Status of the SABRE NaI(Tl) Dark Matter Experiment

Sodium-iodide with Active Background REjection

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on behalf of SABRE Collaboration

SABRE: motivated to test results of DAMA/LIBRA

DAMA/LIBRA annual modulation
- 250-kg NaI(Tl) array
- 14 solar cycles
- 9.3 σ stat. significant

Interpretation as WIMPs in tension with other experiments.

Need an independent experiment using the same target.
- lower background
- lower threshold energy

0.0112 cpd/kg/keV modulation on top of ~1 cpd/kg/keV

R. Bernabei et al. (DAMA coll.), EPJ C (2013) 73:2648.
SABRE: motivated to test results of DAMA/LIBRA

DAMA/LIBRA annual modulation
- 250-kg NaI(Tl) array
- 13 solar cycles
- 9.3 σ stat. significant

Interpretation as WIMPs in tension with other experiments.

Need an independent experiment using the same target.
- lower background
- lower threshold energy

0.0112 cpd/kg/keV modulation on top of ~1 cpd/kg/keV

R. Bernabei et al. (DAMA coll.), EPJC (2013) 73:2648.
The SABRE strategy

Lower background.

1. **Grow NaI(Tl) crystals** with higher purity than DAMA/LIBRA
   a. Improve radio-purity of NaI powder
   b. Develop high-purity crystal growth method
   c. Low-radioactivity enclosure, PMTs, etc.

2. Employ **liquid scintillator veto/shielding**

Lower energy threshold.

1. High-Q.E. Hamamatsu PMTs **directly coupled** to NaI(Tl) crystals

Twin detectors in northern and southern hemisphere
LNGS, Italy & SUPL, Australia
Reduces seasonal effects
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Twin detectors in **northern** and **southern** hemisphere

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The SABRE design

- Proof-of-principle: 5-kg ultra-low background NaI(Tl) crystals
- Upgrade: NaI(Tl) array, 30-50 kg total target mass, 2~3 years exposure
- Liquid scintillator veto (vessel: 1.4 m diameter, 1.5 m length)
Background suppression with veto

Veto reduces background from:

- **Crystal** radioactivity:
  - $^{40}\text{K}$ (factor of ~10 reduction), $^{22}\text{Na}$, $^{238}\text{U}$, etc.

- $\gamma$ from **PMTs**, enclosure, vessel

- $\gamma$ and neutron from **rock**, etc.

- **Cosmic-ray** induced $\gamma$ and neutron

![Diagram of Crystal Module and PMTs with photons and electron paths]
Veto reduces background from:

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- $\gamma$ from **PMTs**, enclosure, vessel

- $\gamma$ and neutron from **rock**, etc.

- **Cosmic-ray** induced $\gamma$ and neutron
New high-purity NaI(Tl) crystal successfully grown!

“Astrograde” NaI powder
- SAFHC-Hitech, Sigma-Aldrich
- 2.0 kg, 88-mm diam
- close to the planned diameter

Crystal growth
(Radiation Monitoring Devices)

Chemical analysis (Seastar Chemicals)
- Mass spectroscopy, calibrated with γ-counting
- Preliminary confirmation by PNNL

<table>
<thead>
<tr>
<th></th>
<th>This crystal</th>
<th>DAMA crystal</th>
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</thead>
<tbody>
<tr>
<td>K [ppb]</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Rb [ppb]</td>
<td>&lt; 0.1</td>
<td>&lt; 0.35</td>
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Expected background with veto

**Total background** in 2-6 keV is simulated to be **0.13 cpd/kg/keV**.
- Extensive data-based simulation was performed
- $^3$H & $^{210}$Pb still unknown
- neutron background found to be small (preliminary)
Expected background with veto

Total background in 2-6 keV is simulated to be 0.13 cpd/kg/keV.
- $^{40}$K no longer dominant (improved crystal purity, veto)
- $^{87}$Rb can be the dominant background (upper limit, beta-decay, cannot be vetoed)
- Other components still subdominant (veto)

$^{87}$Rb: 0.07 cpd/kg/keV (upper limit from crystal)

$^{40}$K: 0.03 cpd/kg/keV (data from crystal)

$^{238}$U, $^{232}$Th, $^3$H, $^{210}$Pb, etc. in crystal: 0.02 cpd/kg/keV (U & Th: from measurement)

$\gamma$-background from PMTs, enclosure, vessel, rocks, etc. 0.002 cpd/kg/keV
Expected background with veto

DAMA observed

SABRE expected

DAMA modulation
Expected sensitivity

Assume 50-kg, 2-6 keV, stable operation for 3 years, no systematic or other seasonal effect.

- No modulation:
  0.13 cpd/kg/keV flat: $6 \sigma$ to refute
  0.3 cpd/kg/keV flat: $3 \sigma$ to refute

- Modulation of 0.01 cpd/kg/keV:
  0.3 cpd/kg/keV: $3 \sigma$ to confirm.
Current status and goal

Proof-of-principle

- Operate 5-kg crystals for a few months counting
- Funding by NSF, INFN, and ARC.
- Approved by LNGS

Commissioning the scintillator vessel, PMTs, and DAQ.

Crystal measurement starts in 2016.

Upgrade after “proof-of-principle”
First underground lab in the southern hemisphere

Located in Stawell gold mine
- 1 km underground
- 3.1 km w.e.

Status:
- Funding secured
- Lab completed by 2017

Start SABRE construction in 2017
Conclusion

Successful growth of an ultra-high pure NaI(Tl) scintillating crystal.
- 2 kg, 88 mm diameter
- $[K] = 9$ ppb, $[Rb] < 0.1$ ppb
- Continuing efforts to further improve crystal purity

Background after veto is projected to be $\sim 0.13$ cpd/kg/keV.
SABRE Industrial Partners

Radio-purity of NaI powder
- SAHC Hitech (Sigma-Aldrich);
- MV Industries
- SEASTAR CHEMICALS Inc.

Mass spectroscopy measurements
- SEASTAR CHEMICALS Inc.

Crystal growing method
- Radiation Monitoring Devices, Inc.

PMT development
- Hamamatsu

The work reported would have been impossible without the collaboration with and support from these companies / organizations. Many details are confidential; the products will be made available for everyone.
List of SABRE Collaborators

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Thank you very much!