MADMAX: A new road to axion dark matter detection

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for the MADMAX interest group

OUTLINE:

• Axions as dark matter: The post inflationary scenario

• Experimental idea

• First proof of principle measurements

• Outlook
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CEA IRFU, Saclay

DESY Hamburg

MPI für Radioastronomie, Bonn

MPI für Physik, München

University of Hamburg

University of Zaragoza
Axion DM: Scenario PQ – Inflation

Axion Photon coupling $g_{\text{av}}$, [GeV$^{-1}$]

Axion mass [μeV]

Dark matter axion predictions:
- KSVZ
- DFSZ

Post-inflation symmetry breaking preferred region

1 m² mirror 10T 1 week
1 m² mirror 10T 5 years

ADMX limit
ADMX-HF limit
IAXO projection

Limits Haloscop

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TAUP 2017, Laurentian University, Sudbury, 2017, Jul. 24-28
MADMAX
MAgnetized Disc and Mirror Axion eXperiment

Mirror

~2m

10 T dipole magnet

Horn antenna (+ receiver)

Parabolic Mirror

80 adjustable dielectric discs
Ø: ~1m

Separate cryogenic volume
Experimental idea

Chose dielectric material:

- High dielectric constant $\varepsilon$ (for large boost & conversion)
  - Low loss $\rightarrow$ low tan $\delta$ (reduce photon losses)
    - Stable
    - Cheap

$\rightarrow$ Sapphire ($\text{Al}_2\text{O}_3$) @ 300K, 10 GHz:

$\varepsilon \sim 10; \quad \tan \delta \sim \text{few} \cdot 10^{-5}$

$\rightarrow$ Lanthanide Aluminate ($\text{LaAlO}_3$) @ 77K

$\varepsilon \sim 24; \quad \tan \delta \sim 3 \cdot 10^{-5}$

$\rightarrow$ Titanium dioxide – Rutil ($\text{TiO}_2$)

$\varepsilon \sim 100; \quad \tan \delta \sim 0.001(?)$
Experimental idea

Heterodyne detection:

Signal analyzer (3 samplers)

2. Local oscillator

1. Local oscillator

Rubidium time standard (oscillator and sampler synchronization)

1. Amplifier + high pass
First measurements:

Low noise preamp:

• Inject fake 18GHz axion signal with $1 \cdot 10^{-22}$ W power
  • Measurement for 28 hours (integrate signal):
    Receiver at LHe temp.

→ Cross correlation analysis (8kHz Lorentz shaped)
  → found $> 6\sigma$ signal succesfully

→ For 1 week measurement:
  expect Sensitivity at the level of $\sim$ few $10^{-23}$ W (t.b.c.)
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First prototype booster setup:

Transmissivity measurement:
First prototype booster setup:

Transmissivity measurement:

Transmissivity

Simulation

Measurement

Frequency [GHz]
First prototype booster setup:

- Removable copper mirror
- Dielectric discs (Sapphire)
- "Wave guide"
- Horn antenna
- Mirror

Reflectivity measurement:
First prototype booster setup:

Reflectivity measurement:
First prototype booster setup:

Reflectivity measurement:

- Reflectivity Measurement
- Reflectivity Simulation
- Group Delay Measured
- Group Delay Simulated

Frequency [GHz] vs. Reflectivity
First prototype booster setup:

Position reproducibility:

- Space 1 (mm): ±80μm
- Space 2 (mm): ±25μm
- Space 3 (mm): ±70μm
Prototype booster Upgrade:

20 disc setup:
Prototype booster Upgrade:

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20 disc setup:
OUTLOOK:

Sensitivity for QCD dark matter axions with $A=1\, \text{m}^2$, $B_{||}=10\, \text{T}$, $T_{\text{sys}} = 8\, \text{K}$, $\beta^2 = 5 \cdot 10^4$

$\tan \delta \lesssim 10^{-4}$ (???)
OUTLOOK:

Sensitivity for hidden photons with $A=1m^2$, $T_{sys}=8K$, $\beta^2=5 \cdot 10^4$

$\tan \delta \lesssim 10^{-4} (???)$
OUTLOOK:

• Sign MoU → officially establish collaboration

• Magnet innovation partnership with (2018) Bilfinger Bacock Noell CEA IRFU

• Desin study for booster realization (2018)

• Build prototype 3-4 T magnet & 20 discs 30cm diameter booster (2021?) → First QCD axions results 2021

• Build full scale experiment (>2022) Considering DESY as site
First prototype booster setup:

- Wave guides
- Removable copper mirror
- Dielectric discs
- Mirror
- Horn antenna
- Ref. signal in
- Precision motors
- Slides for discs
- Signal out

Prototype setup partly funded as seed project by:
Axion DM: Scenario PQ – Inflation

(Pre Inflationary PQ breaking)

Scenario II: PQ symmetry breaking first:

- $\theta_i$ has a single random value which determines the dark matter density
- No “topological defects”

QCD dark matter axions can have any mass $\leq 1\text{meV}$!
Axion DM: Scenario Inflation – PQ

(Post Inflationary PQ breaking)

Scenario Inflation first:

- PQ broken after inflation
- $\theta_i$ has random values in every casual region, with the dark matter density determined by the average
- Topological defects such as strings and domain walls exist in the early universe
  - decay leads to axion production
  - influence axion density

Predicted axion mass $\sim 100 \, \mu\text{eV}$
First measurements:

Low noise preamp:

InP HEMT preamplifier from LowNoiseFactory

Frequency range: 6-20 GHz

detector noise: $T \sim 7K$ (measured, quick and dirty)
$T_{ds} \sim 6K$ (data sheet)