Axion Dark Matter search at CAST with the RADES detector

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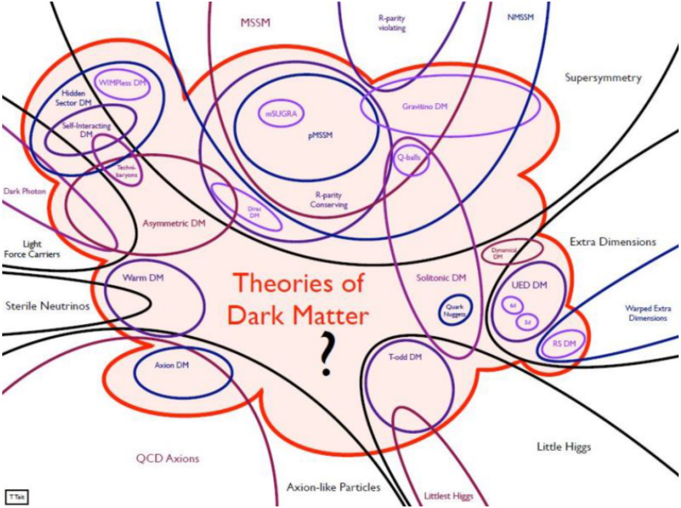
Outline

- What is an axion?
- How does RADES look for an axion?
- Inductive irises prototype.
- Alternating irises prototype.

Dark Matter

- Observations hints for the existence of a form of matter that has not yet been detected in the lab, known as dark matter.
  1. Astrophysical: Rotation curves and velocity dispersion of galaxies and clusters do not match with the predicted values from Kepler's second law and the viral theorem for the observed mass distribution.
  2. Cosmological: Gravitational lensing and the observed CMB angular power spectrum provides powerful evidence in support of dark matter.



T. Tait/University of California, Irvine

Figure 1: Dark Matter Candidates [1].

Motivation for the Axion

- The strong force should be able to break the Charge-Parity symmetry.
- The CP violation term of the QCD Lagrangian is: $L_\theta = \theta \frac{g^2}{32\pi^2} F_a^{\mu\nu} \bar{F}_{a\mu\nu}$.
- The experimental upper limit for the neutron EDM is 10^{-26}e $\cdot$ cm. This would constrain θ to a value below 10^{-10}.
- This is known as the strong CP problem.

Motivation for the Axion

- Peccei and Quinn introduced their solution to the strong CP problem. By promoting the θ parameter into a field.
- Similar to other fields, this predicts a particle excitation of the field, known as the axion.
- The main search channel to look for the axion is its coupling to a photon.

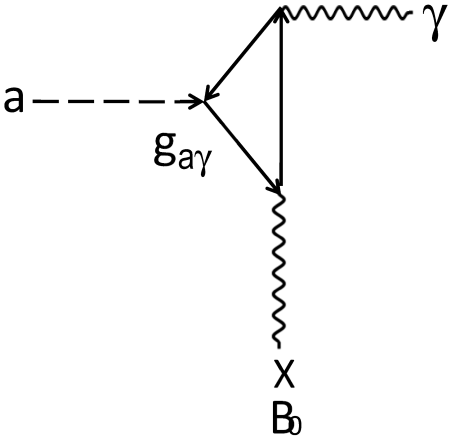


Figure 2: Axion Photon Coupling [2].

Axion search space

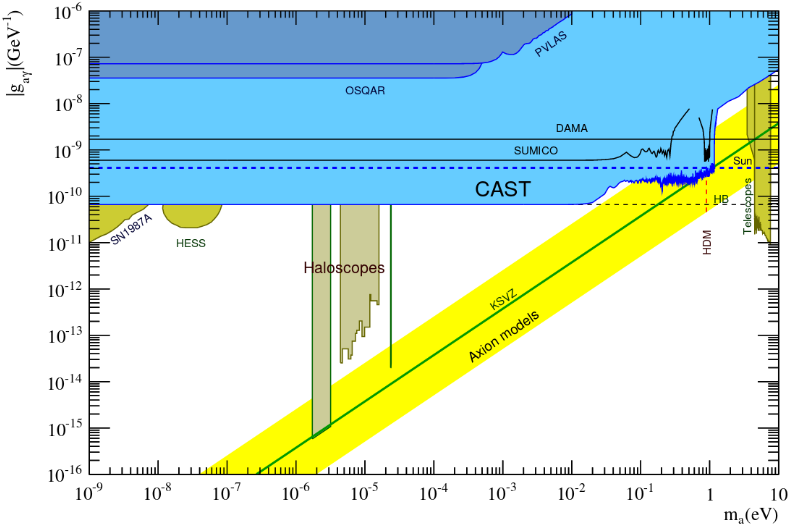


Figure 3: Axion search space and current $g_{a\gamma}$ constrains [3]

CERN Axion Solar Telescope (CAST)

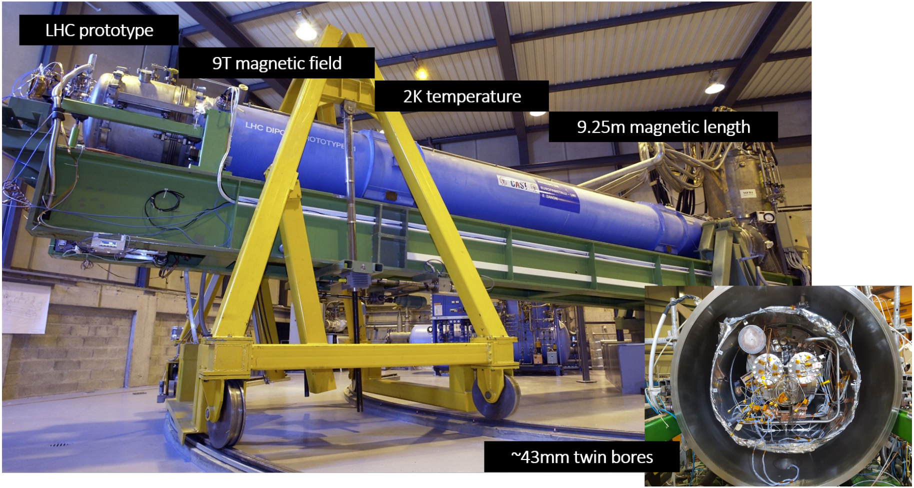


Figure 4: CAST magnet

Measurement principle

- In the presence of a magnetic field, the conversion of axions into photons is triggered.
- A cavity resonating at the frequency of the expected axion mass will increase its output power.
- A figure of merit for our experiment is given by: $F \sim g_{a\gamma}^2 m_a^2 B^4 V^2 T_{sys}^{-2} G^4 Q$

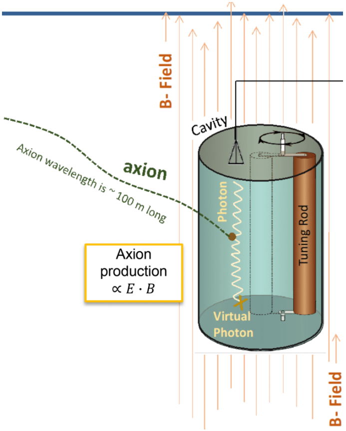


Figure 5: Scheme of a dark matter haloscope experiment [4].

Challenges of going to higher frequencies

- $F \sim g_{a\gamma}^2 m_a^2 B^4 V^2 T_{sys}^{-2} G^4 Q$
- Increasing in mass means shorter cavities and smaller volume.
- Q value decreases for higher frequencies.
- Decreasing in volume will decrease the figure of merit of this type of experiment.
- To tackle this problem, RADES proposed, designed and built filters of N stainless steel sub-cavities joined by rectangular irises.

RADES inductive irises prototype

- Consists of 5 sub-cavity structures joined by inductive irises.
- One can choose the working frequency by changing the dimension of the unit cell.
- Afterwards, the dimensions are optimized using simulations to achieve the best geometric factor.

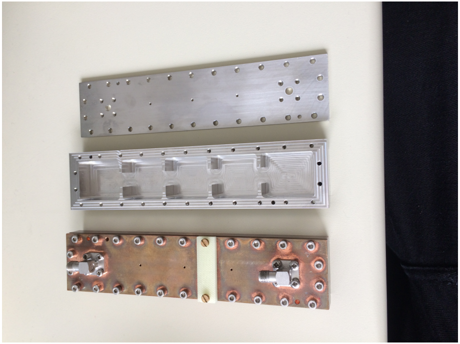


Figure 6: RADES first prototype [5].

Inductive irises prototype

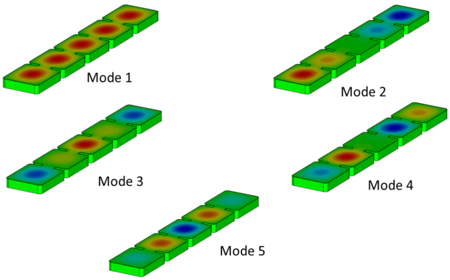


Figure 7: Electric field configuration of the 5 modes [5].

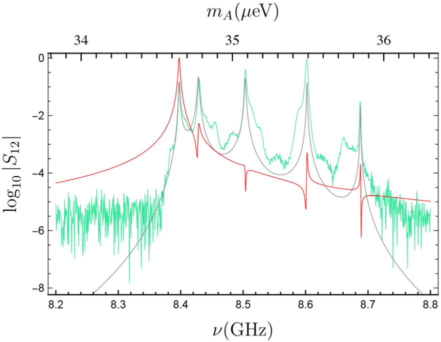


Figure 8: Transmission parameter: measurement (green) and theoretical model (gray). Red is axion coupling for the 5 modes [5].

2018 data taking

- This 5-cavities prototype was installed in the CAST magnet and first data taking took place in 2018.
- Approximately 103 hours of data were recorded.
- The analysis of the first run is about to be finished.

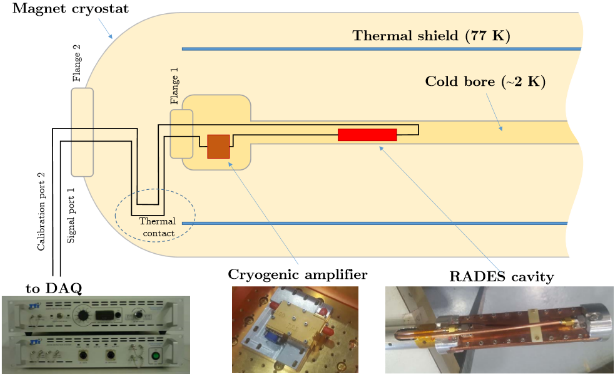


Figure 9: RADES setup at CAST [5].

2018 data analysis

- One recorded N number of power spectra during the data taking. These power spectra are a combination of thermal noise, the resonance structure of the cavity, electronic background and a possible axion signal.

- The first step of the analysis is to remove the resonance structure and the electronic background.

- Then one combines all the spectra together. The power of the fluctuations of the thermal noise will decrease proportional to $1/\sqrt{t}$. While the power of the possible axion signal should not change over time.

Inductive and capacitive prototype small prototype

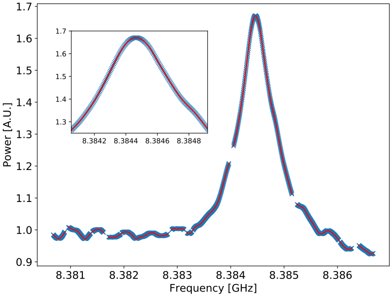


Figure 10: Typical RADES power spectrum.

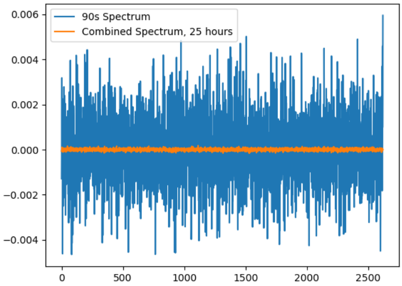


Figure 11: Simulated fluctuation of thermal noise for 90s and 25 hours.

2018 data analysis

- The axion analysis is based on the following 3 equations:

$$P_a = g_{a\gamma}^2 \rho_{\mathrm{DM}} \frac{\beta}{1+\beta} \frac{1}{m_a} B^2 V Q_L G^2$$

$$P_N = k_b T_{\mathrm{sys}} \Delta\nu,$$

$$\mathrm{SNR} = \frac{P_a \sqrt{t \Delta\nu}}{P_N}.$$

- Using the following values, one can give a prospect of the sensitivity of our detector:
- $\beta = 0.97$.
- Q = 7874.
- T = 7.8 K
- $\Delta\nu$ = 4577 Hz
- B = 8.8 T
- G = 0.65

RADES setup at CAST

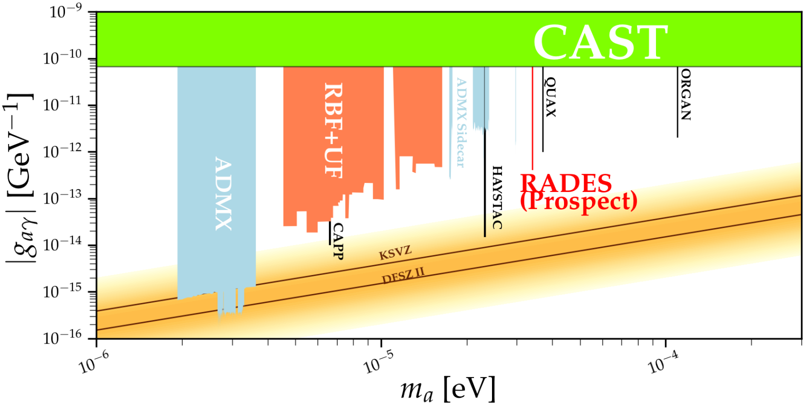


Figure 12: RADES prospect

Cavity development

- The results of the first prototype were satisfactory.
- To grow in volume and at the same time having a working frequency higher than 8 GHz, one had to add more sub cavities.
- The addition of more sub cavities increases the possibility of mode mixing.
- To avoid this, one can work with a higher mode by introducing alternating irises.

Inductive and capacitive prototype small prototype

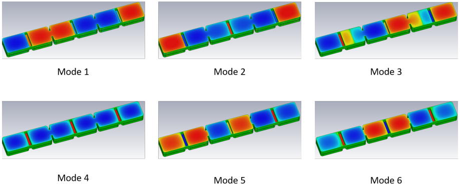


Figure 13: Electric field distribution of the 6 modes [6].

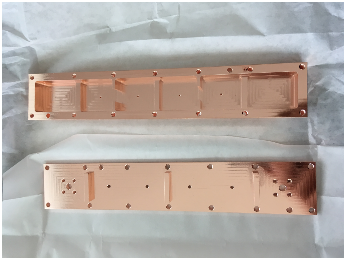


Figure 14: Alternating irises prototype [6].

- Following this idea, a 30 cavity structure was design and built at CERN.
- The new cavity was installed at the CAST magnet.
- Increasing almost 6 times in volume will increase our sensitivity.
- We are currently taking data with this cavity.

Figure 15: Alternating irises 30 sub-cavities prototype [6].

Conclusion

- RADES is looking for a dark matter candidate called axions using RF cavities resonating at frequencies between 8 and 9 GHz.
- Data acquired with first 5-cavity pathfinding prototype in the CAST magnet provided first results at this frequency.
- The alternating irises prototype allows the possibility of increasing in volume without mode mixing.
- RADES is also doing R&D to include a tuning mechanism and have a superconductive cavity.

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