CULTASK, Launching Axion Experiment in Korea

Woohyun Chung

Center for Axion and Precision Physics Research (CAPP)
Institute for Basic Science (IBS)
• OVERVIEW
  – Axion & Dark Matter
  – CAPP’s Axion programs
  – R&D projects

• CULTASK *(CAPP’s Ultra Low Temperature Axion Search in Korea)*
  2016 with Two BlueFors DRs
  – Cavity Development & RF Testing
  – Engineering Run (complete RF chain) in 2016

• Plans beyond 2016
  – Low Vibration Pads (LVP) with Four more DRs in 2016
  – Major improvements by 2018

• Summary
• Peccei and Quinn (1977) postulated an elegant solution by adding a new global symmetry to resolve the Strong CP Problem in Standard Model

• Axion is an excellent (and attractive) dark matter candidate
  – Pseudo Goldstone Boson
  – No Electric Charge
  – Small Mass (1μeV<m_a<10meV)
  – Extremely Weakly Interacting
  – Local Halo Density of 0.45 GeV/cm³
  – β ~ 10⁻³ \rightarrow Q_a ~ 10⁻⁶

• Detection scheme by P. Sikivie (PRL 51:1415 1983) : Haloscopy
  – Axions will convert to photons in a strong magnetic field

\[ L_{a\gamma\gamma} = g_\gamma \frac{\alpha}{\pi} \frac{a}{f_a} \bar{E} \cdot \bar{B} \]
Overview

Axion Research at CAPP

CULTASK

Lead: Woohyun Chung
2 DRs installed and operational
Complete RF chain (w/ DAQ) soon
4 more frig. in Nov. at LVP

CAPP/CAST

Lead: Lino Miceli
First installation at CAST

ARIADNE

Lead: Yunchang Shin
NMR based
R&D in progress

Large Toroid

Lead: Beongrok Ko
Requires big collaboration
R&D in progress
P. Sikivie’s Haloscope:

**Axion Conversion Power (\(\sim 10^{-24}\text{W}\)):**

\[ P_{a \rightarrow \gamma \gamma} = g_{a \gamma \gamma}^2 \frac{\rho_a}{m_a} B^2 V C_{mnp} \min(Q_L, Q_a) \]

**Signal to Noise Ratio:**

\[ SNR \equiv \frac{P_{\text{signal}}}{P_{\text{noise}}} = \frac{P_{a \rightarrow \gamma \gamma}}{k_B T_{\text{syst}} \sqrt{t_{\text{int}}} \Delta f_a} \]

**Scan rate:**

\[ \frac{df}{dt} \sim B^4 V^2 C^2 Q_L T_{\text{syst}}^{-2} \]

**Cryogenics**

<100mK

Prof. Hyoungsoon Choi of KAIST

**High Field SC Magnet**

25T and then 35T or 40T

BNL (HTS Technology) Design

**SQUID Amplifier**

Outsourced Research from KRISS

**High Q Tunable Cavity**

Superconducting Coating

Prof. Jinhwan Lee of KAIST

(Reverse) Primakoff Effect
R&D for Axion Research

SC Magnets
HTS 25T-10cm (->35T or 40T) by BNL
HTS 21T-5cm (SuNAM)
HTS 26T-3.5cm (SuNAM:WR)
LTS 12T-35 cm (Oxford)
Small Toroid 12T, V=80 L
Giant Toroid 5T, V=9900 L

SC High Q Cavity
Jhinhwan Lee and Wonjun Jang
Equipment setup in progress
First Sputtering Sc coating

SQUID Amp
Yong-ho Lee of KRISS
Delivery in 3 years
In parallel: JPA / SLUG
commercial:ez-SQUID

Multiple Cavities
SungWoo Youn
Higher Freq.
Phase locking
R&D in progress
RF Room

BF3: RF and Cavity test
BF4: Complete RF readout with DAQ + HEMT + 10cm Cu cavity + FTS

LVP

BF4: Complete RF readout with DAQ + HEMT + 10cm Cu cavity + FTS

BF5

BF6

HTS 8T-10cm

HTS 8T-15cm

DRS-1000

JANIS-He3

JANIS

HTS 25T-10cm
From BNL

HTS 21T-5cm
SuNAM

HTS 26.4T-3.5cm
SuNAM - WR

HTS 21T-5cm
SuNAM

HTS 25T-10cm
From BNL

LTS 12T-35cm
Oxford

NbTi 8T-10cm

NbTi 8T-15cm

From BNL

SuNAM
## Superconducting Cavity

### Process for manufacturing of superconducting cavity

<table>
<thead>
<tr>
<th>R&amp;D of recipe for Nb&lt;sub&gt;3&lt;/sub&gt;Sn or FeSe film on small substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Molecular beam epitaxy system  (Growth of Nb&lt;sub&gt;3&lt;/sub&gt;Sn film)</td>
</tr>
<tr>
<td>2. LEED &amp; RHEED  (Characterization of Nb&lt;sub&gt;3&lt;/sub&gt;Sn film)</td>
</tr>
<tr>
<td>3. Low temperature UHV-STM  (Superconductivity)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Application of growth of Nb&lt;sub&gt;3&lt;/sub&gt;Sn film on cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Molecular beam epitaxy system  (Growth of Nb&lt;sub&gt;3&lt;/sub&gt;Sn film)</td>
</tr>
<tr>
<td>2. Radiative thermal heater  (Superconductivity)</td>
</tr>
<tr>
<td>3. 4 probe measurement  (Superconductivity)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Anodized Al oxide for vortex pinning</th>
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<tbody>
<tr>
<td>1. Chemical etching system  (Growth of AAO surface)</td>
</tr>
<tr>
<td>2. Atomic force microscope  (Characterization of AAO surface)</td>
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</tbody>
</table>

By Won-Jun Jang
Superconducting Cavity

**Part Name:** Split SC Cavity
**Material:** OFHC
**Quantity:** 2 (nearly identical except for 6 mating holes)
**Contact:** Jhinhwan Lee
**Phone:** 010-8584-6580
**Email:** jhinhwan@kaist.ac.kr

Two nearly identical cavity parts are to be mated with 6 screw holes. One part has M3 threaded holes. The other has M3 flathead screw holes.

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수량: 2
재질: OFHC Copper
연락처: KAIST 이진환
(010-8584-6580, jhinhwan@kaist.ac.kr)

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정격 내부면을 거울 수준 (요철 1um 미만) polishing 처리.
눈에 보이는 수준의 가공 요철, 단차, 주름 등은 일체 없어야 함.
Polishing에 의해 생기는 약간의 완만한 굴곡(범위 10mm이상에서 높낮이 0.1mm미만)은 허용.

5mm R값의 필요시 의논후 변경 가능

M2.5 tap
내부로 통합되지 않도록 주의 요망

두 개 제작된 이 여섯개 조립 구멍을 이용한 조립이 가능하도록, 하나는 M3 tap, 하나는 M3 접시 머리 볼트 구멍으로 제작.

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SolidWorks 교육용 사용권
교육용에 한함
Two BlueFors Dilution Refrigerators were delivered, installed and are operational now!

### 2016

<table>
<thead>
<tr>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
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<tbody>
<tr>
<td>Delivered</td>
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<td>Installed</td>
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<tr>
<td>Test and Training</td>
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<tr>
<td>Cavity Development w/ pure Cu and Al Noise Figure Measurement w/ HEMT amp</td>
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## CULTASK 2016 w/ Two DRs

<table>
<thead>
<tr>
<th></th>
<th>BF3</th>
<th>BF4</th>
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<tbody>
<tr>
<td><strong>Model</strong></td>
<td>BlueFors LD400</td>
<td>BlueFors LD400</td>
</tr>
<tr>
<td><strong>Magnet</strong></td>
<td>None</td>
<td>8T (AMI), 12cm ID</td>
</tr>
<tr>
<td><strong>RF lines</strong></td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td><strong>DC lines</strong></td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td><strong>Cool down to &lt;10 mK</strong></td>
<td><strong>20 ~ 24 hours</strong></td>
<td><strong>40 ~ 48 hours</strong></td>
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<tr>
<td><strong>Base temp at MXC</strong></td>
<td>9 mK</td>
<td>7 mK w/ SC magnet</td>
</tr>
<tr>
<td><strong>MXC temp w/ Load</strong></td>
<td>11 mk w/ Al cavity (4cm id) and HEMT amp</td>
<td>30 mk w/ 10 kg OFHC copper support structure and cavity + HEMT amp + Network Analyzer + Piezo Controller</td>
</tr>
</tbody>
</table>
CULTASK 2016 w/ Two DRs

BF3

BF4
CULTASK 2016 w/ Two DRs

BF3

BF4
OFHC Support Structure and Frequency Tuning System

- Cu Cavity of 10cm OD
- Modular design
- Sapphire tuning rod, 1cm OD
- Rotational piezo for tuning
- Linear piezo for antenna
- Piezo holder thermally linked to 1K plate
High Q-Factor Cavity Development:

- Variety of samples (OFHC Cu, 5N Al, 6N Al with sizes and different types of lids were tested)
- Beginning to use Annealing Furnace to investigate annealing temp. and duration
- **Superconducting Al:**
  - Al becomes superconducting below 1.2K
  - Q-factor grows to >200,000 for TM010
  - TE011 mode (no contact problem: Fritz’s suggestion)
  - Q-factor: ~2M at ~800 mK and ~20M at 11 mK
- **Split cavity < --- > diffusion bonding**
  - Q-factor of cavity cut in half stays the same – verified
  - It could eliminate contact problem between lids and wall
  - Will be useful for superconductor coating
Complete RF chain with DAQ
CULTASK 2016 w/ Two DRs

- New Lab space in
  - KAIST Munji Campus Creation Hall (RF room) completed
- Two BlueFors DRs (one w/ 8T SC magnet)
  - RF Room infrastructure done (esp. electricity and chiller)
  - Delivered and installed: end of Feb.
  - Design 10 cm cavity (~2.5 GHz) and support structure with frequency tuning system
  - Cryo RF noise figure measurement
  - Complete RF chain set-up with DAQ
  - Fake axion signal injection (blind test?)
  - Take reasonable sensitivity DATA in 2016
- 4 More DRs and 2 magnets in Oct. (LVP)
Axion Lab with 7 Low Vibration Pads in KAIST Munji campus
## Plans beyond 2016

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<thead>
<tr>
<th></th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<tbody>
<tr>
<td><strong>Lab Space</strong></td>
<td>Munji Campus Design &amp; Renovation</td>
<td>LVP</td>
<td>Occupation</td>
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<tr>
<td><strong>High Field Magnet</strong></td>
<td>Prototype, testing of SuperC cables</td>
<td>25T-10cm design</td>
<td>21T-5cm delivery</td>
<td>15T-35 cm production</td>
<td>Magnet Delivery</td>
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<tr>
<td><strong>SC Cavity Development</strong></td>
<td>Procure Equip. Study res. and geom.</td>
<td>Development of high Q SC resonator</td>
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<tr>
<td><strong>SQUID Amplifier</strong></td>
<td>Design and production of prototype SQUID for 1-10 GHz</td>
<td>Acquire JPA and test</td>
<td>SQUID delivery from KRISS Develop higher freq. amplifier</td>
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<tr>
<td><strong>Axion Cavity Experiment</strong></td>
<td>Building infrastructure. Engineering Run at KAIST</td>
<td>Experimental Setup at Munji Test Runs</td>
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<tr>
<td><strong>Cryogenics</strong></td>
<td>Setup plan, acquisition</td>
<td>4 Dry DRs + Wet He3 DR + Wet DR</td>
<td></td>
<td>Main DR and He liquefier</td>
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August 7th 2016

ICHEP 2016 Satellite (IBS), Chicago
Summary

• State of the Art Axion Research at CAPP/IBS in Korea

• Major R&D Efforts
  – Higher B Field: HTS (21T, 25T...) + LTS (12T-35cm)
  – Higher Q Factor with B Field: Factor of >10 Improvement
  – Larger Volume: Toroidal Cavity
  – R&D for Higher Frequencies (>10 GHz)

• CULTASK 2016 ready to build a complete experiment
  – Cavity R&D and Cryo-RF testing
  – Could reach close to QCD Axion Sensitivity soon!

• Major improvement in Axion Experiment
  as early as in 5 years
Thank You For Your Attention!