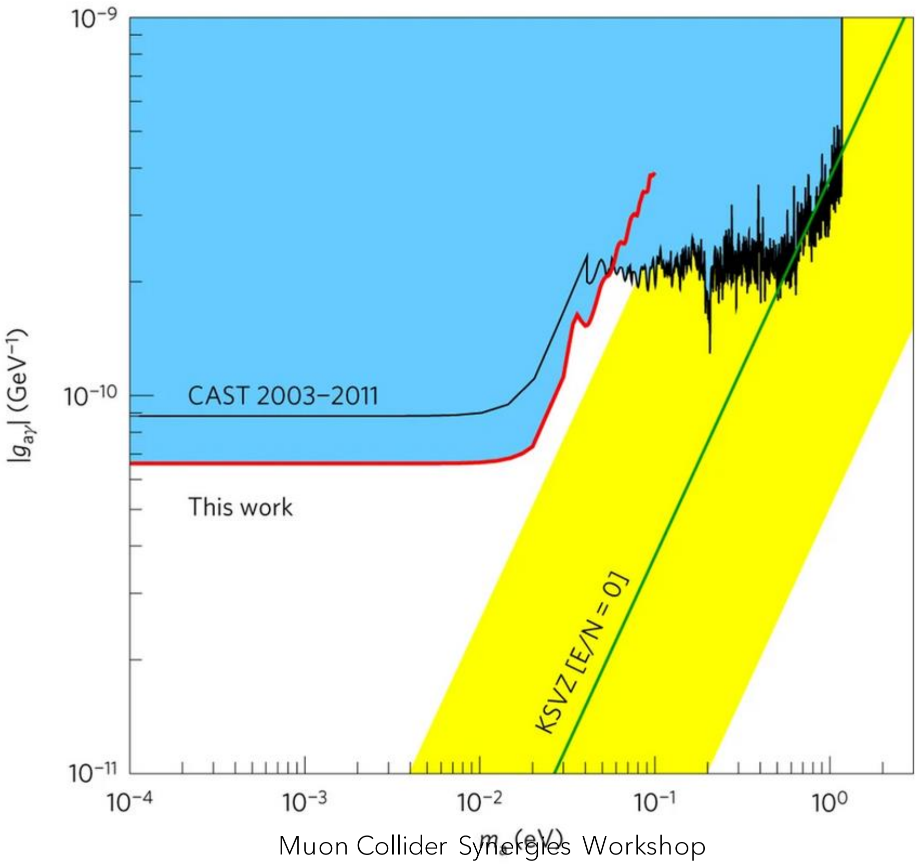
Results – helioscope

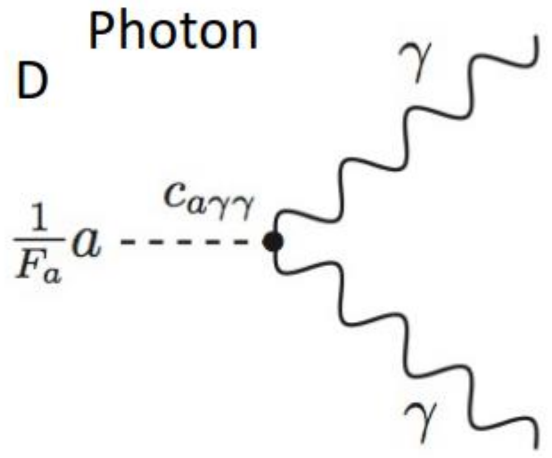
Open Access | Published: 01 May 2017

New CAST limit on the axion–photon interaction

CAST Collaboration

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

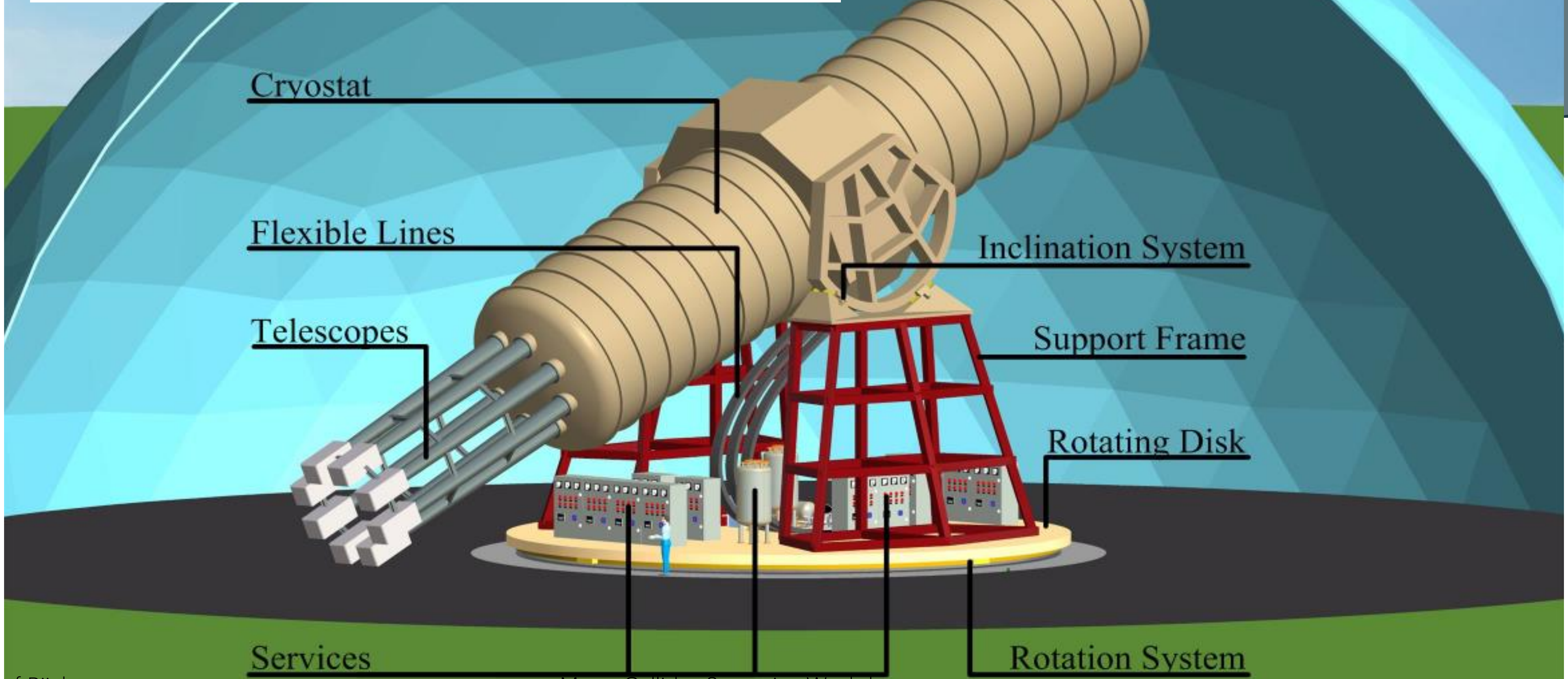




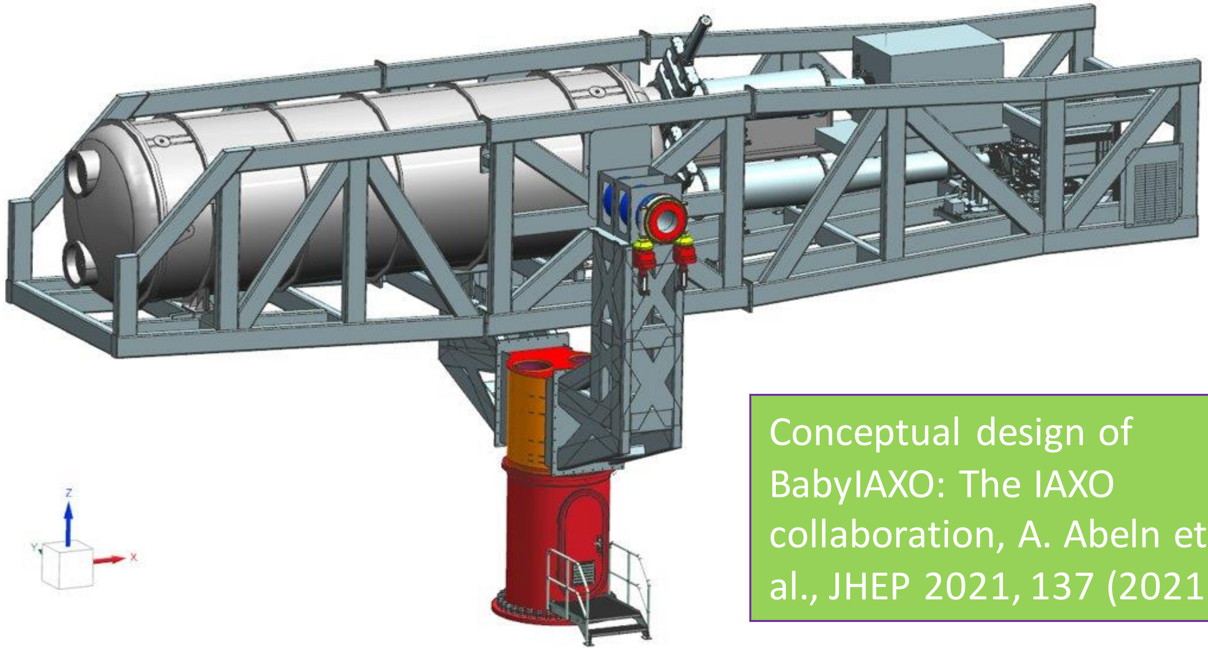
The International AXion Observatory

- **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**

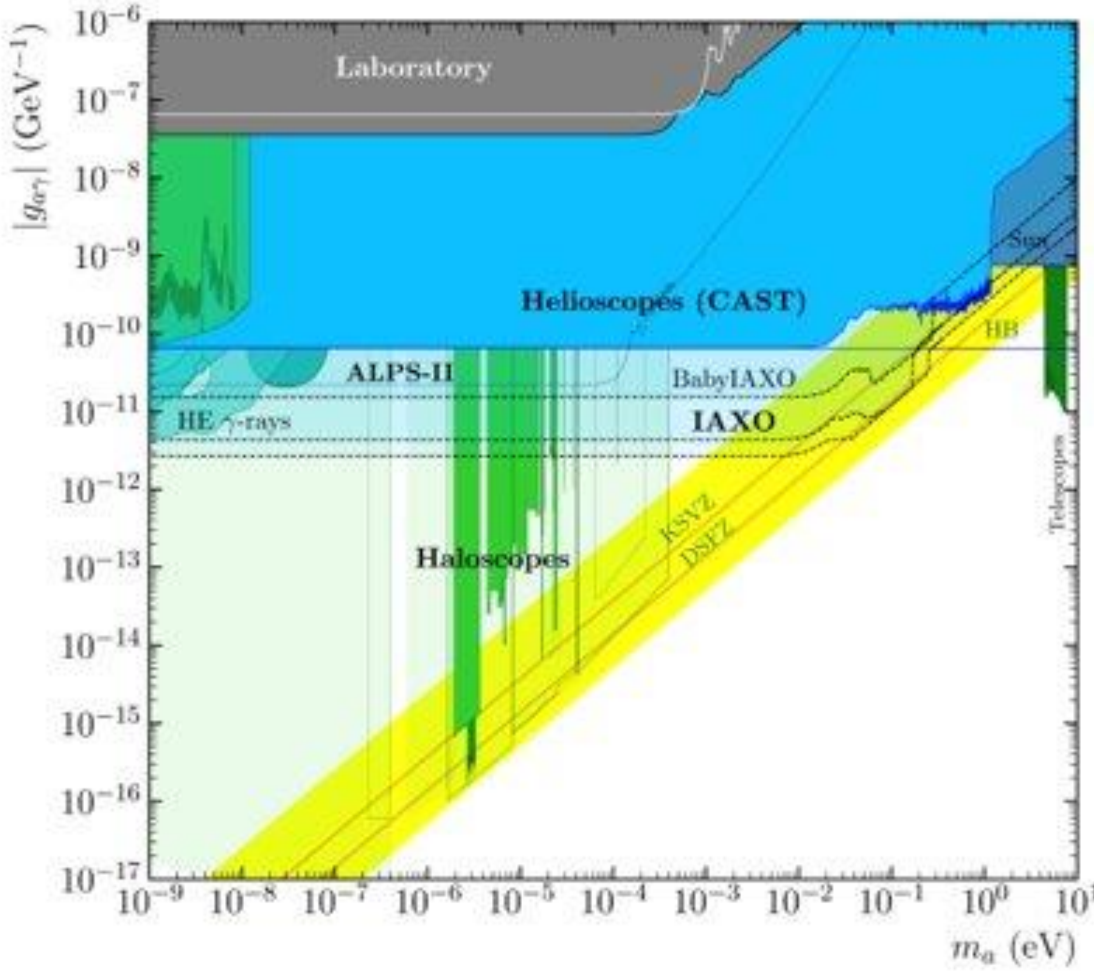
Conceptual Design of the International Axion Observatory
Armengaud et al. *JINST* 9 T05002 (2014)



The International AXion Observatory



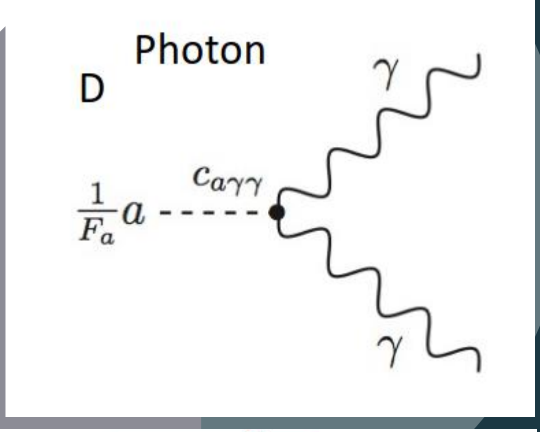
Conceptual design of BabyIAXO: The IAXO collaboration, A. Abeln et al., JHEP 2021, 137 (2021)

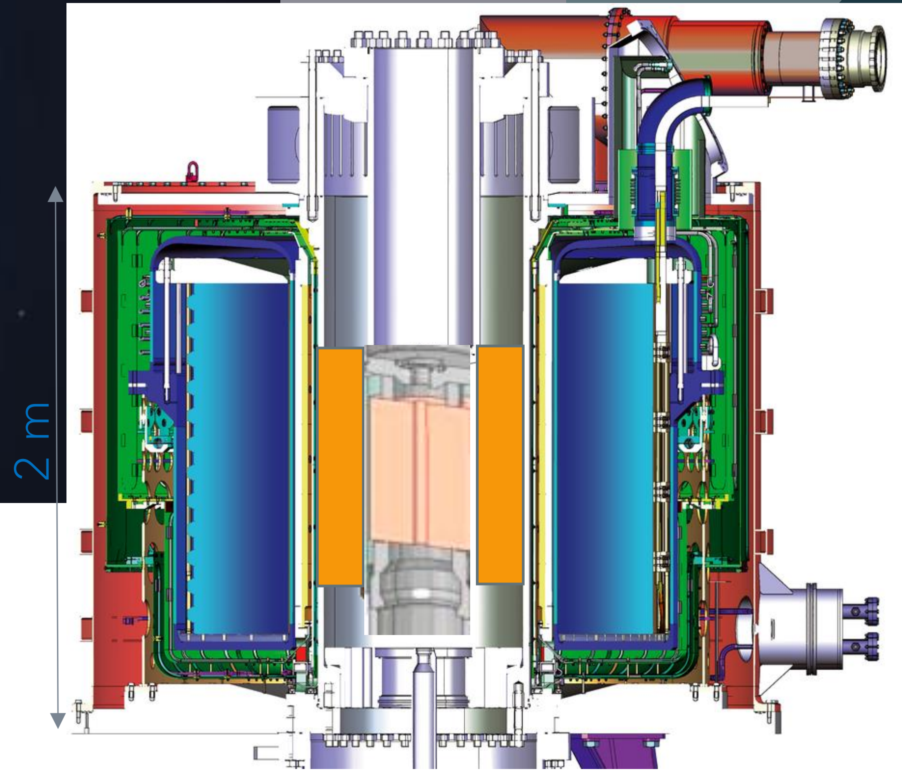


- Technological prototype with only two magnet bores (10 m, ⌀ 70 cm)
- 2 detection lines with one x-ray telescope and one ultra-low background detector each
- Moving platform to track the Sun

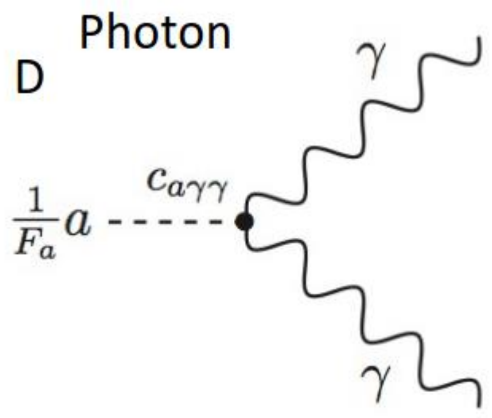
Haloscopes

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





CAST - CERN Axion Solar Telescope
- galactic halo



CAPP

RADES

CAST

Results – haloscope

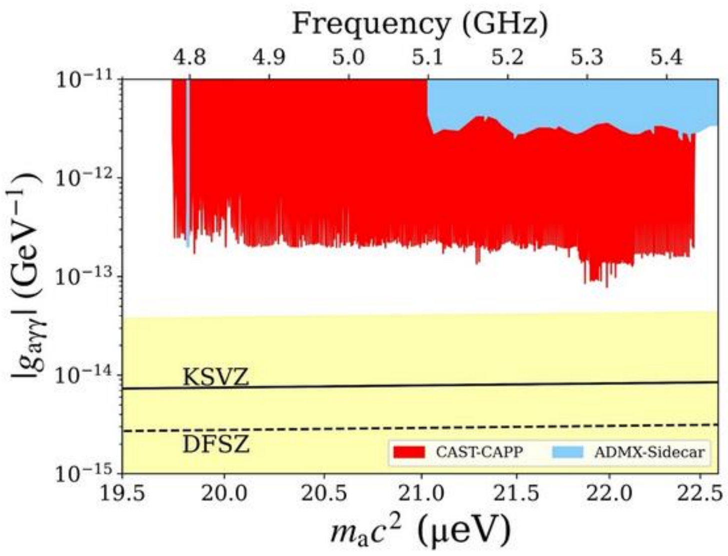
Article | Open Access | Published: 19 October 2022

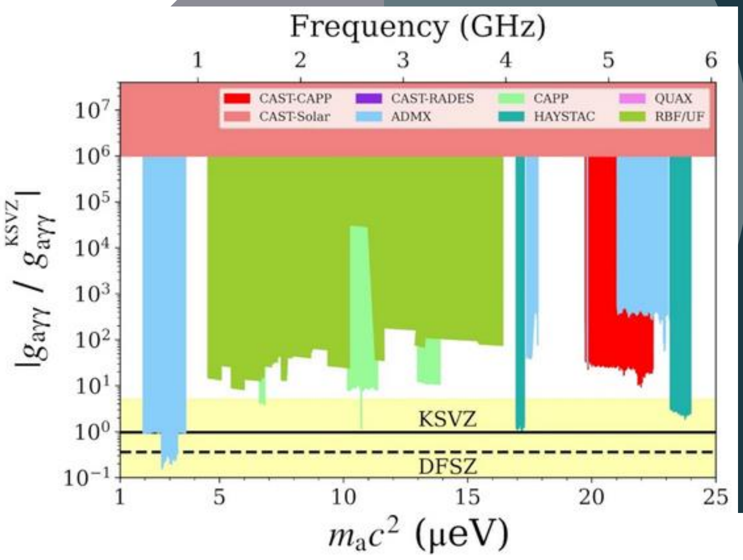
Search for Dark Matter Axions with CAST-CAPP

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





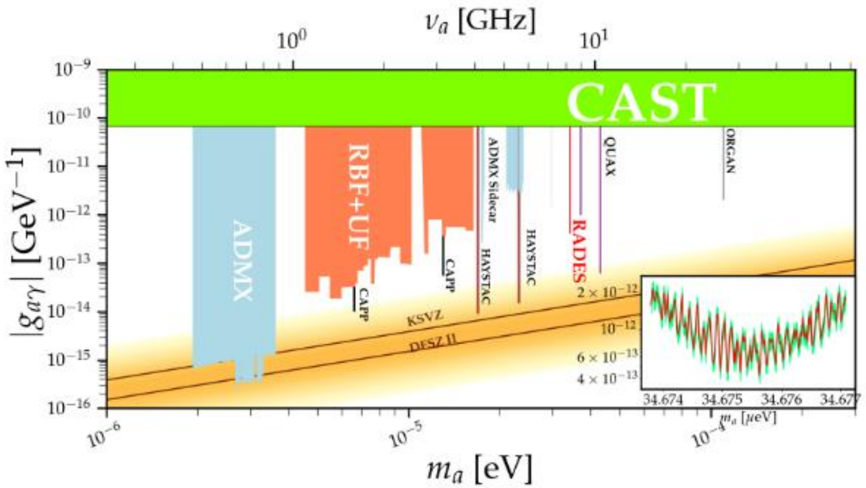
Regular Article - Experimental Physics | Open Access | Published: 08 October 2021

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

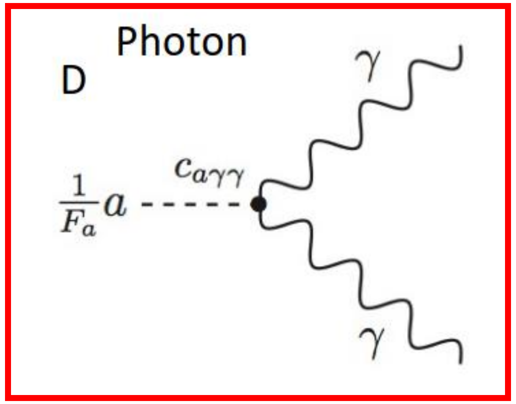
A. Álvarez Melcón, S. Arguedas Cuendis, J. Baier, K. Barth, H. Bräuninger, S. Calatroni, G. Cantatore, F. Caspers, J. F. Castel, S. A. Cetin, C. Cogollos, T. Dafni, M. Davenport, A. Dermenev, K. Desch, A. Díaz-Morcillo, B. Döbrich, H. Fischer, W. Funk, J. D. Gallego, J. M. García Barceló, A. Gardikiotis,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

+ Show authors

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



Haloscopes
QUAX

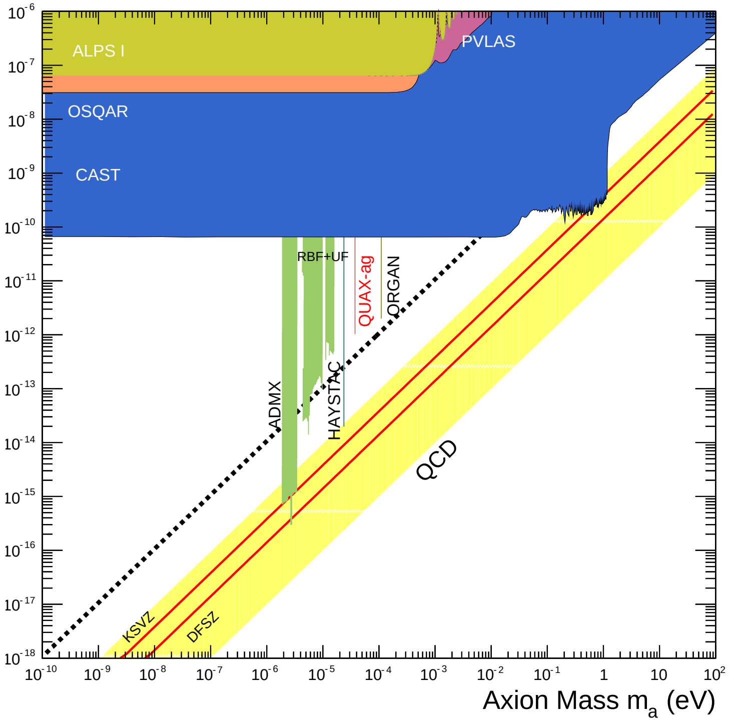


QUAX-aγ Result with Superconductive Resonant Cavity at m_a = 37.5 meV, Phys. Rev. D **99**, 101101(R) (2019).

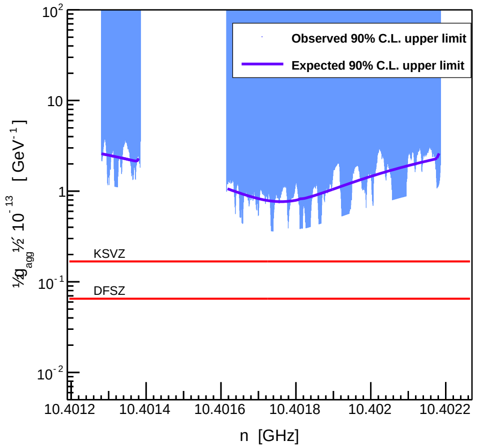
Search for Invisible Axion Dark Matter of mass m_a = 43 meV with the QUAX-αγ Experiment, Phys. Rev. D 103, 102004 (2021).

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

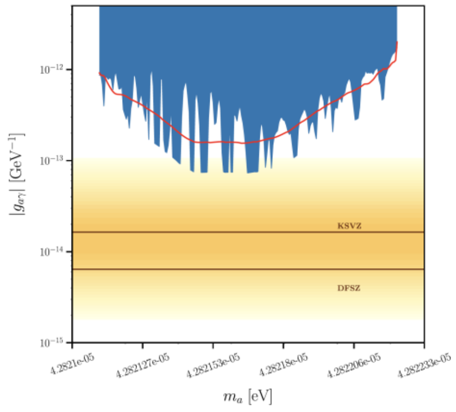
Quax-aγ 2019



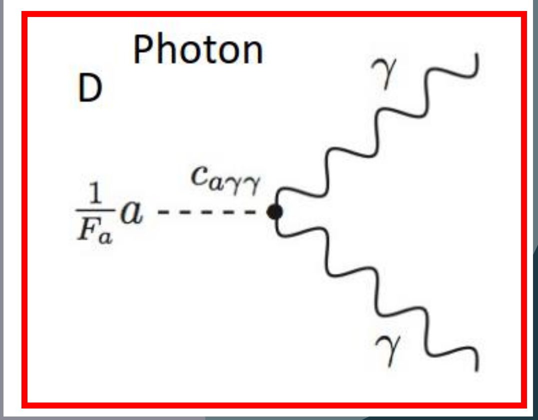
Quax-aγ 2021



Quax-aγ 2022



Haloscopes QUAX



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

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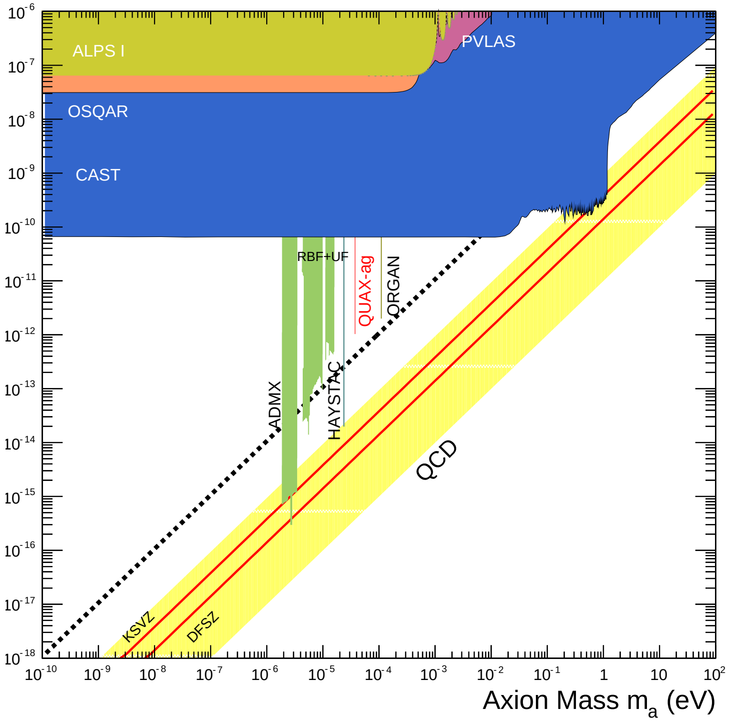
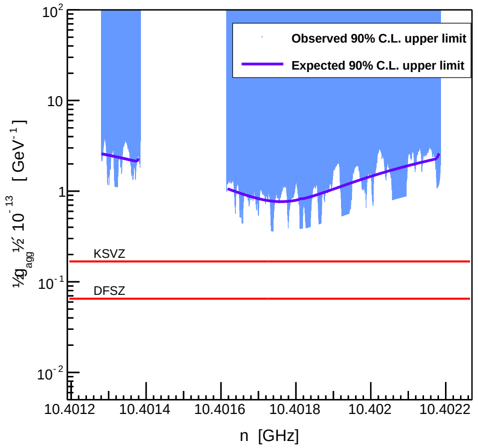
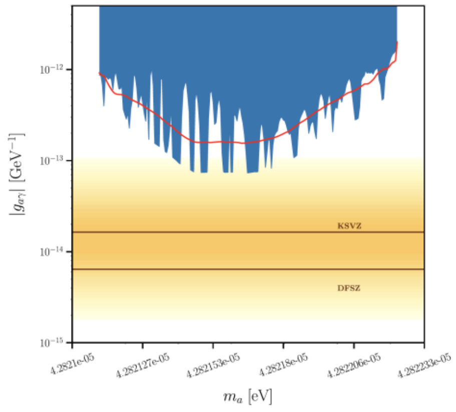
Quax-aγ 2019



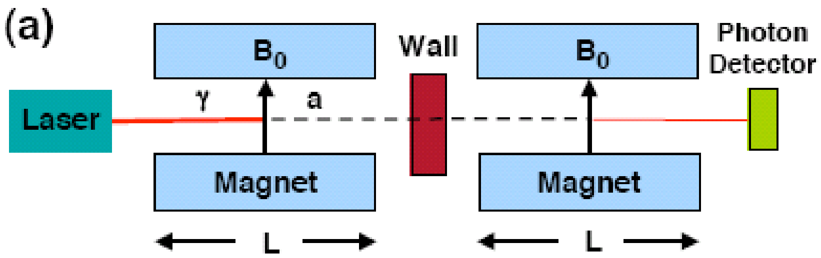
Quax-aγ 2021

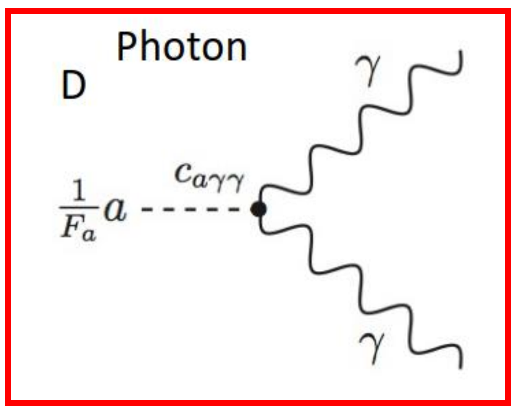


Quax-aγ 2022



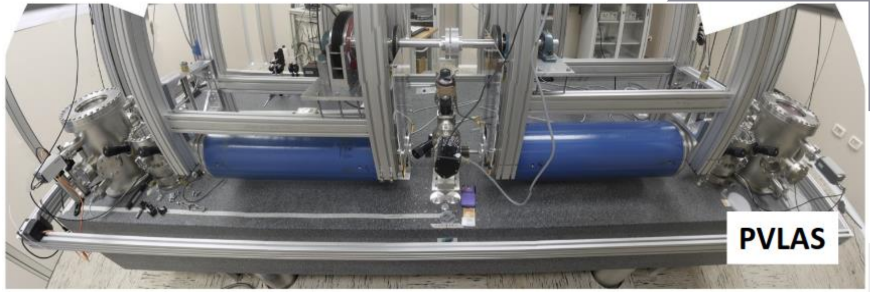
Laboratory

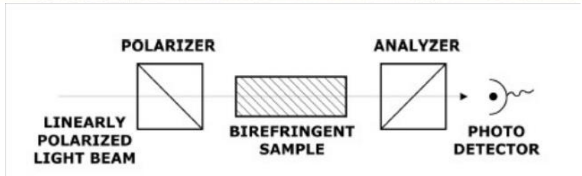




LSW
- ALPS
- OSQAR

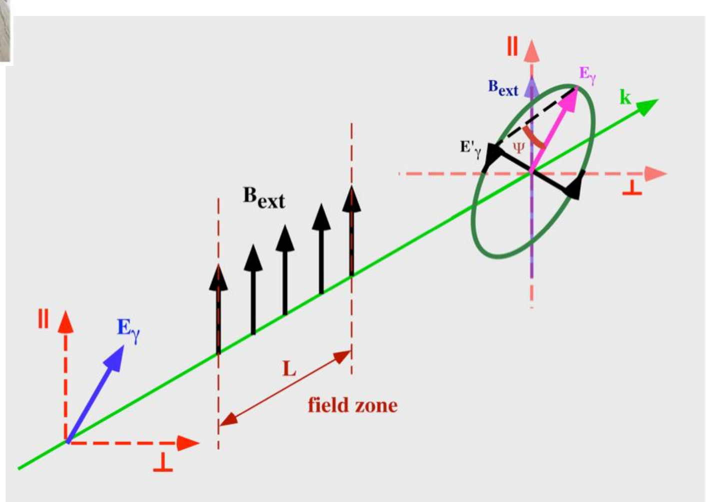
Polarization
- PVLAS
- BFRT
- BMV
- OSQAR
- Q@A





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

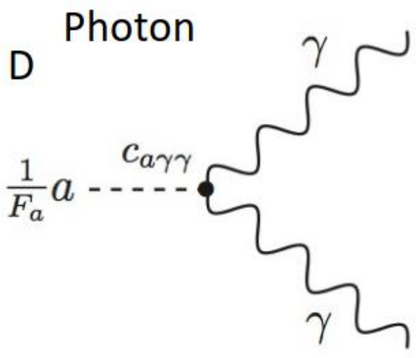
L.Maiani, R. Petronzio, E. Zavattini, Phys. Lett B, Vol. 173, no.3 1986

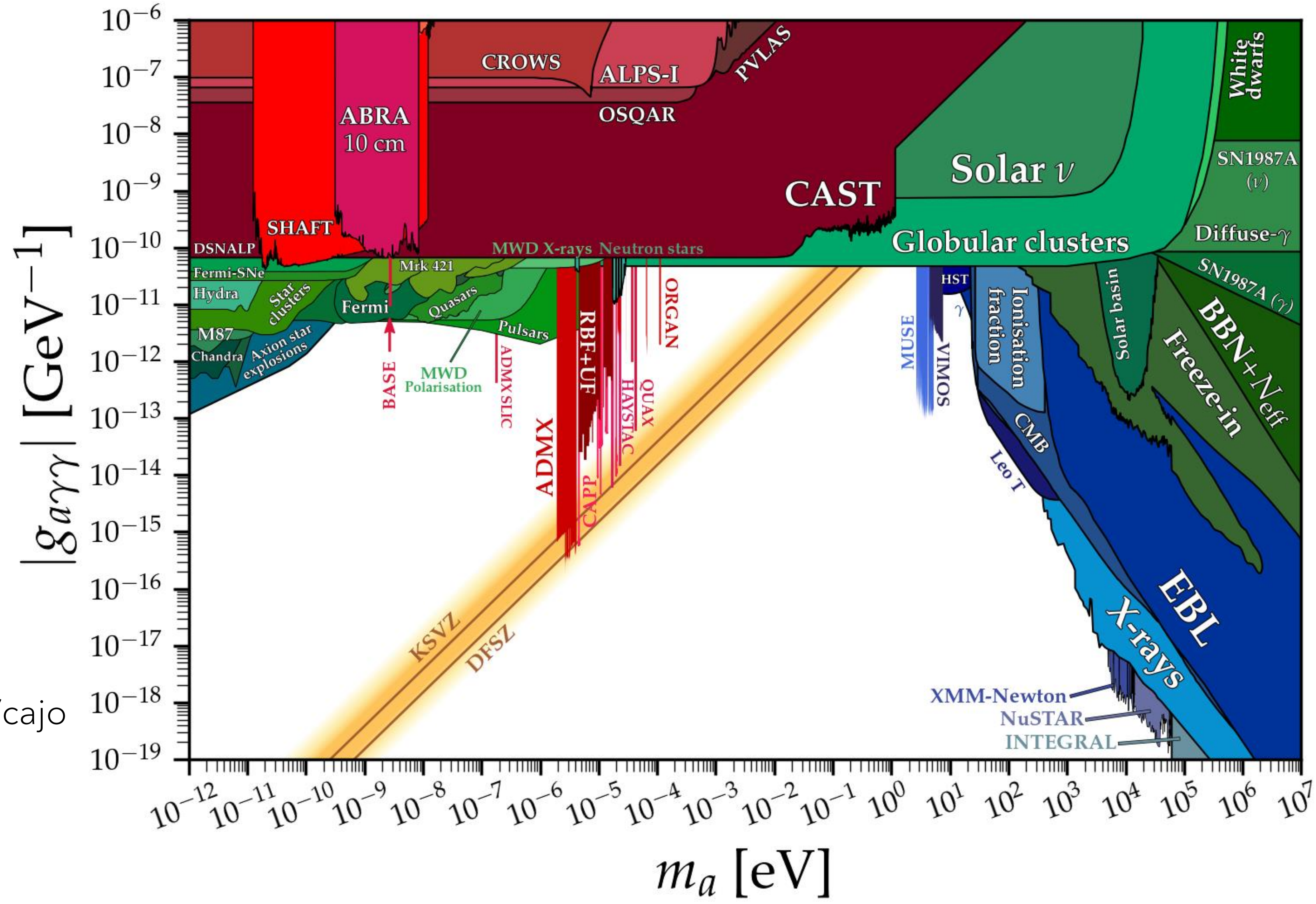


RESULTS

αγ

D



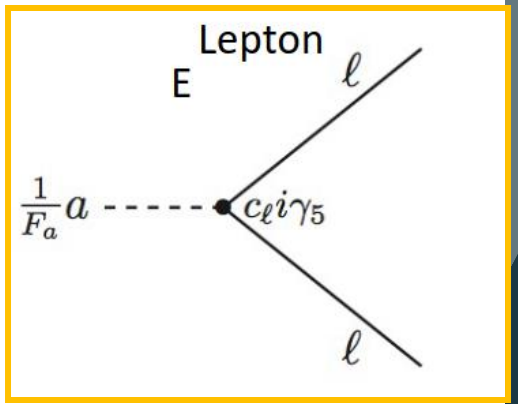


https://github.com/cajohare/AxionLimits

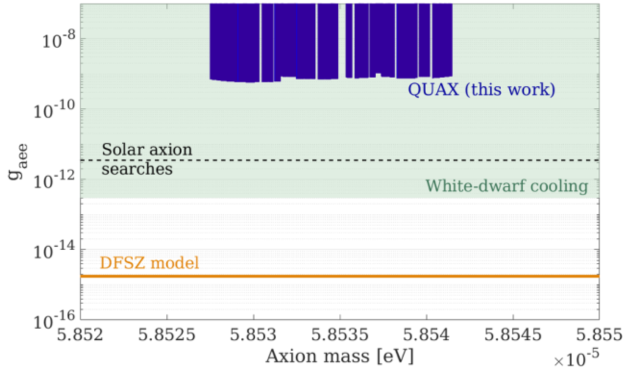
QUAX

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

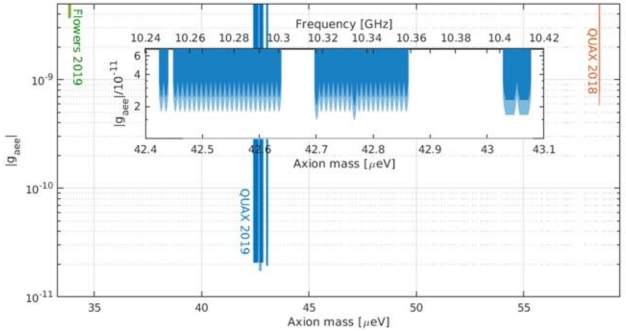
QUAX-ae with Quantum-Limited Ferromagnetic Haloscope, Phys. Rev. Lett. **124**, 171801 (2020).



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

CA21106

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)

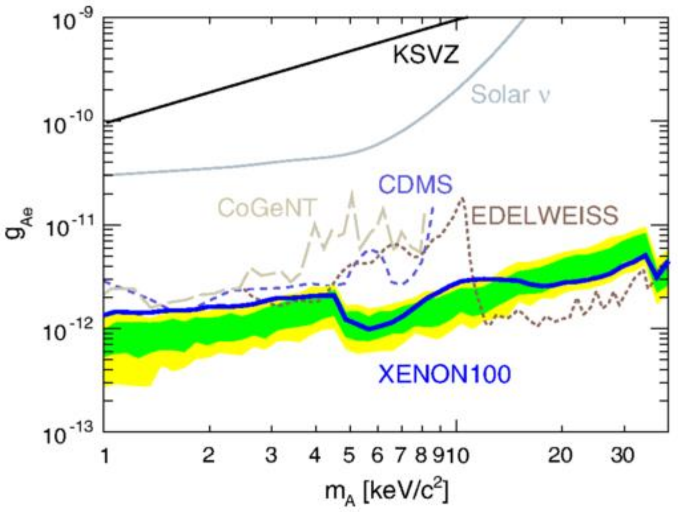


Figure 7

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].

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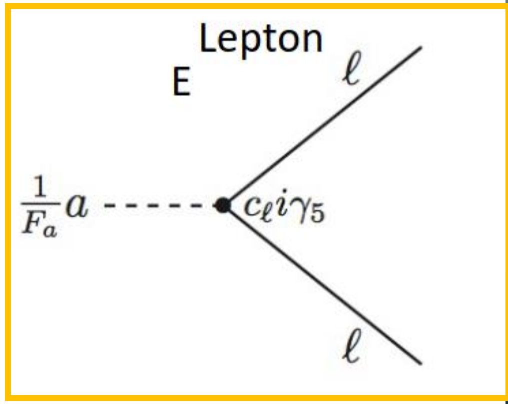
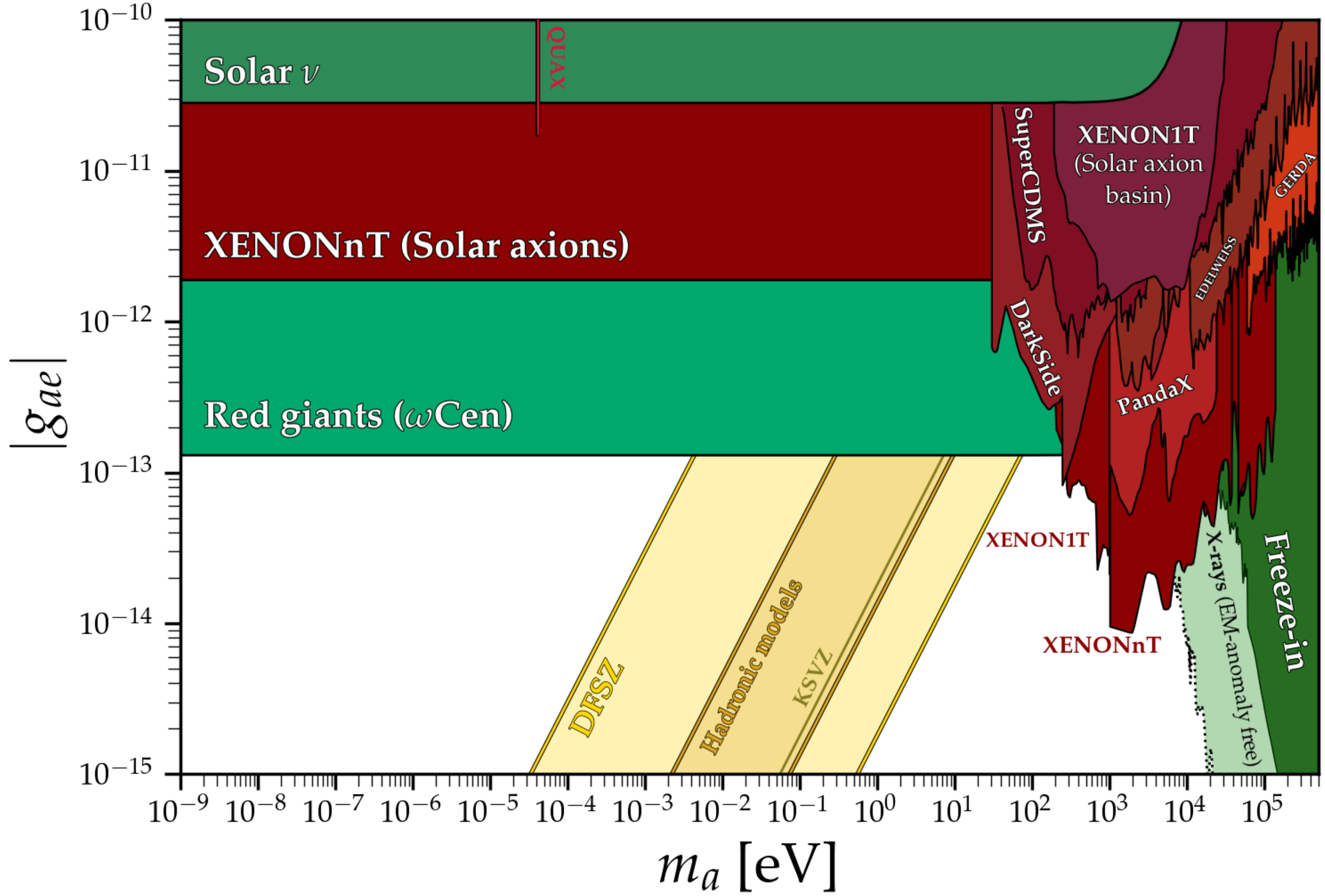
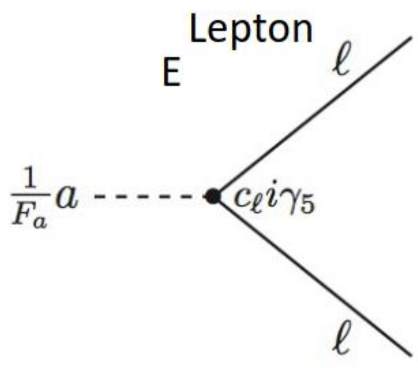


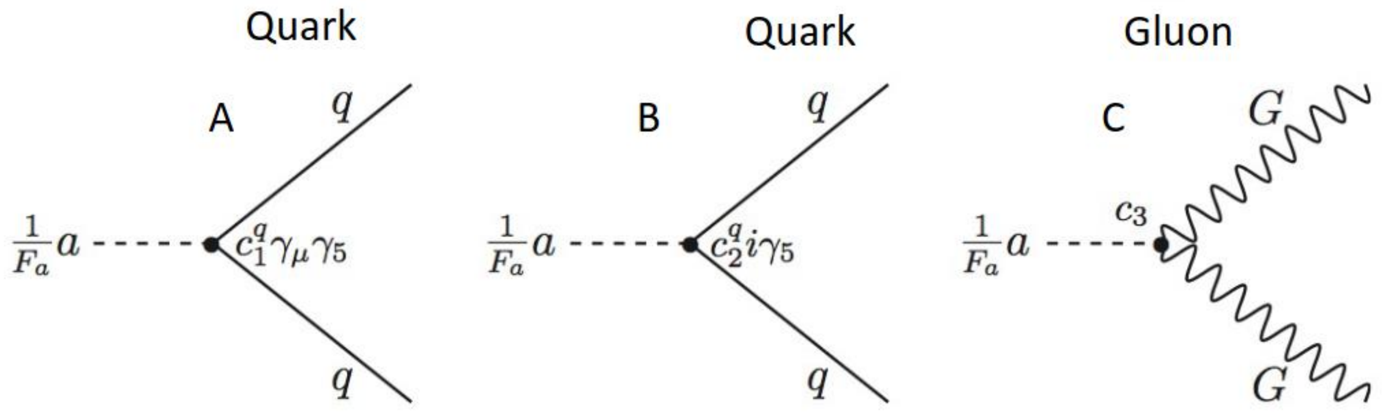
Results - ae

https://github.com/cajohare/AxionLimits





"Exotic"

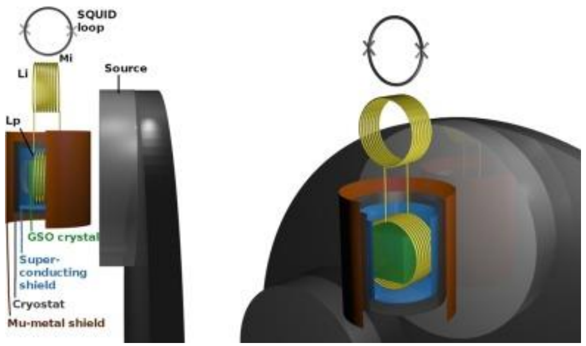


QUAX

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

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

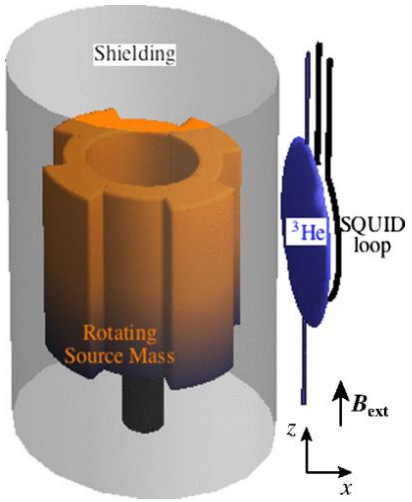
N. Crescini [a, b], C. Braggio [c], G. Carugno [c], P. Falferi [d], A. Ortolan [b], G. Ruoso [b]



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

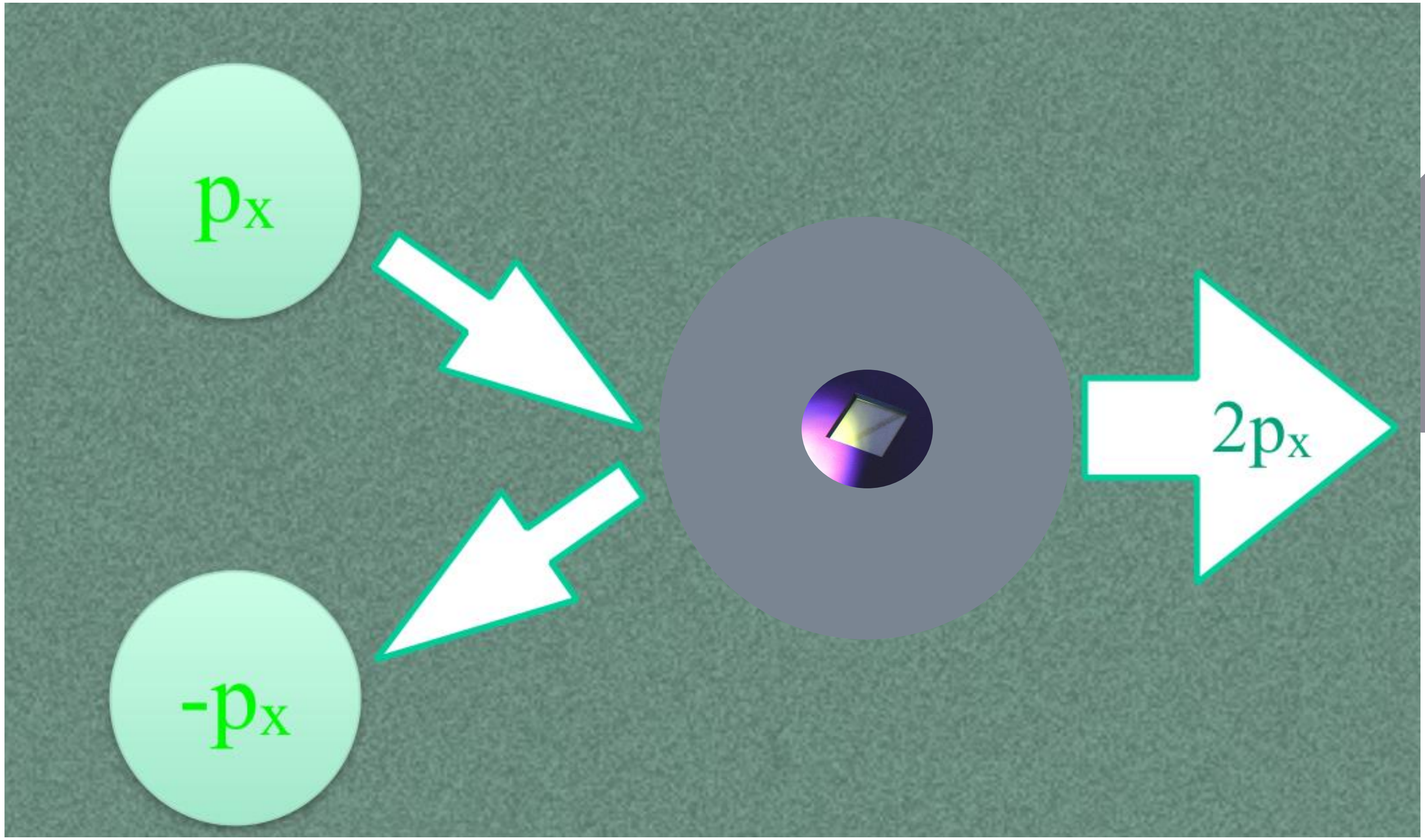
Nature Physics 18, 1181–1185 (2022) | Cite this article

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]

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

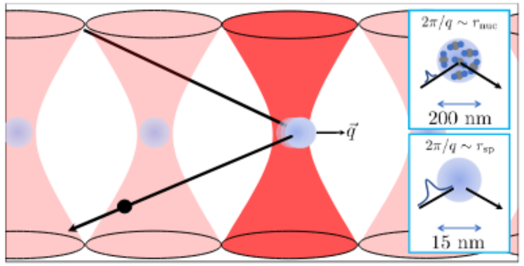
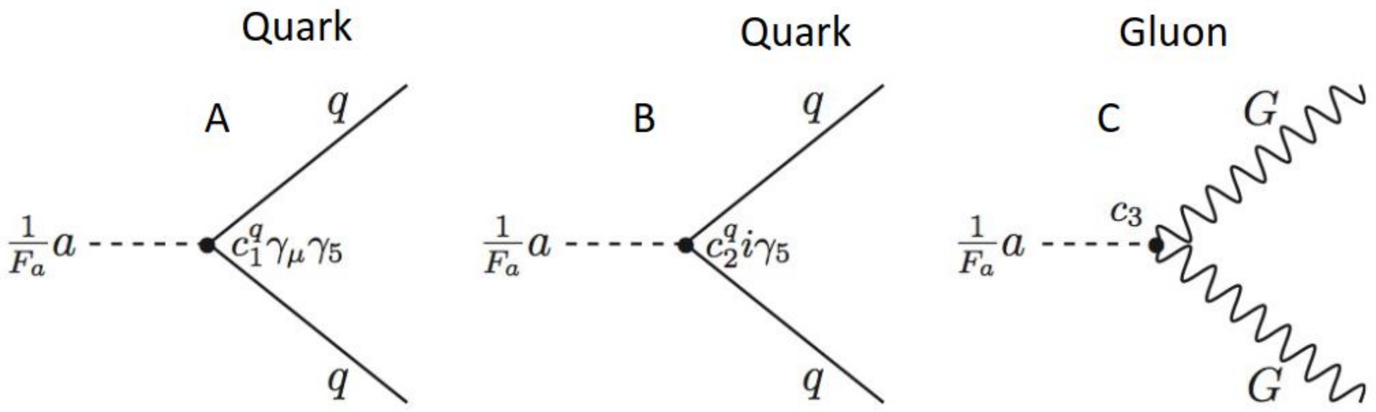


FIG. 1. As a dark matter particle scatters from a levitated optomechanical sensor (possibly part of a large array), it transfers to it momentum $\vec{q}$. For "large" sensors (upper inset) the interaction is coherent over a single nucleus. For "small" enough sensors, such that the inverse transferred 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.

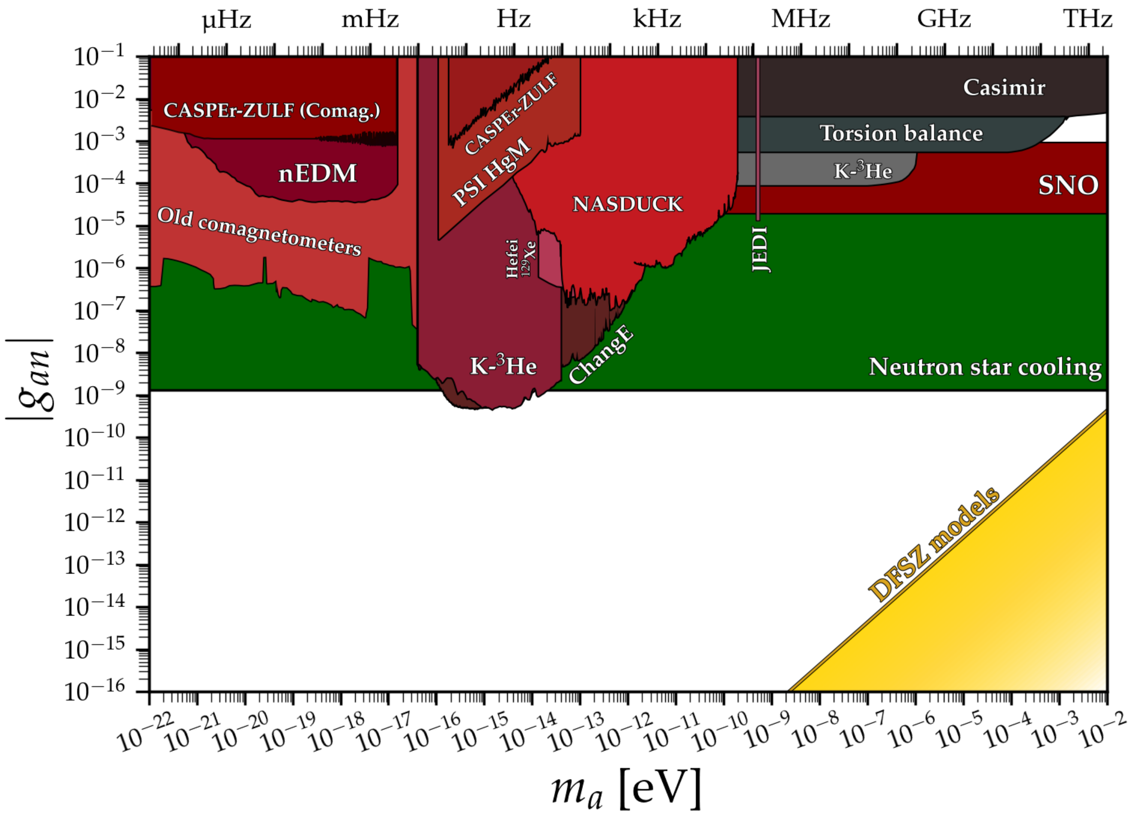
Develop a radiation pressure detector!

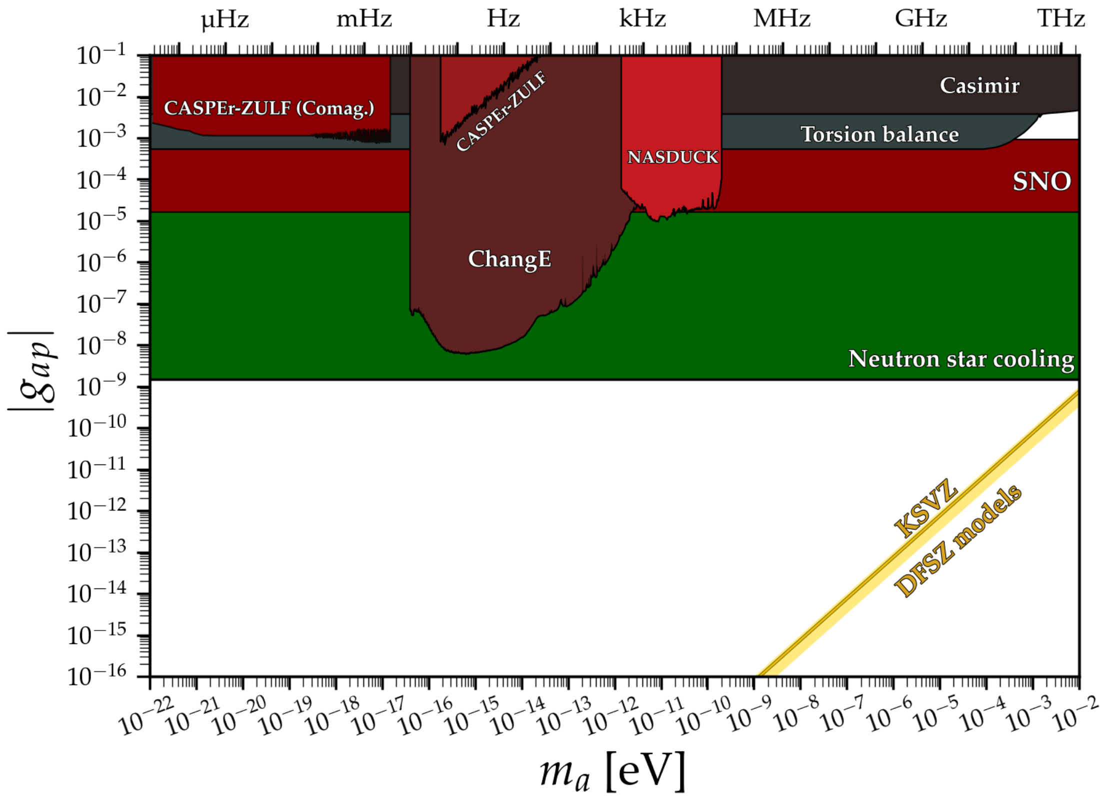
-measure momentum transfer

- high sensitivty



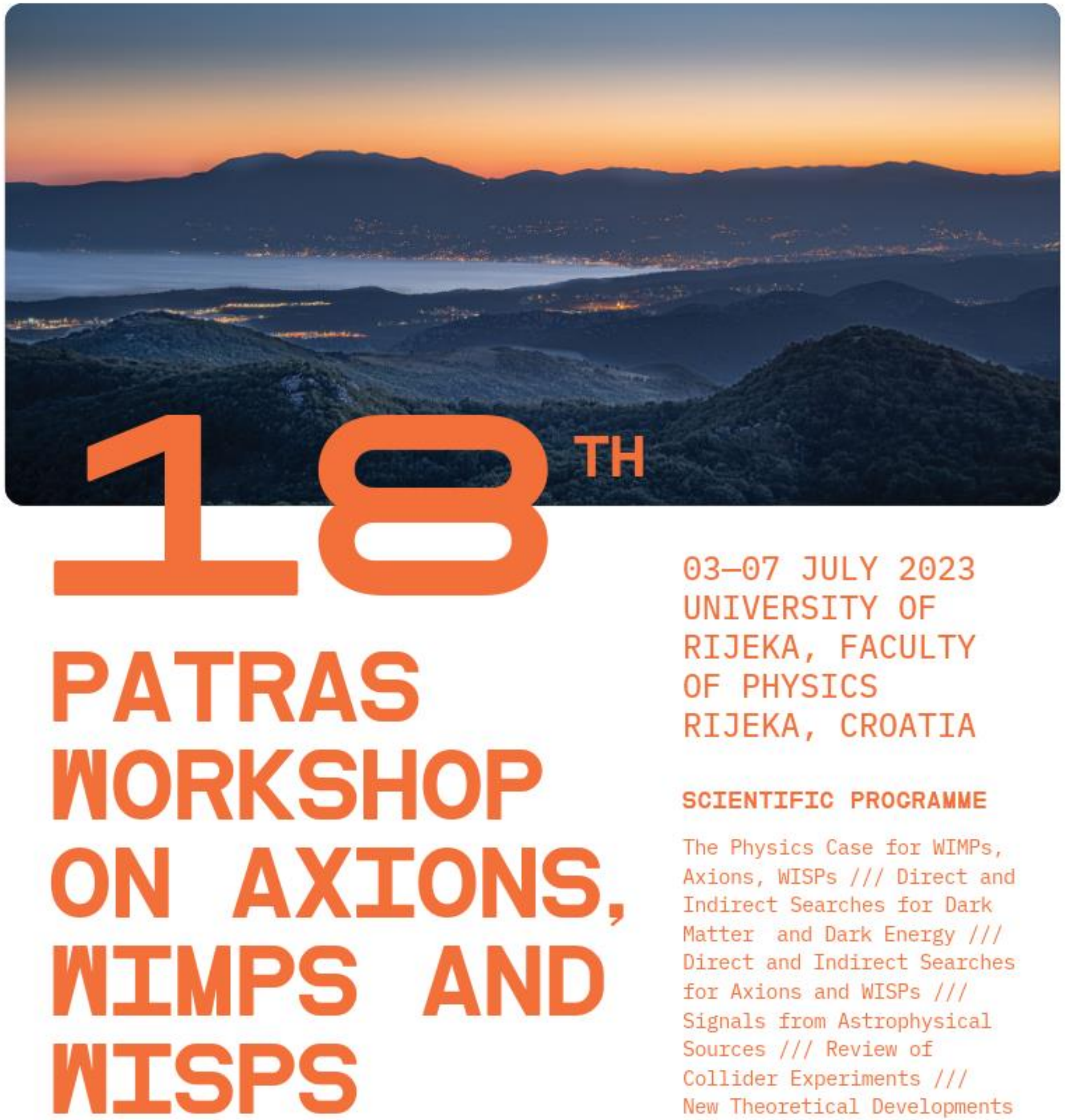
https://github.com/cajohare/AxionLimits





CONCLUSION

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



THANK YOU