MAX-PLANCK-INSTITUT FÜR PHYSIK

# WHAT IS A RADES?

## Status of the RADES/IAXO group at MPP

Cristian Cogollos
for the RADES/IAXO Working group at MPP

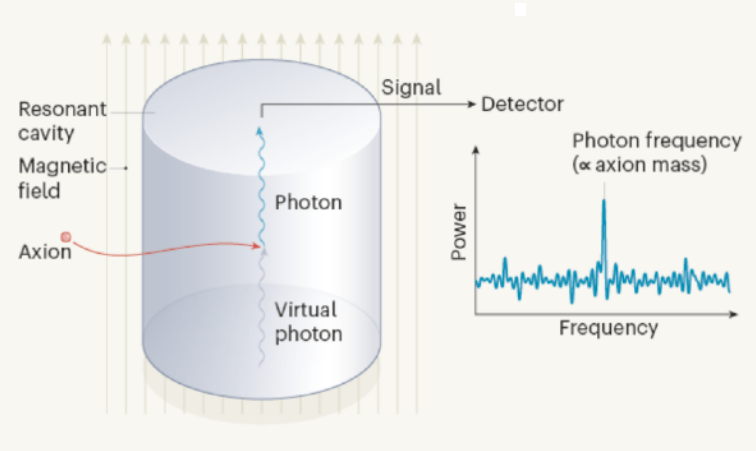
# WHAT IS A RADES?

## RADES: Relic Axion Detection Exploratory Setup

**The RADES team originated in 2016 as a satellite group of the CAST (CERN Axion Solar Telescope) experiment, for the search for dark matter axions with haloscopes.**

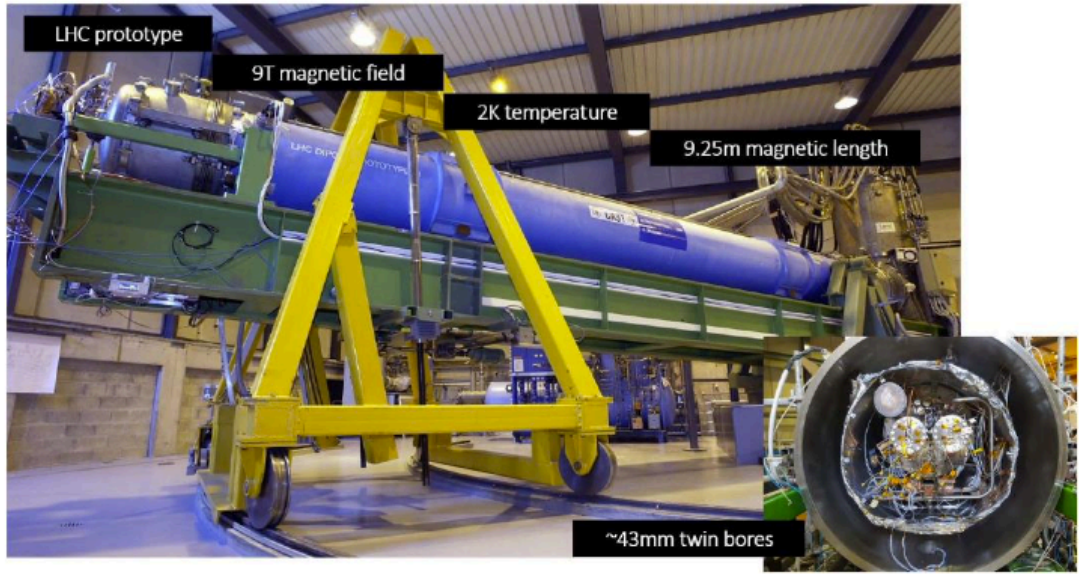
***Current Status of RADES Installation in CAST'***

*65rd CAST collaboration meeting*
*September 26, 2017*
*Antonio José Lozano Guerrero, Alejandro Álvarez Melcón, Benito Gimeno Martínez, Igor García Irastorza, Cristian Cogollos, Javier Redondo, Carlos Peña, Juan Daniel Gallego, Babette Döbrich and Alejandro Díaz Morcillo*




*Principle scheme of a cavity haloscope (from I. G. Irastorza, Nature **590**, 226-227 (2021) )*

## CAST: CERN Axion Solar Telescope



# WHAT IS A RADES?

## In the press:

**RADES joins the hunt for dark matter**

One of the latest additions to the CAST experiment has set a new limit on the strength of the interaction between photons and hypothetical dark-matter particles called axions

25 MAY, 2021 | By Ana Lopes

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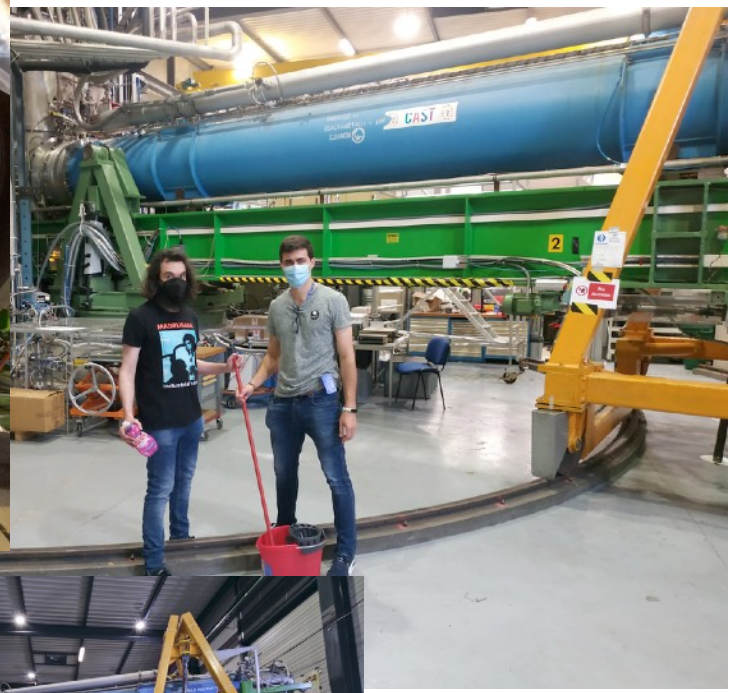
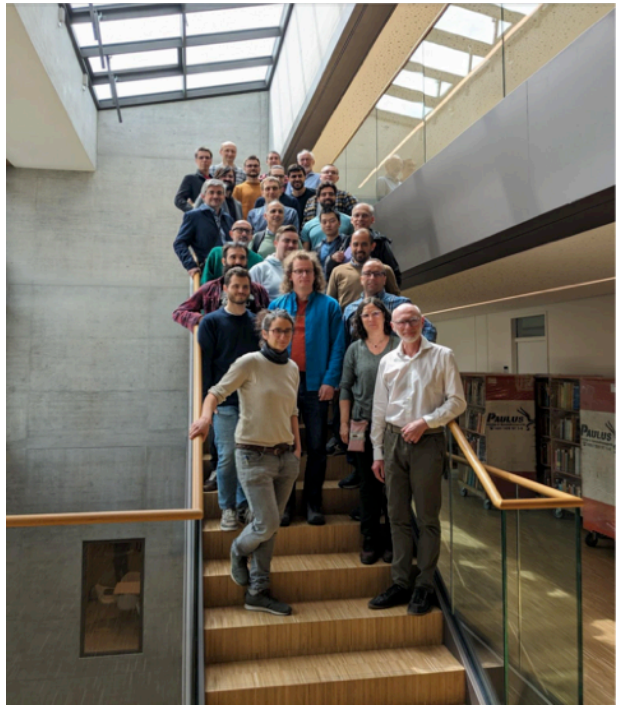
## Behind the scenes:



# RADES AS OF TODAY

## The RADES Collaboration:



*Collaboration Meeting at MPP last May*

*~ 30 people from different institutes all around the world*

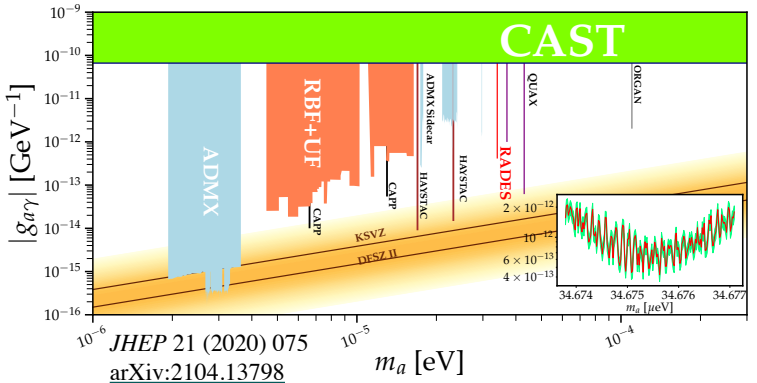
**Funding currently secured through different European grants:**

- ERC-Stg
- QUANTERA Project
- Lise Meitner Excellence Program
- ERC-Syg

*MPP RADES funding*

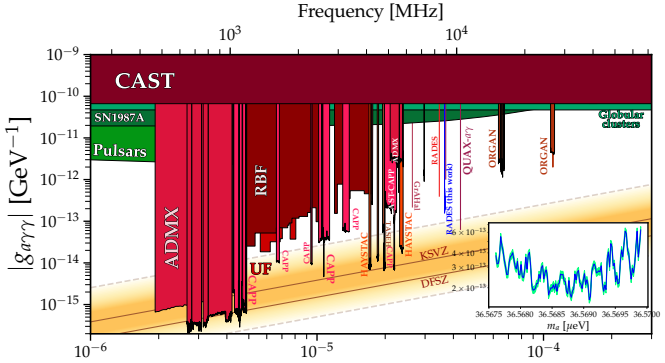
## Three physics runs so far:

### 1st - High frequency multi-cavity in 2018 at CAST (CERN)




*JHEP* 21 (2020) 075
arXiv:2104.13798

### 2nd - HTS coated cavity in 2021 in a 12T dipole at CERN



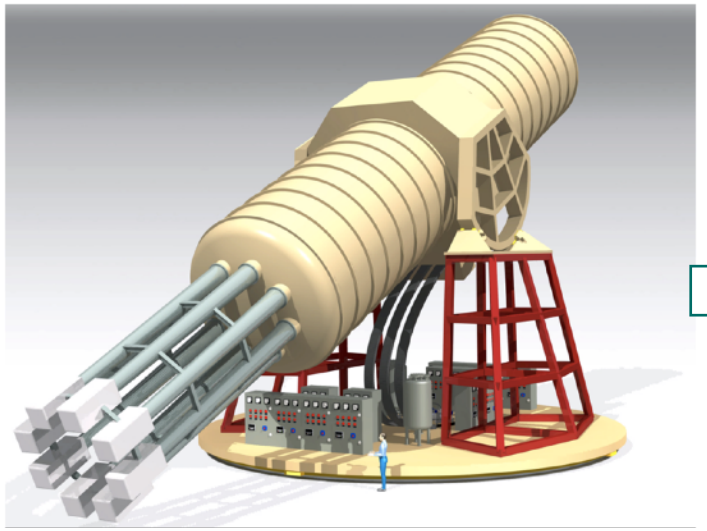

arXiv:2403.07790

### 3rd - HTS coated cavity in 2024 in a 12T dipole at CERN

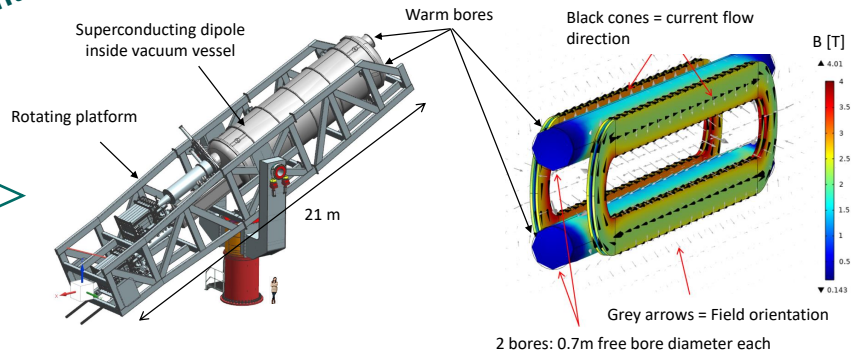
*(Ongoing analysis)*

# CONNECTION TO IAXO/BabyIAXO

**IAXO (International AXion Observatory) is projected as the fourth-generation solar axion telescope**



**Intermediate experimental stage under development**




**BabyIAXO**

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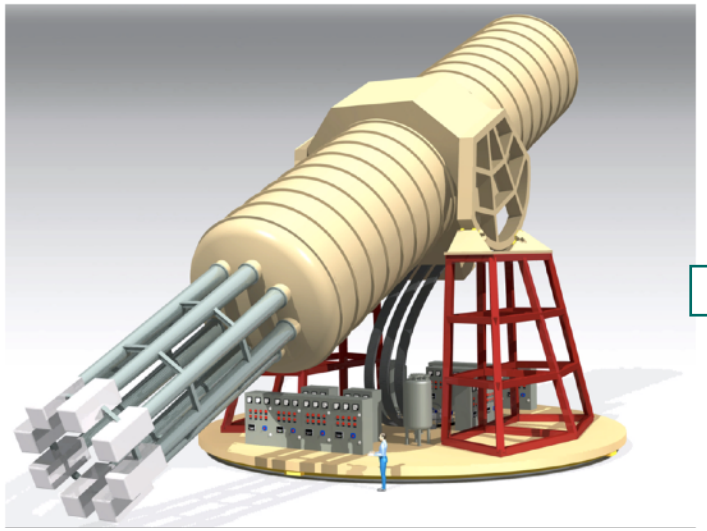

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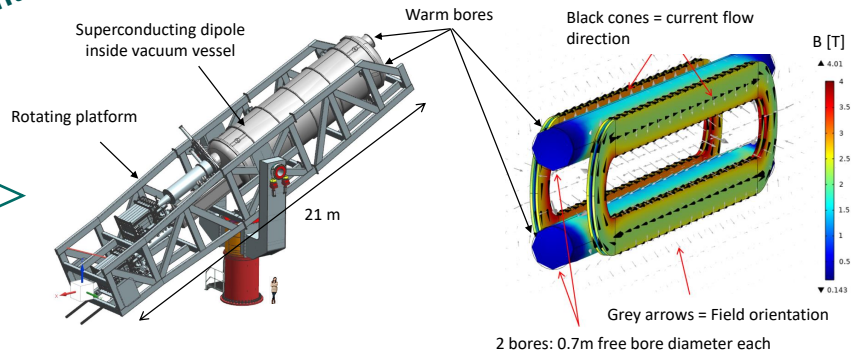



**BabyIAXO**

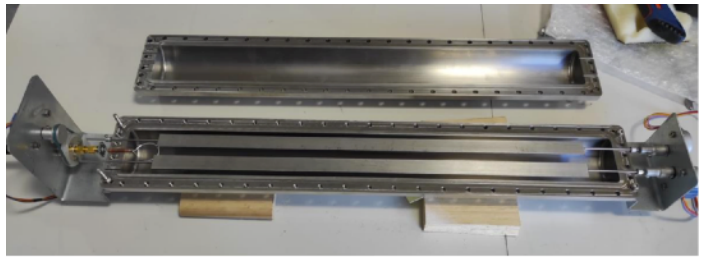
## RADES proposal for a low frequency (1-2 μeV) haloscope in the BabyIAXO experiment

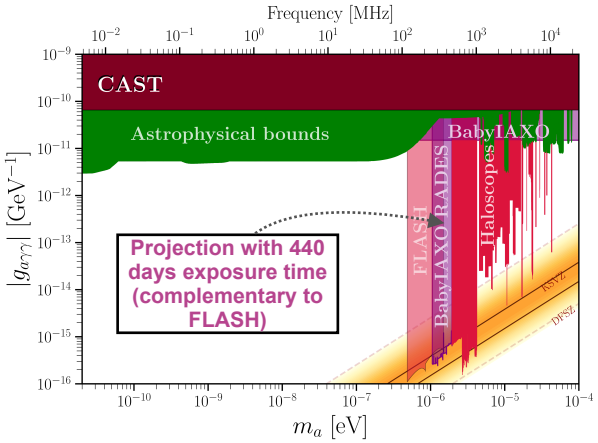
- Complementary to the solar axion search
- Covering unexplored region (Lack of large magnets)

*Annalen Phys.* 535 (2023) 12, 2300326 [2306.17243]

**Technology:**

- Cylindrical cavities
- Set of rotating tuning plates





# RADES PEOPLE AT MPP

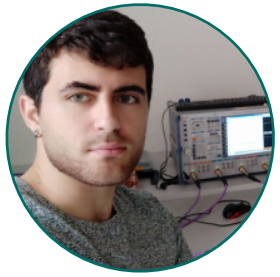
Babette Döbrich
Group Leader

Cristian Cogollos
Postdoc

David Kittlinger
Engineer

Diego Nicolás Lobato
Bachelor Student

Jessica Golm
Finishing
PhD at CERN

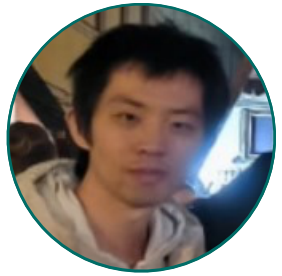


Jose M. García Barceló
Postdoc

Louis Herwig
Master's Student

Patricia Örtner
Student Intern

Samridh Dev Singh
Bachelor Student



Ziheng Yang
Master's Student

# RADES AT MPP: WHAT WE DO

- Three main lines of work:
  - Resonator prototyping and characterisation (Hardware and Software)
  - Data analysis (Physics)
  - Receiver chain definition and implementation (Software and Hardware )

- Direct responsibilities inside of the RADES collaboration:
  - Steering committee coordinator
  - Cavities working group convener
  - Analysis working group convener

# RADES AT MPP: RESONATOR STUDIES

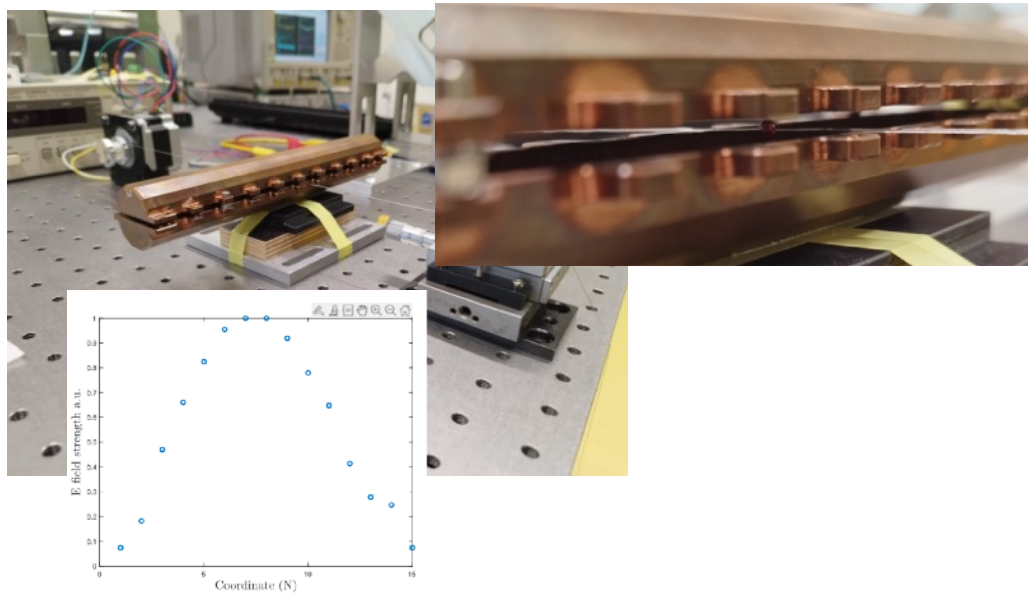
**Main tasks developed at MPP:**

- **Simulation of EM resonators**
- **Development of tuning mechanisms**
- **Manufacture of test devices and data taking prototypes → MPP Mechanics Workshop**
- **Characterisation of manufactured resonators**
- **Estimation of sensitivity for axion searches**

**Example: Electric field profile (Bead pull method)**

**1 - Resonator prototype is designed and built**

**2 - A tiny dielectric bead is used for mapping the E-field distribution**

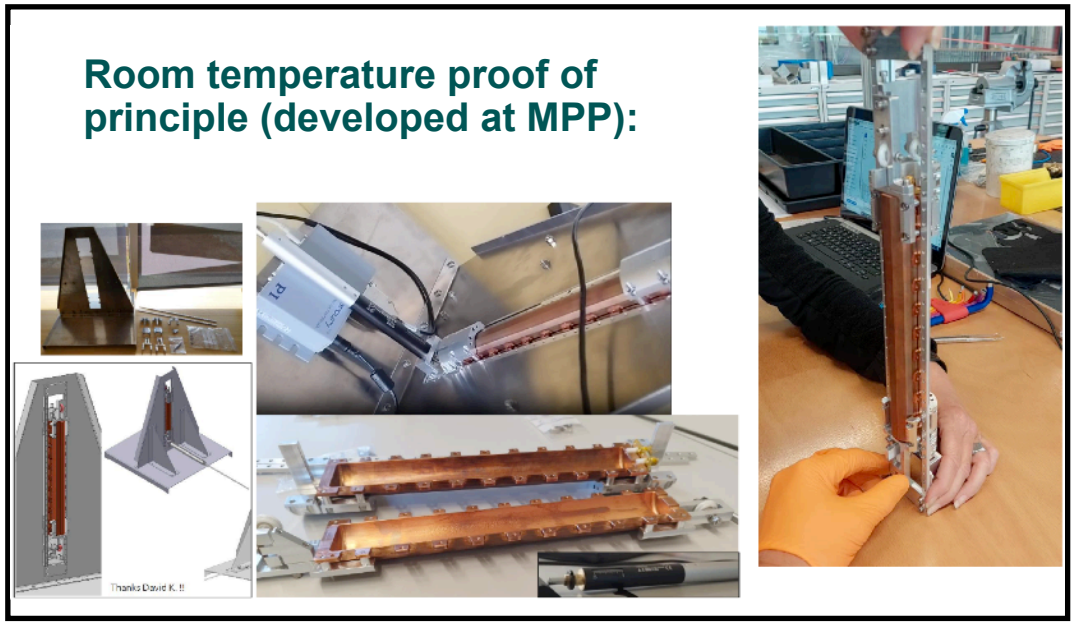


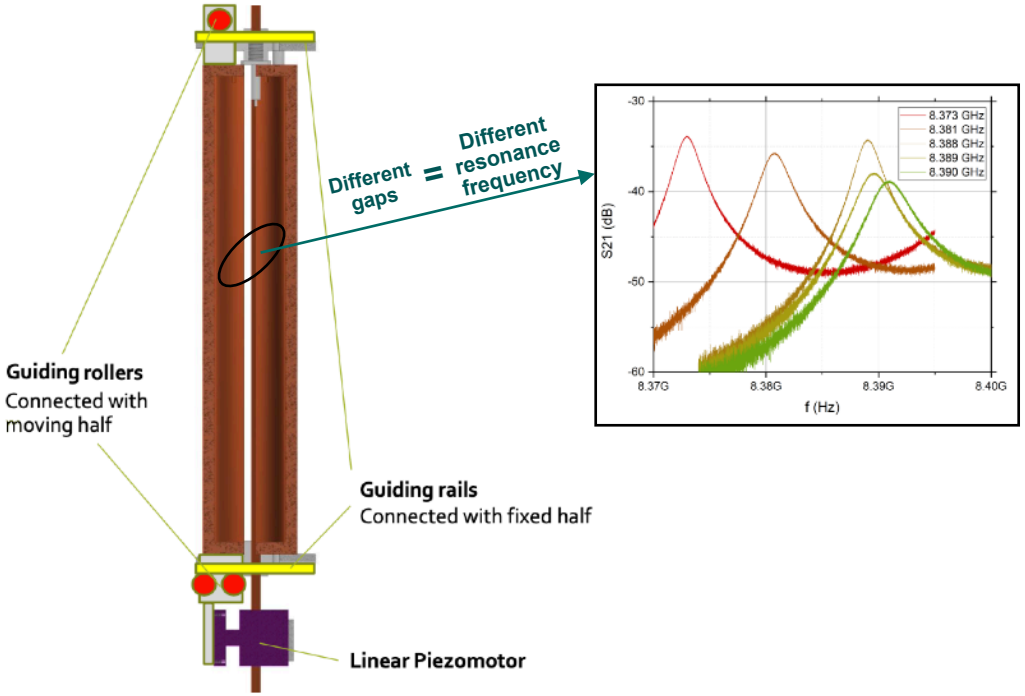

**3 - The results are used for predicting the coupling of the resonator to a potential axion signal**

Many thanks to the MADMAX team, specially A. Ivanov

# RADES AT MPP: TUNABLE PROTOTYPE

- Resonant cavity split in two halves
- Separating the halves tunes the resonance frequency
- Cryogenic motor implemented
- First tests performed inside of a 4K cryostat last week*




**Basic concept published in**
***Frontiers in Physics 12 (2024) 1372846***

**[2312.13109]**

*Many thanks to the MADMAX team for allowing us to use their 4K Cryovac cryostat. And to C. Gooch and D. Kreikemeyer for their help operating it.

# RADES AT MPP: ANALYSIS

- Analysis bears resemblance to radio astronomy and radar searches
- RF background requires dedicated study and careful removal

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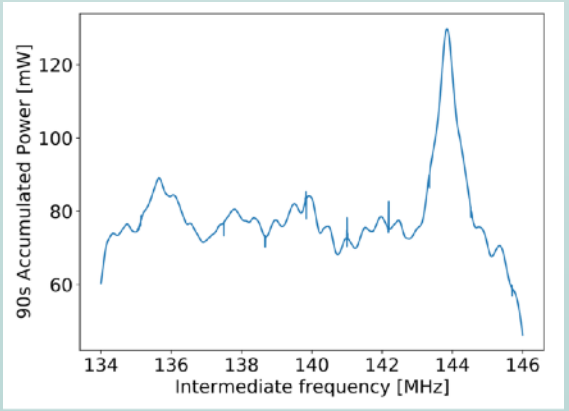
- RF background requires dedicated study and careful removal

**Analysis: The very simplified picture**

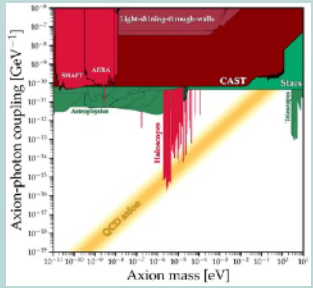



Raw data

if signal:


else:

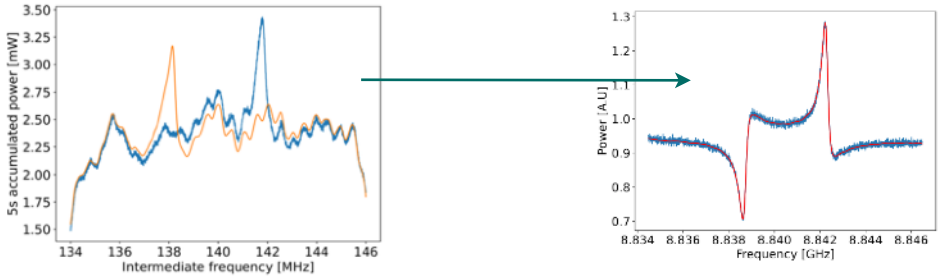
```
import axionlims
axionlims.set_newlimit()
```



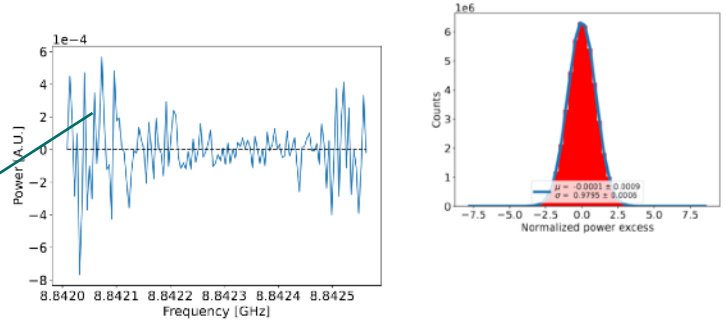
# RADES AT MPP: ANALYSIS

**Analysis: A less simplified guide**

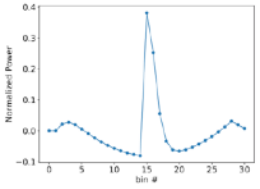
## 1st - Pairs of datasets are combined to remove certain systematics



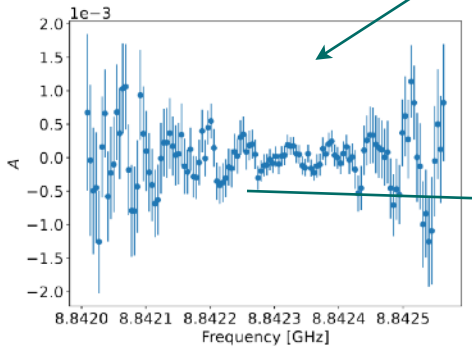

## 2nd - Unified spectrum is built (all datasets combined)



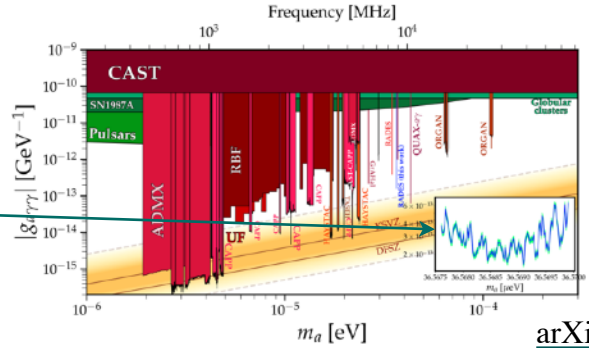

## 3rd - Model dependent fit is used to search for an axion signal in the grand unified spectrum




DM axion lineshape




## 4th - If a signal is not found, a limit is set based on experimental parameters (B-field, resonator volume, etc.)




arXiv:2403.07790

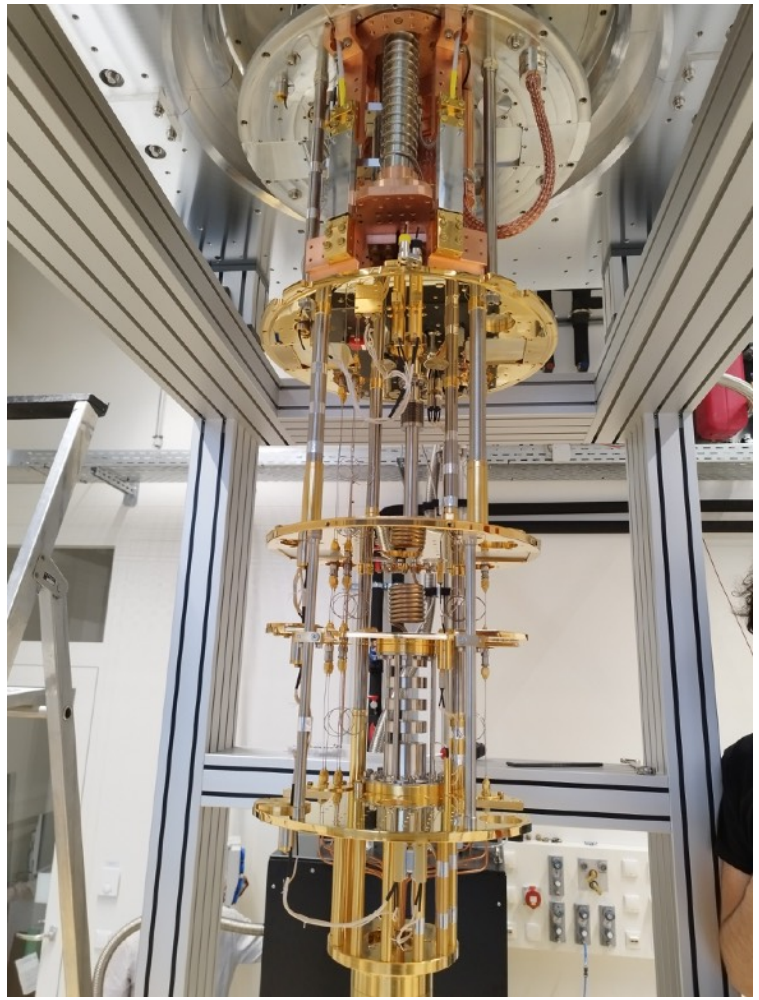
# RADES AT MPP: mK CRYOSTAT WITH MAGNET

## Technical specifications:

- Dilution fridge with 6.5 mK base temperature
- Cold volume of 294mm ⌀ below the mixing chamber
- Equipped with a solenoid magnet: 12T, 65mm ⌀, ~400mm L

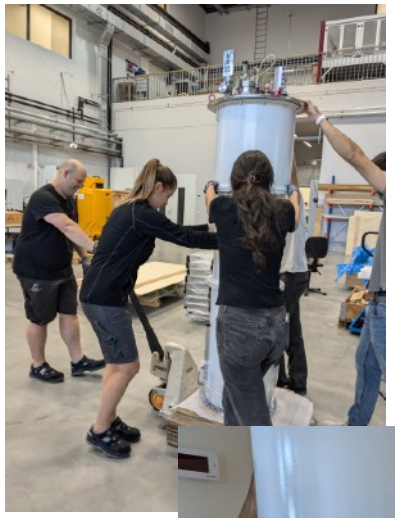
## Goals:

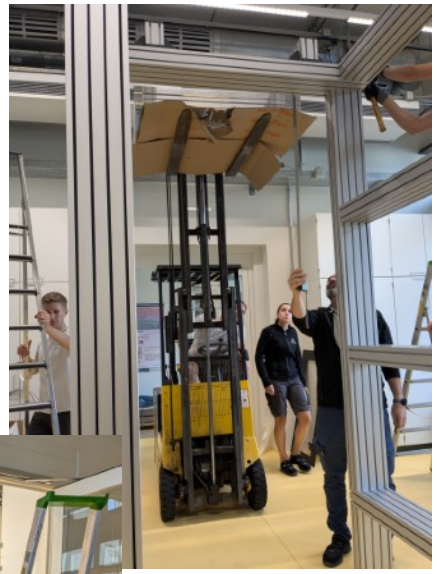
- Implementation of quantum noise limited amplifiers
- Exploring new detection schemes, e.g. single photon counting
- Possibility of a first physics run at MPP

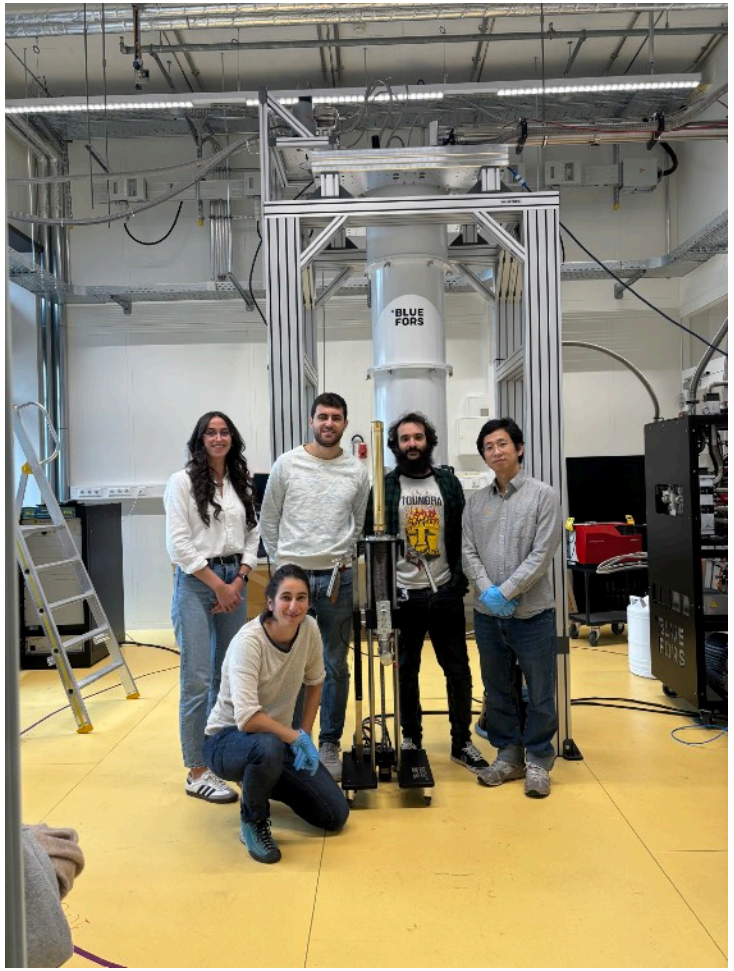


# RADES AT MPP: mK CRYOSTAT WITH MAGNET

**Many thanks to the workshop, haustechnik, and all people involved in the installation for the invaluable help.**








**Special thanks to HeeSu Byun from the MADMAX MPP team for his help, advice and patience**

# SUMMARY

- The RADES group originated in 2016 as a collaboration exploring higher frequency haloscopes
- After a first successful run in 2018 new lines of R&D have been explored
- Proof of concept for a mechanically tunable haloscope
- Consolidated group in MPP active in experimental physics and engineering

<u>Outlook (next couple of years)</u>

- Development of a data acquisition protocol for the tunable prototype
- Acquisition and performance tests of quantum limited amplifiers (TWPA)
- Investigation of single photon (qubit) readout technologies
- Sensitivity assessment and search of non-trivial signals (DM streams, axion stars, etc.)

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**None of this would have been possible without the help and support of all the marvellous people in the institute**

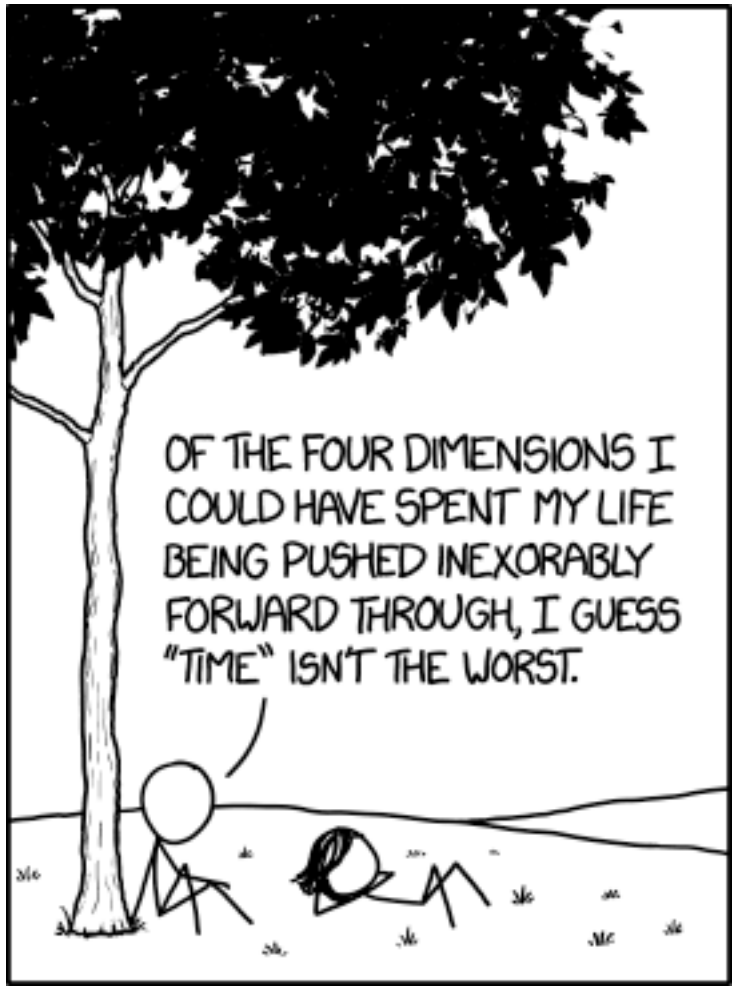
**The help of every single non-scientific department has been an invaluable asset**

## Special thanks to:

The haustechnik team in its entirety, Xiang and Chris for every hour they have spent in hour labs in the last months
Ina and Susanne for their endless patience and help navigating the administration
Alfons, Georg and the mechanical workshop team for their help
Katrin and Manuel for their always fast response and willingness to help
Olaf for allowing us to bother him, regularly, while we get to learn a bit more about electronics
Béla and the MADMAX team for all the support, both in working hours and in equipment
Karo for her assistance helping us understand what is wrong and what not with the cryostat
Barbara for helping us making ourselves a bit more known outside of the scientists bubble

**And thanks to all of you I forgot to mention, I owe you a Helles on Thursday**

# THANK YOU VERY MUCH FOR YOUR ATTENTION.




# (AND YOUR TIME!)