Axion dark matter search at CAST using haloscopes

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15th Patras Workshop on Axions, WIMPs and WISPs

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Introduction

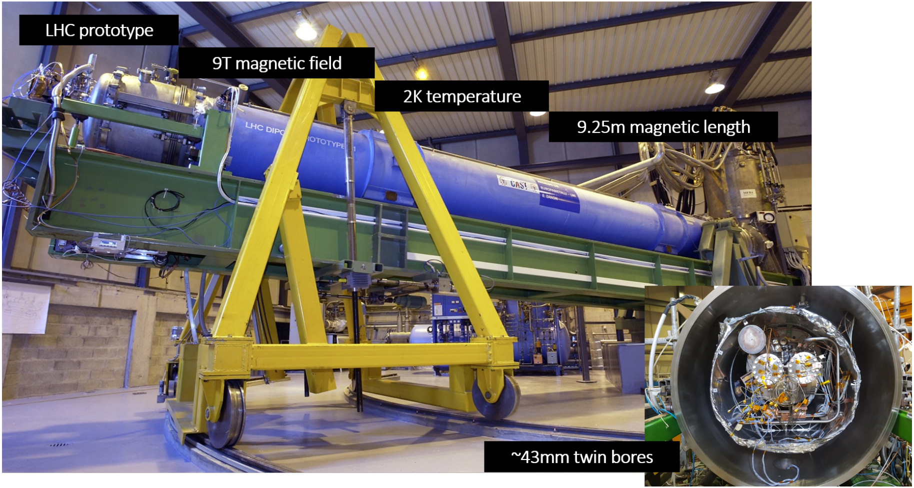


Figure 1: CAST magnet

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:

$$F \sim g_{A\alpha}^2 m_a^2 B^4 V^2 T_{sys}^{-2} G^4 Q \quad (1)$$

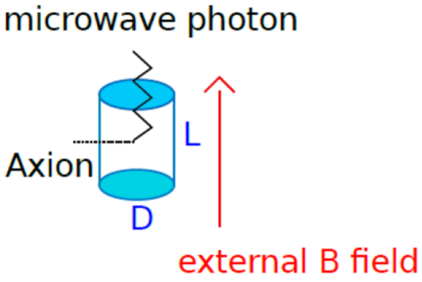


Figure 2: Standard haloscope experiment

Challenges of going to higher frequencies

- Increasing in mass means shorter cavities and smaller volume.
- Decreasing in volume will decrease the figure of merit of these type of experiments.
- RADES proposed, designed and built filters of N stainless steel sub-cavities joined by rectangular irises resonating at 8.4 GHz.
- CAPP-CAST consists of 4 identical tunable rectangular cavities resonating between 5.1 and 5.5 GHz.

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.

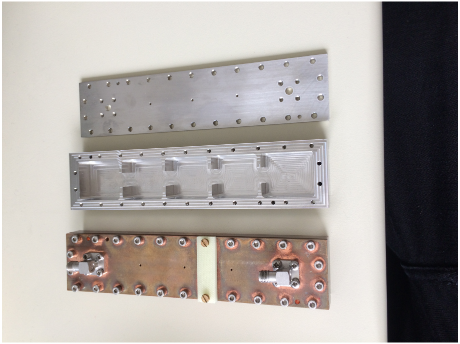


Figure 3: RADES first prototype

Inductive irises prototype

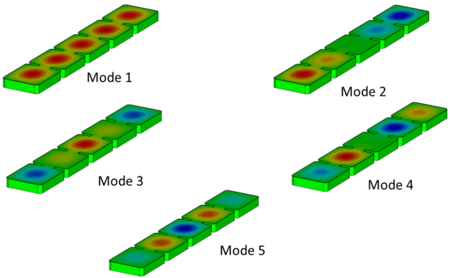


Figure 4: Electric field configuration of the 5 modes

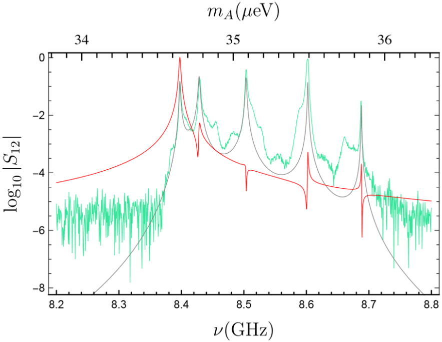


Figure 5: Transmission parameter: measurement (green) and theoretical model (gray). Red is axion coupling for the 5 modes.

Challenges for this prototype

- This prototype was successfully installed at CAST and it was used during the 2018 data taking campaign
- Improve the Q-value.
- Prevent the mode mixing when scaling in volume.
- Introduction of a tuning mechanism.

Alternating irises prototype

- It is better to work with a higher mode in order to avoid mode mixing.
- By alternating inductive and capacitive irises the coupling between the cavities now has negative and positive values.
- Simulations showed that now a higher mode is the one that couples to the axion.

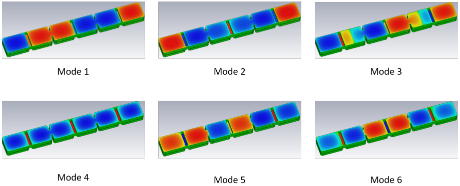


Figure 6: Electric field configuration of the 6 modes

Alternating irises prototype

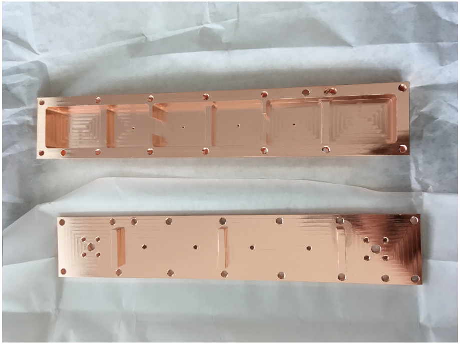


Figure 7: 6 sub-cavity prototype

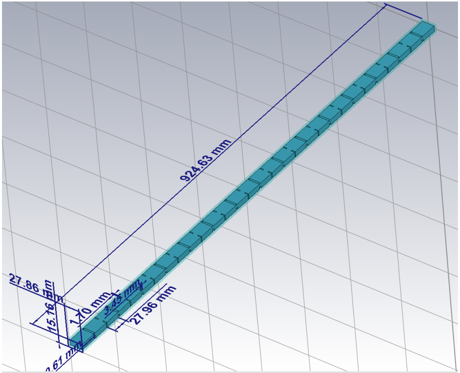


Figure 8: 30 sub-cavity 3D model

Tuning mechanism ideas

- Mechanical tuning with a vertical cut cavity

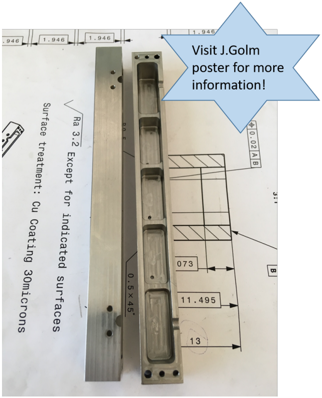


Figure 9: RADES vertical cut cavity

- Electrical tuning with ferroelectric materials.

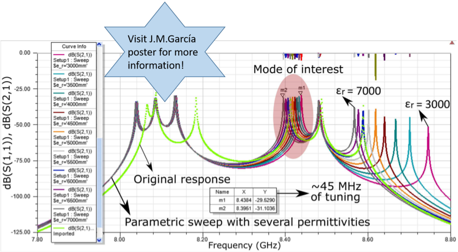


Figure 10: Simulations for ferroelectric tuning

RADES setup at CAST

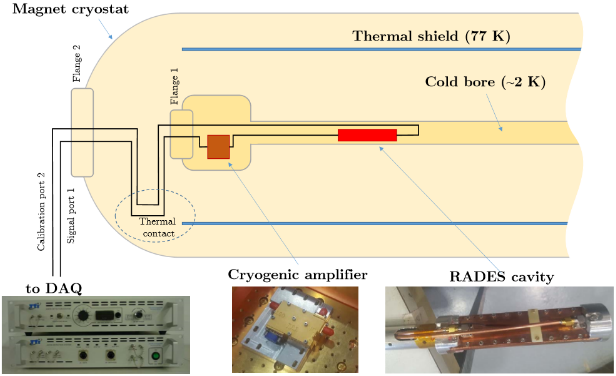


Figure 11: RADES setup at CAST

Preliminary Results

- The 5 sub-cavities filter with inductive irises was used during the first data taking campaign.
- Around 340 hours of data were taken during 2018.
- 14 hours have been analyzed to produce a preliminary exclusion plot.

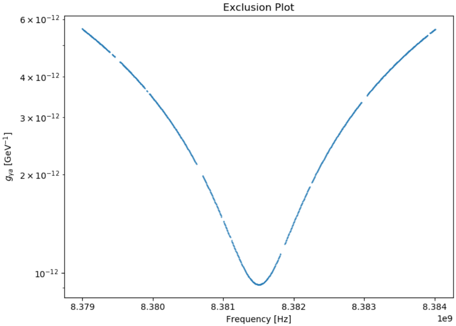


Figure 12: Preliminary exclusion limit

CAST-CAPP cavities

- 4 tunable rectangular stainless steel cavities 25x24x390 mm electroplated with ~30 μm copper.
- Longitudinally split into two identical halves.
- Installed in the magnet with the split plane parallel to the magnetic field along the cavity small face.

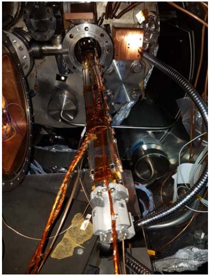


Figure 13: CAST-CAPP cavity at CAST

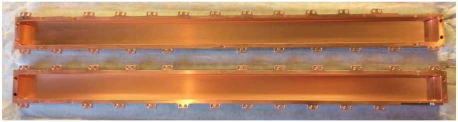


Figure 14: CAST-CAPP cavity

Tuning Mechanism

- 2 long parallel sapphire plates are activated by a single piezoelectric device.
- The cavity frequency is changed by moving the plates towards or away from the split plane.
- Tuning range is $\sim$ 400 MHz (5.1 GHz to 5.5 GHz).
- Phase-matching of 4 cavities achieved.

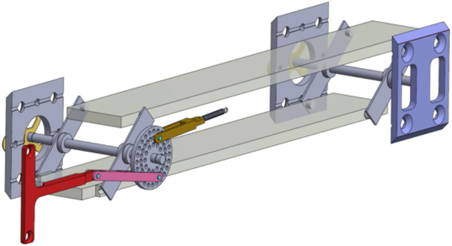


Figure 15: Tuning mechanism 3D model

Tuning Mechanism

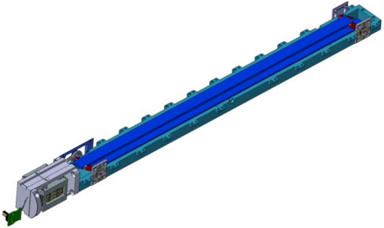


Figure 16: Tuning mechanism

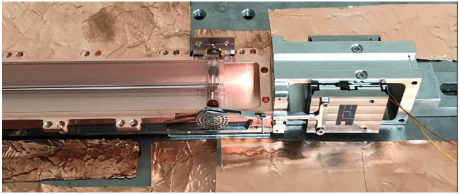


Figure 17: Piezoelectric and sapphire plates

Data taken

- The first mode TE101 is of Interest.
- 2018 run: 134h of data with one cavity at a fixed frequency with 5MHz span.
- 2019 test run: 27h of data with one cavity at a fixed frequency with 5 MHz span. 260 min while tuning in a frequency range of 240 MHz with 5 MHz span.

Figure 18: Example of data taking through SA with calibration peak

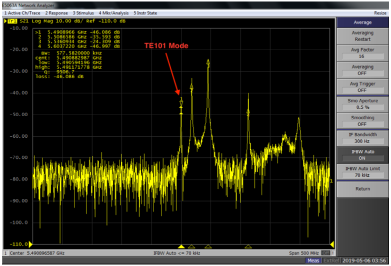


Figure 19: S21 Transmission measurement through VNA

Data Analysis

- All acquired data of 2018 and 2019 datasets have been analyzed.
- No peak above the 5 σ level has been observed.

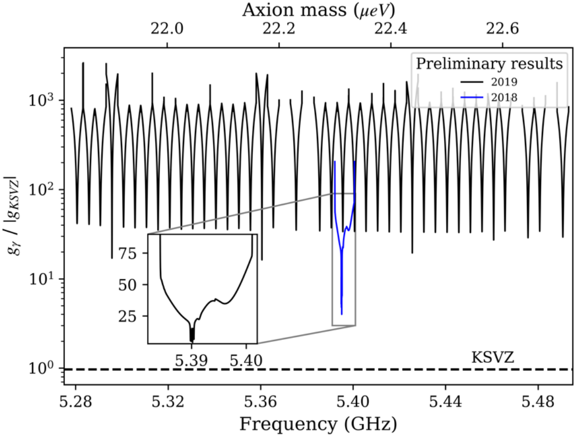


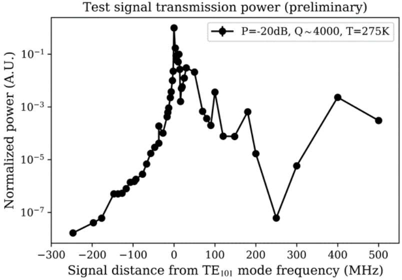
Figure 20: Preliminary exclusion limit

Streaming Dark Matter

- Axion DM streams can increase the local axion density by several orders of magnitude.
- Even a tiny flux might get temporally strongly enhanced due to solar gravitational lensing.
- **Resonant frequency tuning**:
  - The faster the scanning the shorter dense axion burst can be utilized.
  - Each scanning window of 5 MHz can last $\sim$30 seconds thus scanning the whole range ($\sim$400 MHz) can be a matter of $\sim$40 min.

Streaming Dark Matter

- **Wide band scanning**:
  - The power output of the axion to RF-photon conversion is proportional to the quality factor with a Lorentzian structure.
  - Its sensitivity away from the resonance is decreased by factor Q^2, but it is not zero.
  - By changing the center frequency of the signal analyzer we are able to detect with 1 cavity a signal within 250 MHz (could be extended to 1 GHz with 4 cavities) away from resonant frequency (preliminary results for T=275 K).



Prospect for the future

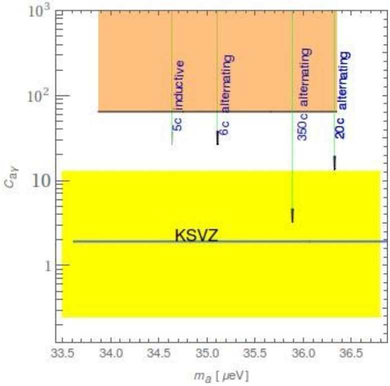


Figure 22: Prospective reach of various CAST-RADES implementations

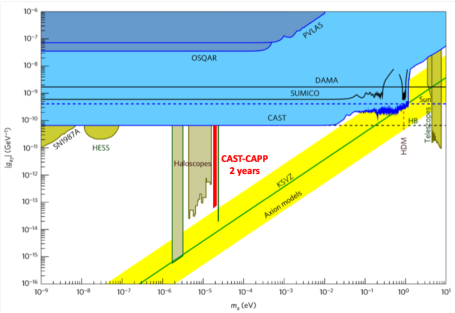


Figure 23: Future prospect of the CAST-CAPP cavities