Constraining Light Dark Matter with CDMS II and SuperCDMS

Scott Hertel
MIT, SuperCDMS Collaboration
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The SuperCDMS Collaboration

Caltech

Fermilab

MIT
A. Anderson, E. Figueroa-Feliciano, S. Hertel, K. McCarthy, S.W. Leman, P. Wikus

NIST
K. Irwin

Queens University
P. Di Stefano, N. Fatemighomi, J. Fox, S. Liu, C. Martinez, P. Nadeau, W. Rau, Y. Ricci

Santa Clara University
B.A. Young

SLAC/KIPAC

Southern Methodist University
J. Cooley, B. Karabuga, S. Scorza, H. Qiu

Stanford University
B. Cabrera, M. Cherry, R. Moffatt, L. Novak, M. Pyle, M. Razeti, B. Shank, A. Tomada, S. Yellin, J. Yen

Syracuse University
R.W. Schnee, M. Kos and M. Kiveni

University of California, Berkeley

University of California, Santa Barbara
R. Bunker, D.O. Caldwell, H. Nelson

University of Colorado at Denver
M. E. Huber, B. Hines

University of Florida
D. Balakishiyeva, T. Saab, B. Welliver

University of Minnesota
P. Cushman, L. Duong, M. Fritts, V. Mandic, X. Qiu, A. Reisetter, O. Kamaev, J. Zhang

University of Texas A&M
A. Jastram, K. Koch, R. Mahapatra, M. Platt, K. Prasad, J. Sander
Motivation: DAMA & CoGeNT

DAMA

CoGeNT

Residual Rate [keV·kg⁻¹·d⁻¹]

Time [day]

Dark Matter Particle Mass [GeV]

SI WIMP-Nucleon Cross Section [pb]

XENON10

CDMS Si

(arXiv:0804.2741)

(arXiv:1007.1005)

(arXiv:1106.0650)

(arXiv:1106.0650)
CDMS II Detectors

4 Phonon Channels

2 Charge Channels

\[
\frac{\text{Charge Energy}}{\text{Phonon Energy}} = \text{“Yield”}
\]
CDMS II at Low Energies

Low Background CDMS II Data

Bulk Electron Recoils
Surface Recoils

“Zero Yield” Sidewall Recoils

Recoil Energy [keVne]

Yield

-0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

0.1 2 10 100

Guard ring
Inner electrode

-3V
CDMS II at Low Energies

Example 2 keV Pulse

Low Background CDMS II Data

Bulk Recoils

Electron Recoils

Surface Recoils

“Zero Yield” Sidewall Recoils

Recoil Energy [keVne]
CDMS II at Low Energies

CDMS timing rejection fails below ~10 keV...

Low Background CDMS II Data

Bulk Electron Recoils
Surface Recoils

“Zero Yield” Sidewall Recoils

Example 2 keV Pulse

Recoil Energy [keVne]

Yield

Low Background CDMS II Data

-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

Example 2 keV Pulse

ADC bins

Time (μs)

0 200 400 600 800 1000 1200

Guard ring
Inner electrode -3V
CDMS II at Low Energies

CDMS timing rejection fails below \( \sim 10 \) keV...

... which is precisely the 7 GeV WIMP signal region.

Low Background CDMS II Data

- Bulk Recoils
- Electron Recoils
- Surface Recoils
- Sidewall Recoils

"Zero Yield"
Low Threshold Analysis

2 keVne Threshold

→ Significant Background Rates

Used only 8 Ge detectors with the lowest trigger thresholds (1.5-2.5 keV)
(Yellin method “optimal gaps” happened to all be in a single detector)

2006-2008 data randomly subdivided:
1/4 used to define cuts in yield
3/4 used to calculate limits  (241 kg-days raw exposure)
The Nuclear Recoil Energy Scale

(Luke from charge measurement)
The Nuclear Recoil Energy Scale

(Luke from charge measurement)

Alternatively, we can eliminate charge noise by assuming a particular yield...

Nuclear Recoil Energy = Measured x Scaling Factor
The Nuclear Recoil Energy Scale

Nuclear Recoil Energy = Measured x Scaling Factor

Step 1:
Calibrate the absolute scale using Ge activation lines.

The 1.298 keV line calibration was pushed in the conservative overestimating direction to the 90% confidence level for each detector.
The Nuclear Recoil Energy Scale

Nuclear Recoil Energy = Measured x Scaling Factor

Step 2:
Define a nuclear recoil scaling factor.

Again conservatively, the slightly low yield seen by CDMS was used. If we are off, we are overestimating phonon energy.
Nuclear Recoil Yield Band Definition

Extrapolating backgrounds into the signal region, it was found that \(-0.5\sigma\) to \(+1.25\sigma\) maximizes reach.
Event Selection

The events within the band are the WIMP candidates.
Spectra

Blue Region: Hooper et al., PRD 82 123509 (2010)
$m\chi=7 \text{ GeV/c}^2$ (90% CL) $\sigma_{SI} \approx 7 \times 10^{-41} - 2 \times 10^{-40} \text{ cm}^2$

CoGeNT
(background model subtracted)
arXiv:1103.3481

CDMS II
(no background subtraction)
all detectors (coadded)
best detector

Rate [keV$^{-1}$kg$^{-1}$d$^{-1}$]

Recoil Energy [keV$\text{nue}$]
Limits

Conservatively assume all candidates may be WIMPs. (ie, no background subtraction)

Limit defined using optimum interval method

Spin-independent elastic scattering WIMP interpretation ruled out for joint DAMA/CoGeNT region.

A portion of the CoGeNT region remains, where only a small fraction of the excess is WIMP recoils.

DAMA/LIBRA, light blue CoGeNT region, and combined region:
Hooper et al., PRD 82 123509 (2010)
Varying the Nuclear Recoil Energy Scale

T1Z5 Electron Recoil Spectrum

Recoil Energy [keVee]

10.39±0.022 keVee
1.333±0.025 keVee

Recoil Energy [keV]

WIMP Mass [GeV/c^2]

T1Z5

Yield

0.25
0.2
0.15
0.1

Recoil Energy [keV]

Lindhard

Lindhard k=0.1

WIMP-nucleon σSI [cm^2]

10^{-30}
10^{-40}

4 6 8 10 12

WIMP Mass [GeV/c^2]

DAMA/LIBRA

CoGeNT
SuperCDMS

Fiducial volume definition is much more stringent, and can be phonon-only.
Luke Phonon Gain

Background rejection destroyed, but threshold greatly lowered (~50eV so far).

Conclusions

A low-threshold, non-zero-background analysis of the CDMS II exposure is inconsistent with the light wimp interpretation of DAMA/CoGeNT.

Future detectors will probe the light mass region significantly more effectively.
Extra Slides
No CoGeNT Background Subtraction
Extrapolating CDMS Backgrounds

Sidebands for background estimate:

1.3 keV line

Expected background spectra:

Event rate (keV^{-1} kg^{-1} day^{-1})

Acceptance

Recoil energy (keV)
How far do we need to push the energy scale for agreement?
Experimental Outlook

- 1 event/kg/year*
- 1 event/10 kg/year*
- 1 event/100 kg/year*
- 1 event/ton/year*

*for a 100 GeV/c² WIMP on Ge target with a 10 keV low energy threshold

WIMP-Nucleon Cross Section [cm²]

WIMP Mass [GeV/c²]

SuperCDMS Soudan
SuperCDMS SNOLAB
GEODM