Dark Matter searches with COSINE-100: present status and perspectives

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On behalf of the COSINE-100 collaboration
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Motivation: DAMA annual modulation signal, to be checked with independent measurements using the same NaI(Tl) target material.

Dark Matter Modulation: 9.2 sigma

Background: ~1 count/day/kg/keV (dru = differential rate unit) above 2 keV

Modulation between 2-6 keV
Modulation is persistent in phase2 data

Down to 1 keV region
Global NaI(Tl) efforts

- DAMA/LIBRA @ LNGS
- SABRE @ LNGS
- COSINE-100 @ Y2L
- PICO-LON @ Kamioka
- ANAIS @ Canfranc
- SABRE @ Stawell
- DM-Ice17 @ South Pole

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ANAIS-112 (total of 112 kg)

Clean data
1 keV threshold
2-5 dru @ 2 keV
The COSINE-100 experiment

Joint collaboration between KIMS and DM-Ice to search for dark matter interactions in NaI(Tl) scintillating crystals.
The COSINE-100 detector components

- 4 X 2 encased crystal array
- Total mass of 106 kg
- 2 tons of liquid scintillator
- 37 panels of plastic scintillator

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The COSINE-100 detector components

- Detachable panels
- Calibration holes

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Exposure (Running for 30 months)

Detector is running smooth (>95% physics data)

COSINE-100 Accumulated Data

- COSINE-100 Preliminary
- Total Lived: 822.3 days (92.9%)
- Good Data: 798.7 days (90.2%)

Days:
- 12/31, 2016
- 12/31, 2017
- 12/31, 2018

Exposure:
- SET1
- SET2
- SET3

Calibrations

Power outage

Detector is running smooth (>95% physics data)
Environmental control/monitoring

Crystal temperature is maintained better than 0.1 deg. C

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PMT noise rejection

**Average waveforms**

- **β/γ scintillation signal**
- **PMT noise (thin pulse)**
- **PMT noise (bell pulse)**

**Energy (keVee)**
- 10
- 20
- 30
- 40
- 50
- 60

**Counts/day/kg/keV**
- 1
- 10
- 2

**No Cut**
- Muon&LS veto+Single hit
- +2 hits/PMT
- +BDT (thin pulses)
- +BDTA (bell pulses)

**Scintillation below 10 keV**

**BDT**
- Thin pulse
- Bell pulse

**BDTA**
- BDTA (bell pulses)

**Energy (keVee)**
- Counts/days/kg/keV

**Average waveforms**

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Single-hit Energy spectrum

~70% Efficiency at 2 keV, Current bkg. is around 3 counts/day/kg/keV

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Understanding Background

Single-Hit
(2-6 keV region not used)

Multiple-Hit

WIMP Search, 59.5 days of Data 
(until enough modulation analysis data are accumulated)

Overlay of DAMA-Na Signal at 10 GeV/c²

With bkg. understanding, 8 single-hit spectra are fit simultaneously with an assumed WIMP signal (SHM as described in Savage et al., Journal of cosmology and astrophysics). Note that bkg. understanding consideration from Kudryavtsev et al. Astropart. Phys. 33 (2010) 91

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Results for likelihood fits in 2-20 keV region with assumed WIMP signals

WIMP masses in 5–10000 GeV/c²
Perform a simultaneous fit with bkg. components and a signal component.
Nuisance parameters for bkg. and systematics

Best fit in 2—6 keV zoomed crystal-average
Spin independent WIMP-nucleon cross section limit with same NaI(Tl) target (59.5 days of the COSINE-100 data)

- Spectrum with known sources of backgrounds
- COSINE-100 excludes DAMA/LIBRA-phase1’s signal as spin-independent WIMP with Standard Halo Model in NaI(Tl)
- Consistent with null results from other direct detection experiments with different target medium

\[ v_0 = 220 \text{ km/s}, \quad \rho_{\text{DM}} = 0.3 \text{ GeV/cm}^3, \quad v_{\text{esc}} = 650 \text{ km/s} \]

\[ \frac{f_p}{f_n} = 1 \]

\[ Q(\text{Na}) = 0.3, \quad Q(\text{I}) = 0.09 \]

Results with SD case and effective field theory with measured quenching are forthcoming.

Nature 564, 83 (2018)
Annual Modulation Analysis (606 days of data, SET2)
Search for oscillatory signature in 2—6 keV region of energy spectrum.

Global fit using cosmogenic and sinusoidal components simultaneously for crystals

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Annual modulation analysis: COSINE-100 preliminary results for 1.7 year exposure shows consistency with null modulation and also with DAMA center.

- We have performed first annual modulation analysis with 1.7 years of data (exposure 97.79 kg.year)

- No significant modulation is found between 2—6 keV region of interest.

- The analysis is currently statistically limited and it will improve with upcoming data.

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ANAIS-112 results
(today@Arxiv:1903.03973)

\[ R(t) = R_0 + R_1 \cdot \exp(-t/\tau) + S_m \cdot \cos(\omega \cdot (t + \phi)) \]

-0.0044 +/- 0.0058 for 2–6 keV
-0.0015 +/- 0.0063 for 1–6 keV

157.55 kg.year exposure

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Down to 1 keV threshold

In near future, we expect to have 1 keV threshold analyses.

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Expected Sensitivity for COSINE-100

*Assumed 2 dru or 4 dru flat backgrounds depending on crystals. The sensitivity should be comparable with the DAMA allowed region.
COSINE-200 (Phase-II)

Goal: Reaching background lower than DAMA (1 dru). A factor two or more improvement is needed.

<table>
<thead>
<tr>
<th>Powder</th>
<th>$^{39}\text{K (ppb)}$</th>
<th>$^{208}\text{Pb (ppb)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astro grade</td>
<td>4.5</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Crystal grade</td>
<td>45.1</td>
<td>6.0</td>
</tr>
<tr>
<td>Cian (99.5%)</td>
<td>180000</td>
<td>1305</td>
</tr>
</tbody>
</table>

Powder purification (Recrystallization)

Crystal growing & Handling

Established a facility at our center

Powder purification

(mass production facility for purification under construction)
Growing low radioactive NaI(Tl) Crystals at our center

Quick encapsulation

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Expected sensitivity for COSINE-200 (Phase-II)

*Assumed 1 dru flat backgrounds

200 kg × 3 year

If DAMA is right...

7.3 sigma observation
(2-6 keV)
Boosted Dark Matter search using 2 tons of liquid scintillator


Dark Photon Interpretation

arXiv:1811.09344 accepted by PRL
Summary & Outlook

- The COSINE-100 experiment was installed at Y2L and runs smoothly for 2.5 years.
- In the COSINE-100 early data, on average, bkg. 3.5 counts/day/kg/keV with 2 keV thresholds was achieved.
- COSINE-100 confirms that DAMA’s modulation signal cannot be from standard WIMP & SHM with NaI(Tl).
- First modulation analysis with 1.7 years exposure shows consistency with null signal and with DAMA signal.
- The modulation analysis is currently statistics limited and the next analysis is developing.
- Currently, the bkg. rate has been lowered to about 3.0 counts/day/kg/keV due to cosmogenic components decaying and we are improving the analysis threshold down to 1 keV.
- Much progress has been made in developing the capabilities to grow and encapsulate more radio-pure NaI(Tl) crystals at IBS-CUP towards COSINE-200 which will answer to the DAMA anomaly.