MAX-PLANCK-INSTITUT FÜR PHYSIK

Search for Dark Matter with the Relic Axion Dark-Matter Exploratory Setup (RADES)

Results based on Cuendis, Golm et. al, in preparation

European Research Council
Established by the European Commission

Louis Herwig

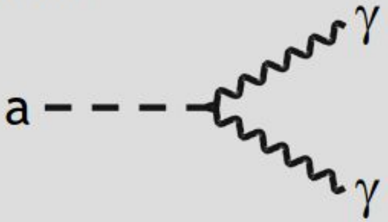
on behalf of the RADES Group

1 Particle-Physics Motivation

CP conservation in QCD by Peccei-Quinn mechanism

→ Axions $a \sim \pi^0$

$m_\pi f_\pi \approx m_a f_a$



For $f_a \gg f_\pi$ axions are “invisible” and very light

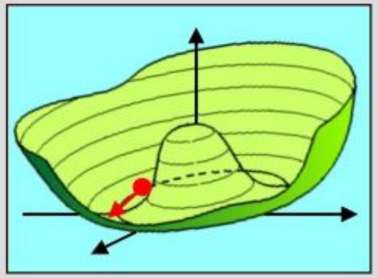
3 Solar and Stellar Axions

Axions thermally produced in stars, e.g. by Primakoff production

- Limits from avoiding excessive energy drain
- Solar axion searches (CAST, IAXO)

2 Cosmology

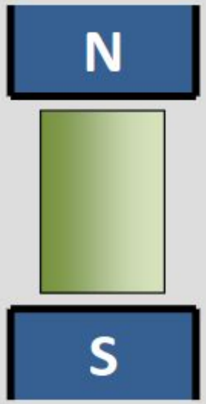
In spite of small mass, axions are born non-relativistically (non-thermal relics)



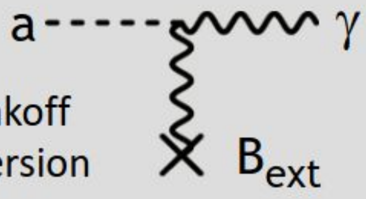
Cold dark matter candidate

$m_a \sim 10\ \mu eV$ (or much smaller or larger)

4 Search for Axion Dark Matter



Microwave resonator (1 GHz = 4 μeV)



Primakoff conversion

RADES

8.84 GHz

from Georg Raffelt

Extra U(1)’ gauge bosons: Dark Photon

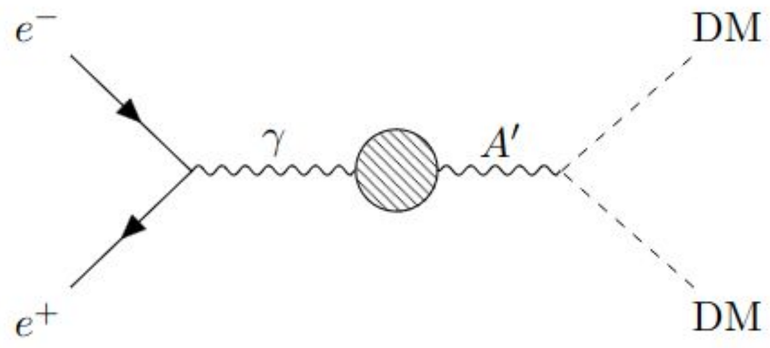
$$\mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \boxed{\times U(1)'}$$

A force beyond the Standard Model
–
Status of the quest for hidden photons

Joerg Jaeckel

Institut für theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

- similarities with the electromagnetic signals generated by axion ⇒ reinterpretation of limits
- intrinsic polarisation ⇒ accounting for polarization enhances sensitivity
- DP-photon mixing is an inherent feature of the model ⇒ no need for external magnetic field



$$\mathcal{L} \supset -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} \boxed{- \frac{\chi}{2}F_{\mu\nu}X^{\mu\nu}} + \frac{m_X^2}{2}X_\mu X^\mu + j_\mu A^\mu$$

“Kinetic mixing”

below electroweak scale

Shift $X^\mu \to X^\mu - \chi A^\mu$ removes the kinetic mixing term:

$$\mathcal{L} \supset -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} + \frac{m_X^2}{2}(X_\mu X^\mu - 2\chi X_\mu A^\mu + \chi^2 A_\mu A^\mu) + j_\mu A^\mu$$

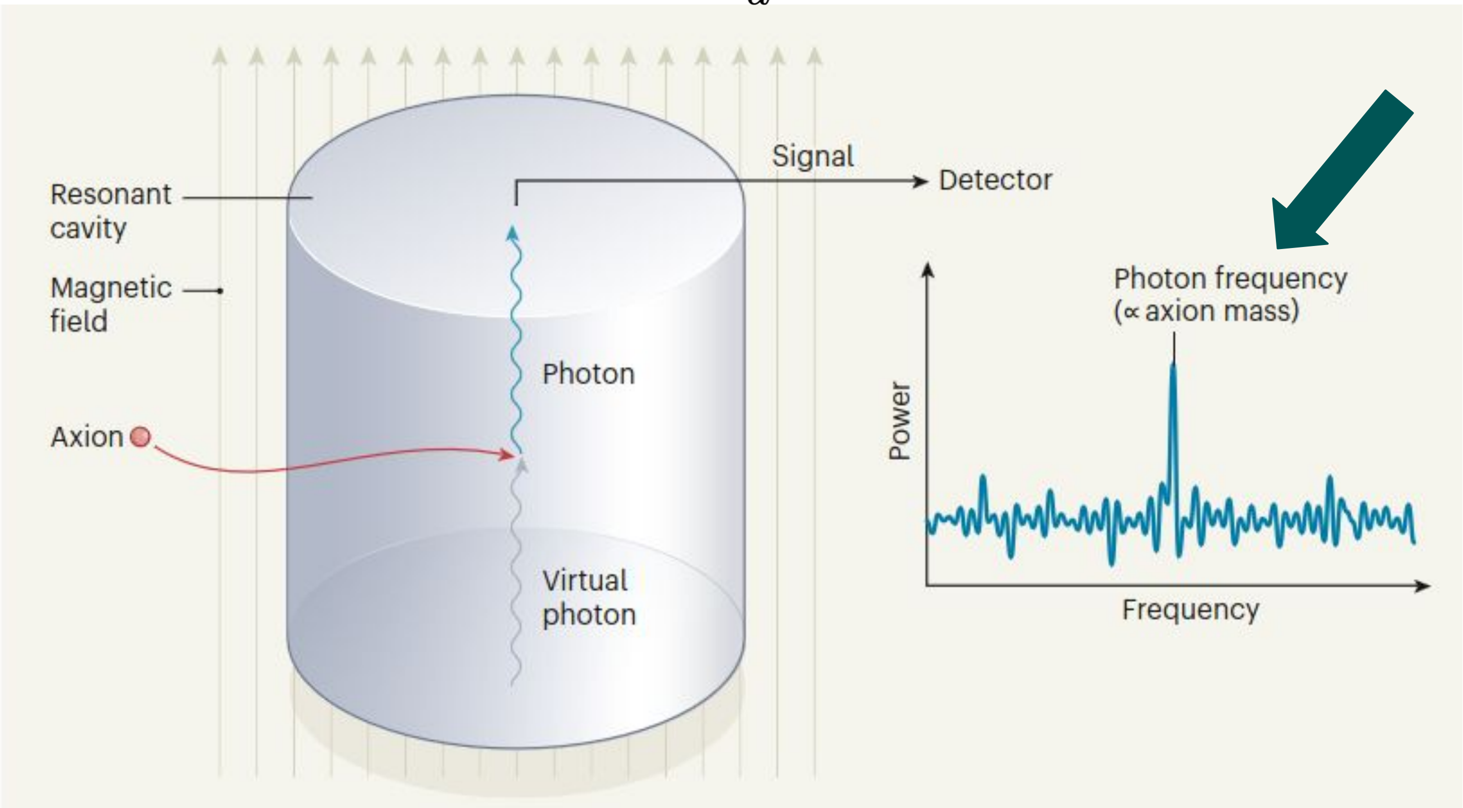
non-diagonal mass term ⇒ mixing X and A, hence A ↔X oscillations

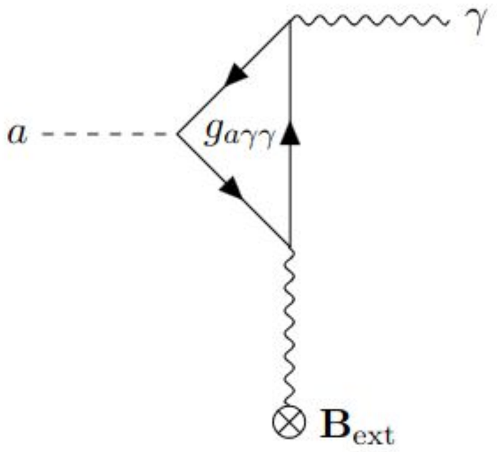
Haloscope Concept

Experimental Tests of the "Invisible" Axion

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

$$P_{cav} \propto g_{a\gamma}^2 \cdot \frac{\rho_{DM}}{m_a} \cdot B^2 \cdot V \cdot Q$$





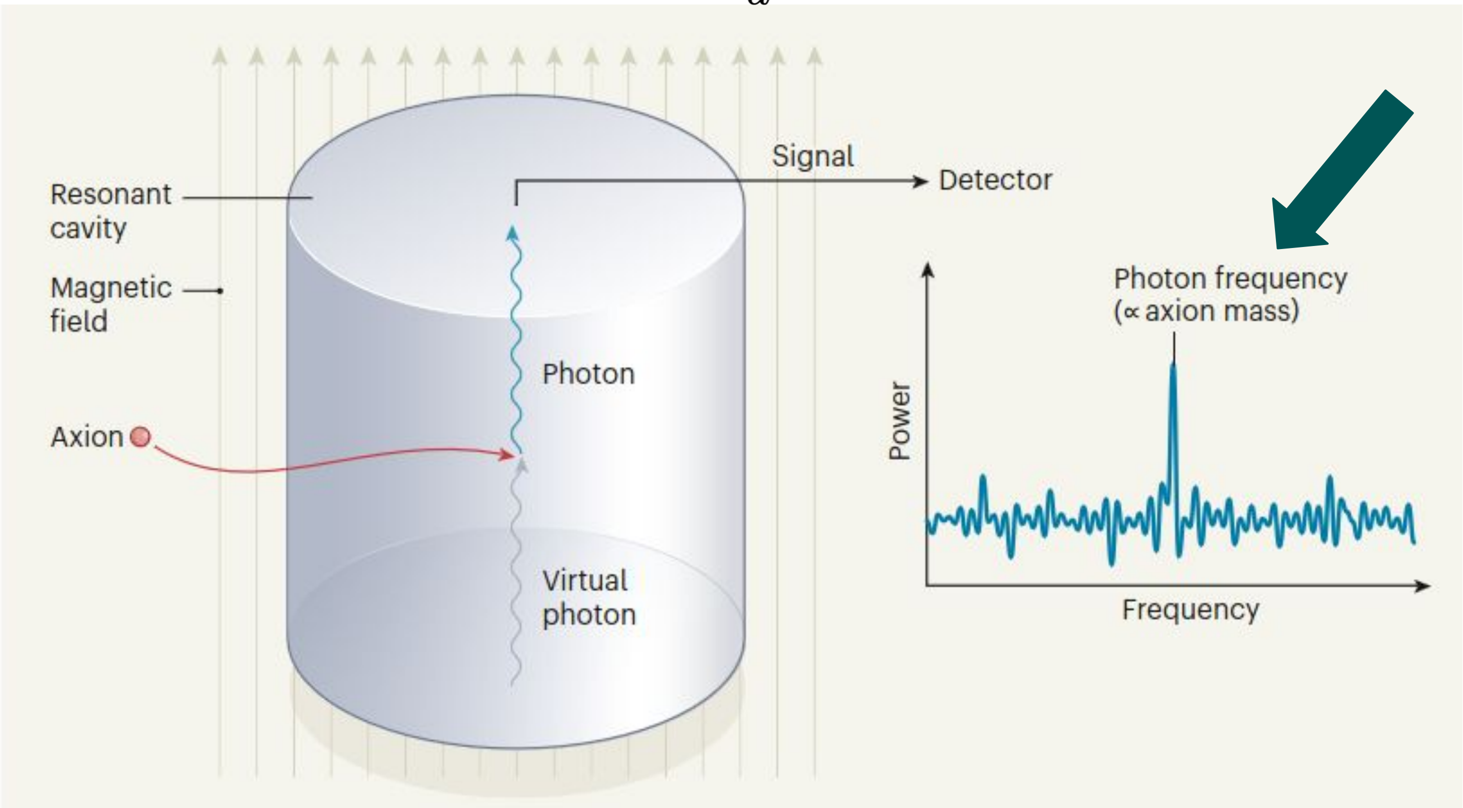
Tunable resonant cavity

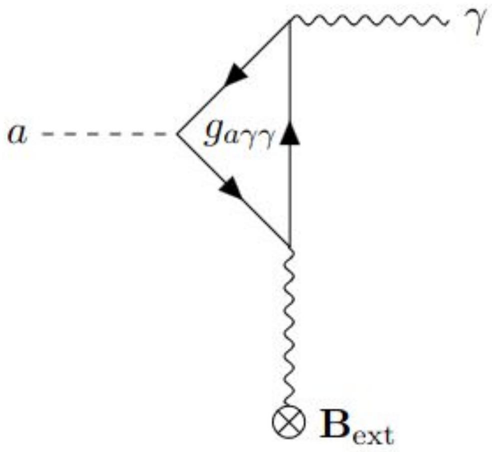
- detect enhanced EM response when resonant mode is tuned to axion mass *
- measure EM power from signal over noise

Haloscope Concept

* challenge:
don't know where
to look exactly…

$$P_{cav} \propto g_{a\gamma}^2 \cdot \frac{\rho_{DM}}{m_a} \cdot B^2 \cdot V \cdot Q$$





Tunable resonant cavity

- detect enhanced EM response when resonant mode is tuned to axion mass *
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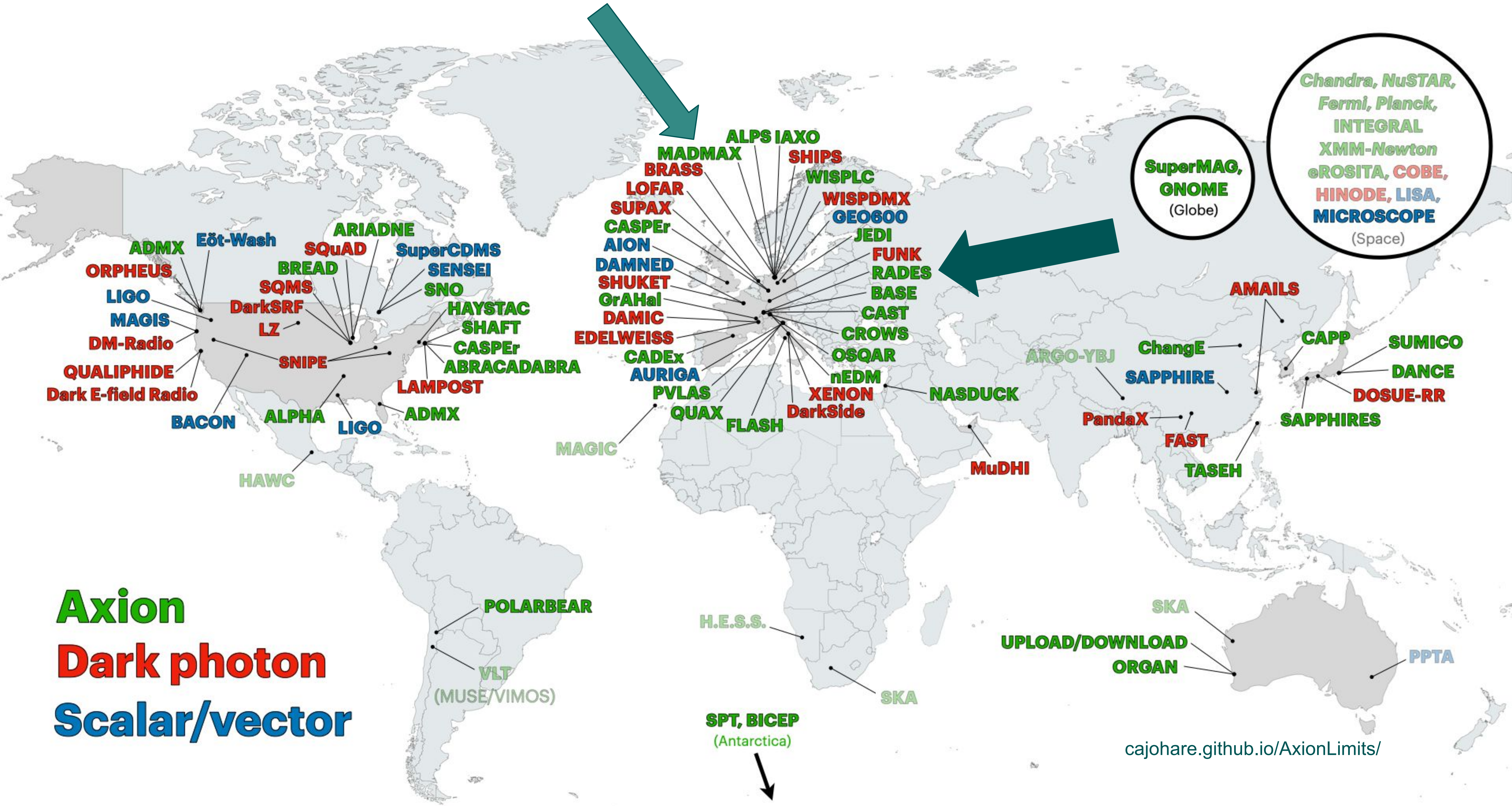

ALPS IAXO
MADMAX
SHIPS
BRASS
WISPLC
LOFAR
WISPDMX
SUPAX
GEO600
CASPEr
JEDI
AION
FUNK
DAMNED
RADES
SHUKET
BASE
GrAHal
CAST
DAMIC
CROWS
EDELWEISS
OSQAR
CADEx
nEDM
AURIGA
NASDUCK
PVLAS
XENON
QUAX
DarkSide
FLASH
MAGIC
MuDHI
SuperMAG, GNOME
(Globe)
Chandra, NuSTAR, Fermi, Planck, INTEGRAL
XMM-Newton
eROSITA, COBE, HINODE, LISA, MICROSCOPE
(Space)
ADMX
Eöt-Wash
ARIADNE
SQuAD
SuperCDMS
ORPHEUS
BREAD
SENSEI
LIGO
SQMS
SNO
DarkSRF
HAYSTAC
MAGIS
LZ
SHAFT
DM-Radio
CASPEr
SNIPE
ABRACADABRA
QUALIPHIDE
LAMPOST
Dark E-field Radio
ALPHA
ADMX
BACON
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CAPP
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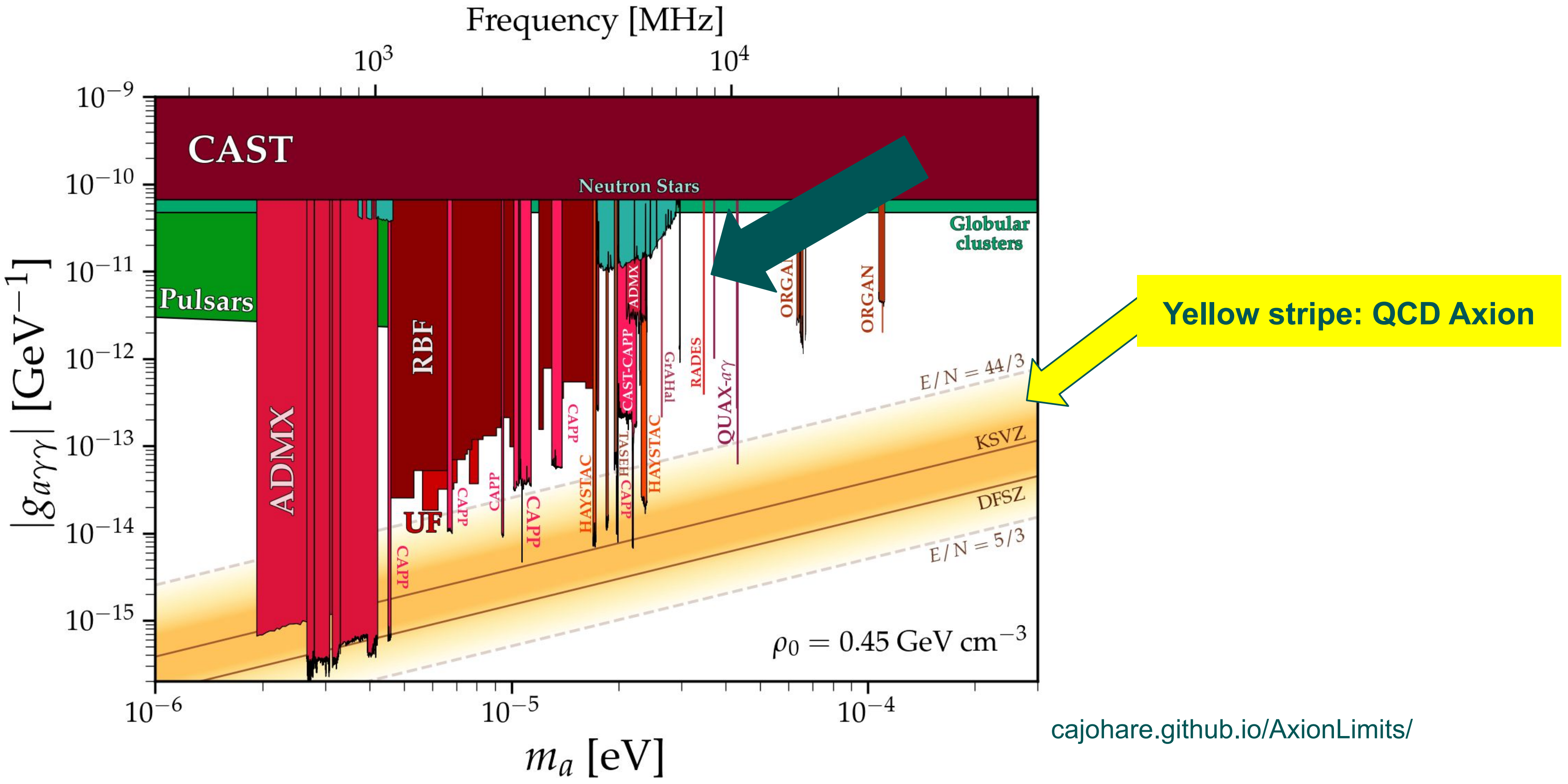
ARGO-YBJ
DANCE
SAPPHIRE
DOSUE-RR
PandaX
SAPPHIRES
FAST
TASEH
POLARBEAR
H.E.S.S.
SKA
UPLOAD/DOWNLOAD
ORGAN
PPTA
VLT
(MUSE/VIMOS)
SKA
SPT, BICEP
(Antarctica)
Axion
Dark photon
Scalar/vector
cajohare.github.io/AxionLimits/

Axion Parameter space - Exclusion Plot

$$P_{cav} \propto g_{a\gamma}^2 \cdot \frac{\rho_{DM}}{m_a} \cdot B^2 \cdot V \cdot Q$$

we will see a lot of plots like this…

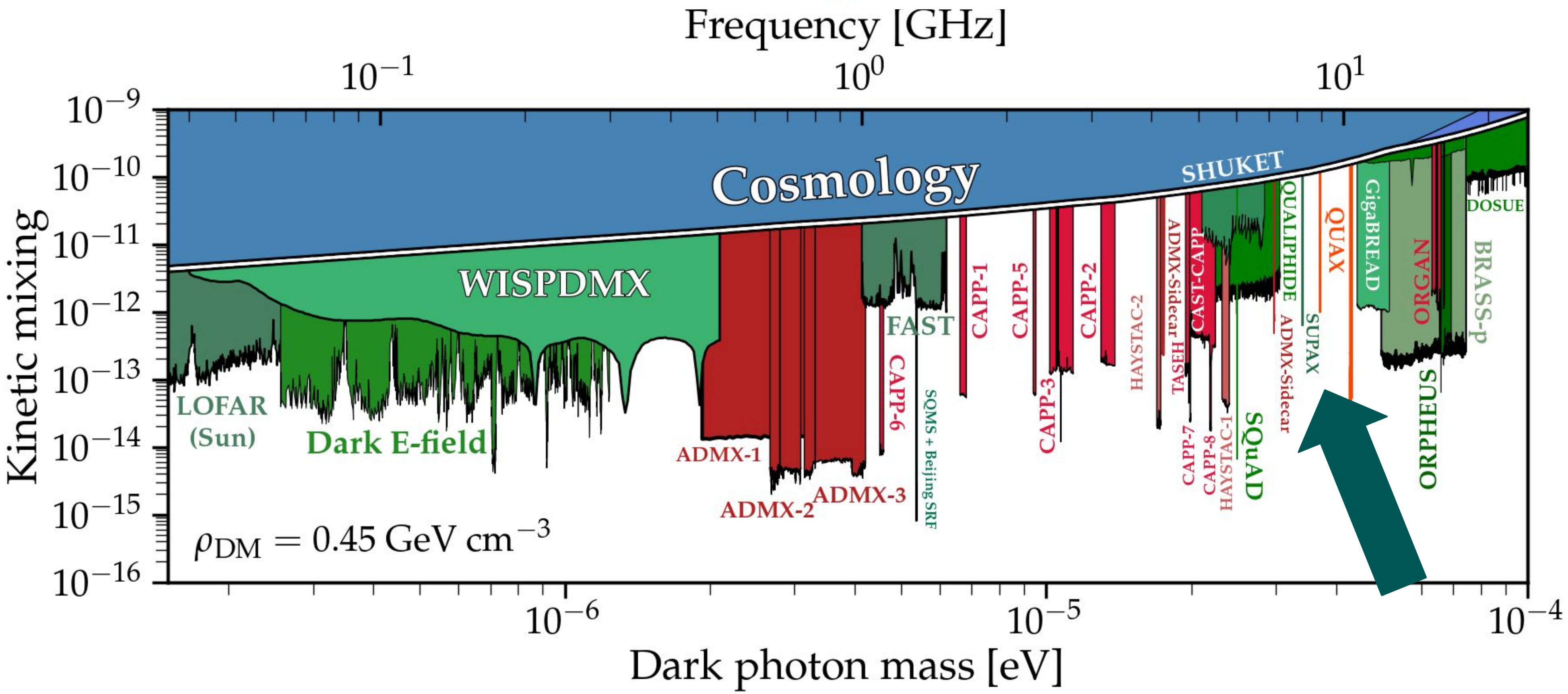


Yellow stripe: QCD Axion

cajohare.github.io/AxionLimits/

Dark Photon Parameter space - Exclusion Plot

$$g_{a\gamma} \rightarrow \frac{\chi m_{\gamma'} \sqrt{\cos^2 \theta_{\text{pol}}}}{B}$$



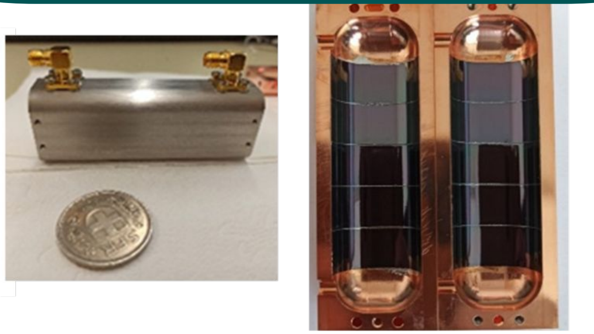
cajohare.github.io/AxionLimits/

RADES Haloscope - SM18 setup

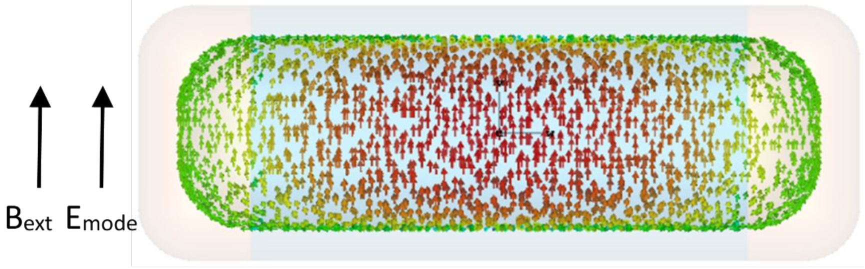
$$P_{cav} \propto g_{a\gamma}^2 \cdot \frac{\rho_{DM}}{m_a} \cdot B^2 \cdot V \cdot Q$$

- Haloscope experiment using a superconducting RF cavity within an 11.7 T dipole magnet at CERN
- searches for cosmic axions originating from the dark matter halo
- Utilization of rectangular cavity optimized with high-temperature superconducting (HTS) ReBCO tapes ⇒ 50% increase in the quality factor over usual copper coatings
- The data acquisition (DAQ) system made of an analog and a digital stage
- Cavity connected to Cryogenic low noise amplifier (LNA) connected DAQ
- Data run: Analysed 27 hours of data: axion mass range of 36.5676 µeV to 36.5699 µeV

Cavity (prototype)uncoated & coated



Surface currents for the axion mode - TE111

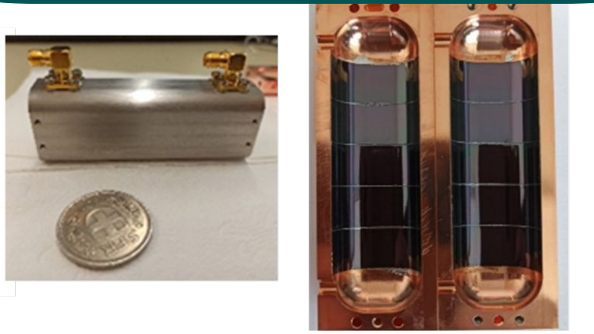


RADES Haloscope - SM18 setup

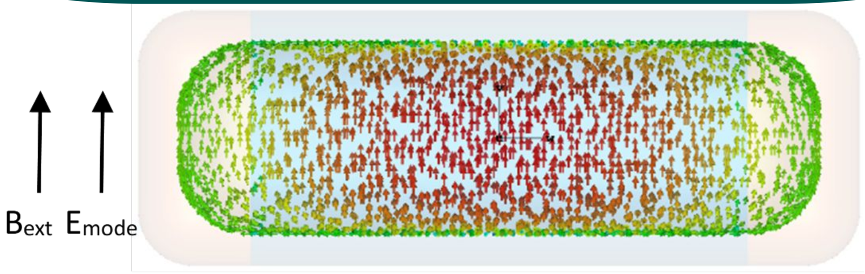
$$P_{cav} \propto g_{a\gamma}^2 \cdot \frac{\rho_{DM}}{m_a} \cdot B^2 \cdot V \cdot Q$$

- higher masses – high frequency very difficult due to reduced cavity volumes
- lower masses – low frequency implies large cavities and thus very big magnets

Cavity (prototype)uncoated & coated



Surface currents for the axion mode - TE111

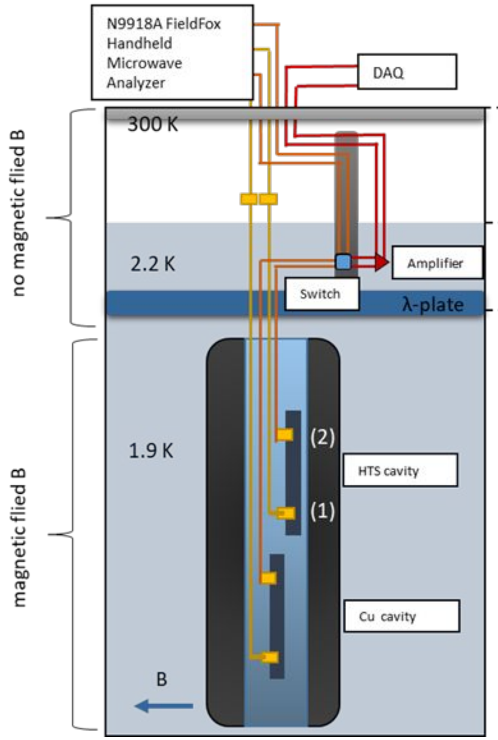


RADES Haloscope - SM18 setup

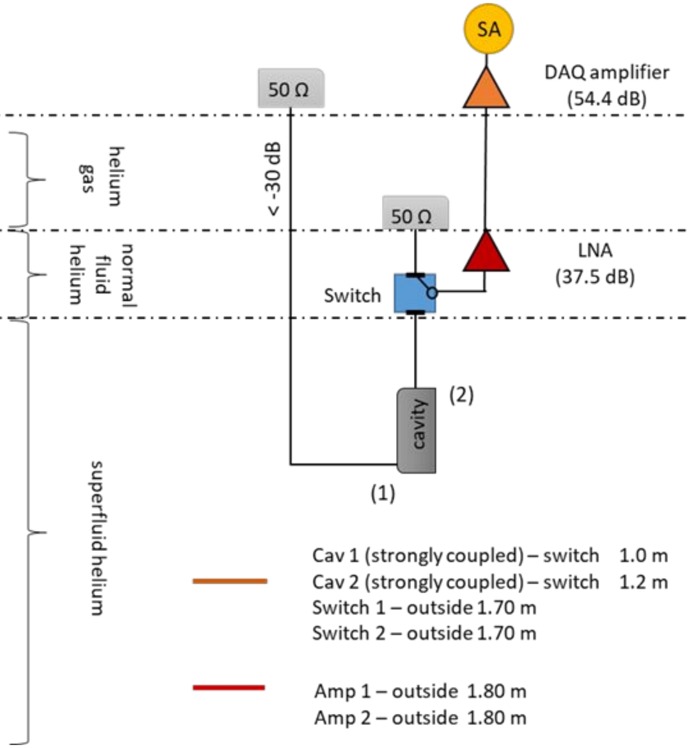
*** difficulty: excess of residual electronic systematics**

$$\Sigma = \frac{P_{\text{sig}}}{k_B T_{\text{sys}}} \sqrt{\frac{\tau}{\Delta \nu_a}}.$$

experimental set-up



wiring diagram



- cavity connected to cryogenic LNA
- magnet & cavity inserted in a cryostat (liquid helium)
- pressure variations in the helium bath

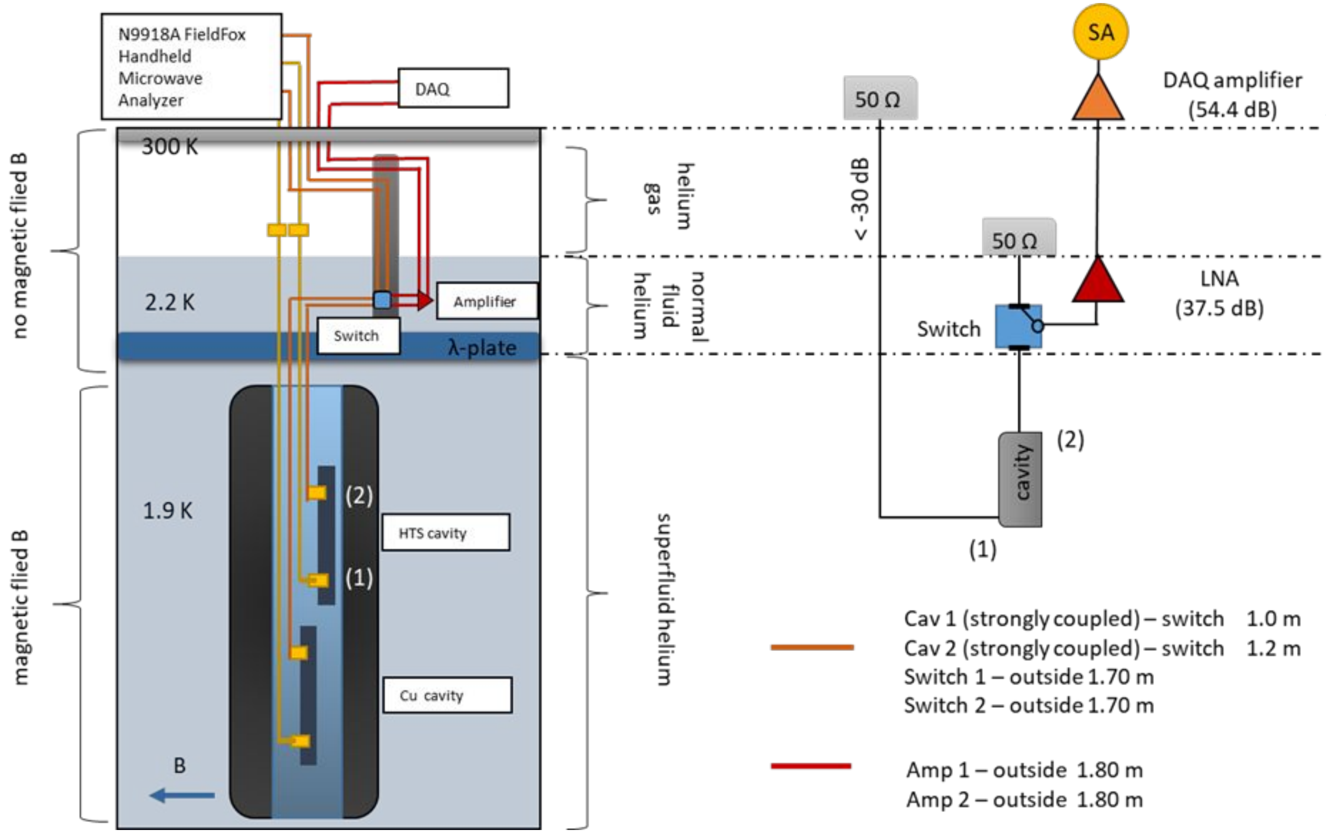
  ⇒ frequency tuning: 312 kHz

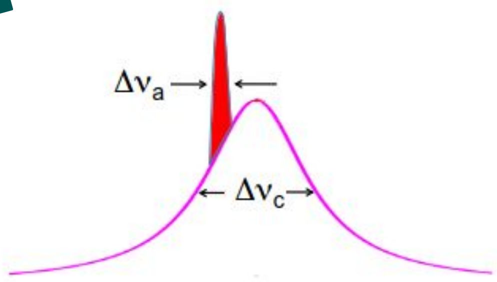
- DAQ* consists of an analog and a digital stage
- analog part amplifies the input signal

  ⇒ converts it to an intermediate frequency (IF) via a Local Oscillator (LO)

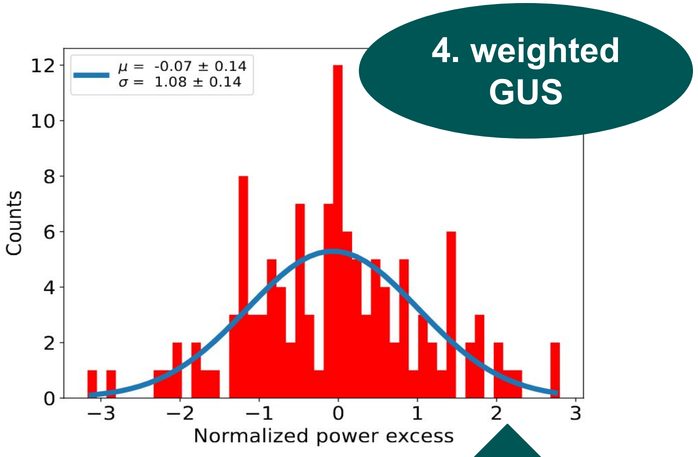
- I = 11850 A B = 11.7 T T = 1.9 K V = 0.0288 L

What to expect ?!

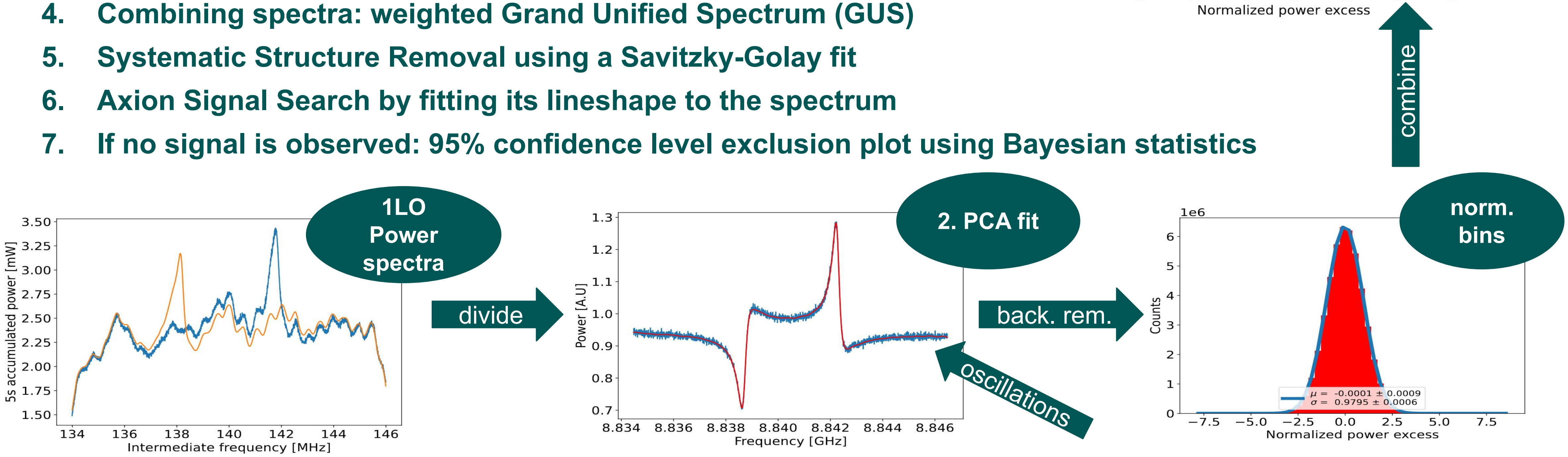




Data Analysis Procedure

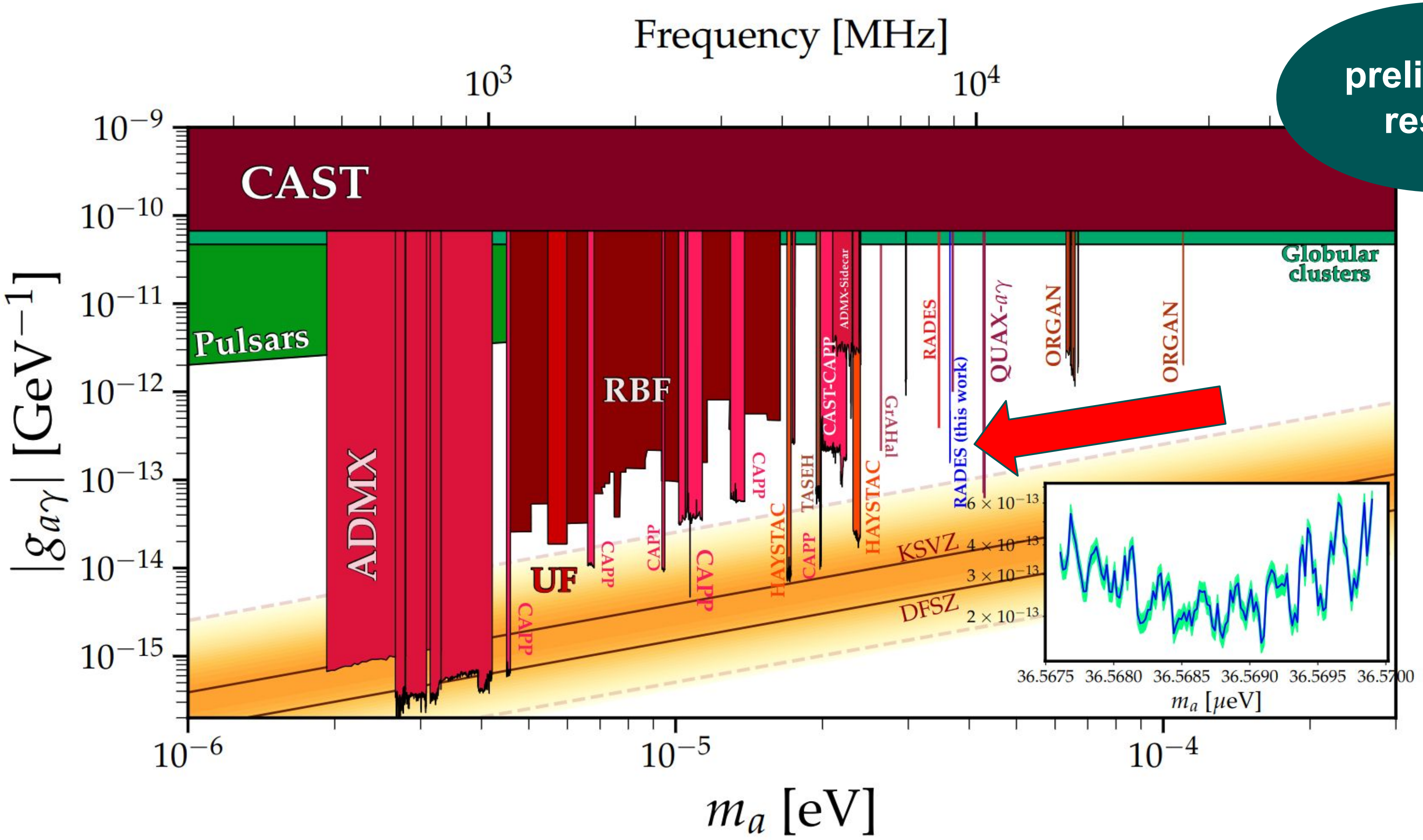


1. Division of LO Power Spectra
2. DAQ Calibration using Principal Component Analysis (PCA)
3. Removal of Electronic Background with modified Lorentzian PCA fit
4. Combining spectra: weighted Grand Unified Spectrum (GUS)
5. Systematic Structure Removal using a Savitzky-Golay fit
6. Axion Signal Search by fitting its lineshape to the spectrum
7. If no signal is observed: 95% confidence level exclusion plot using Bayesian statistics



Results for the Axion

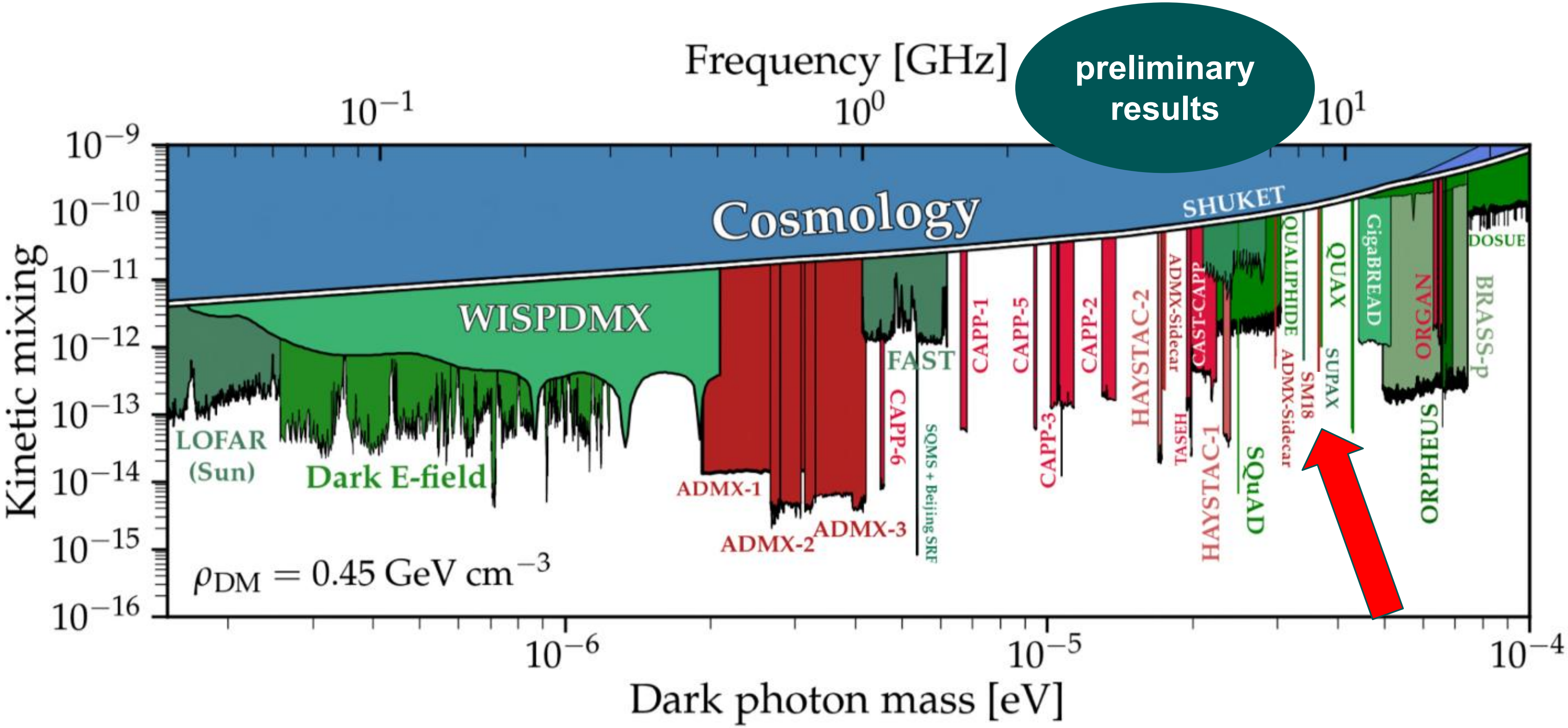
$$36.5676\mu eV \ - \ 36.5699\,\mu eV$$
$$g_{a\gamma} \gtrsim 6.2 \times 10^{-13} GeV^{-1} \, and \, g_{a\gamma} \gtrsim 1.54 \times 10^{-13}\, GeV^{-1}$$



preliminary results

Results for the Dark Photon

$$36.5676\mu eV \; - \; 36.5699\,\mu eV$$



BabyIAXO upgrade promises breakthrough in the hunt for dark matter

by Andrey Feldman | Nov 29, 2023

Scientists propose an enhancement to the BabyIAXO axion detector, paving the way for an intensified search for elusive dark matter particles.

Summary

preliminary results

- **Axion Dark Matter Search: No signal excess detected in the mass range of 36.5676 μeV to 36.5699 μeV**
- **Dark Photon Matter Search: No signal excess detected in the mass range of 36.5676 μeV to 36.5699 μeV**
- **Challenges: residual electronic systematics in the spectral analyzer**

Outlook

- **Data analysis search of Dark photon**
- **RADES R&D Initiatives (e.g tuning) and RADES set up at MPP**
- **Search for High-frequency Gravitational Waves?**
- **Long-Term Vision: data-taking in the magnet of the babyIAXO haloscope, 1-2 μeV mass range**
- **DarkQuantum Initiative: new quantum sensors and their application in experiments to search for axions**

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Thank you very much!

Questions?

Backup slides

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