Search for Annual Modulation at Low Energies in CDMS II

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Setting the Stage

Target: Ge
\( \sigma_{SI} = 1 \times 10^{-4} \text{ pb} \)
\( M_{\chi} = 10 \text{ GeV/cm}^2 \)

\[ \frac{dR}{dE} \text{ [kg keV d]}^{-1} \]

\[ E \text{ [keV]} \]

Mar.
June
Dec.
220 km/s
30 km/s
Sept.
Setting the Stage

Target: Ge  
$\sigma_{SI} = 1 \times 10^{-4}$ pb  
$M_X = 10$ GeV/cm$^2$
Setting the Stage

![Graph showing modulated rate vs. recoil energy](image-url)
Setting the Stage

CoGeNT
DAMA
$m=10 \text{ GeV/c}^2$
$q_{\text{Na}} = 0.3$
Setting the Stage

CoGeNT modulation + origin: simple halo

in tension with...

1. CDMS, Xe100 rates
2. CoGeNT rates
3. simple halo phase

Graph:
- CoGeNT
- DAMA
- $m=10 \text{ GeV/c}^2$
- $q_{Na} = 0.3$

$\text{Modulated Rate [kg day keVnr]}^{-1}$

$\text{Recoil Energy [CoGeNT keVee]}$

$10^{-39}$

$10^{-40}$

$10^{-41}$

$M_x \text{ [GeV/c}^2\text{]}$

$\nu_0 = 220 \text{ km/s, } \nu_{esc} = 550 \text{ km/s}$
Setting the Stage

CoGeNT modulation + origin: simple halo

in tension with...

1. CDMS, Xe100 rates
2. CoGeNT rates
3. simple halo phase

Standard Phase: 152.5 days

CoGeNT Best-Fit: 106 days
CDMS II at low energies

4 Phonon Channels
2 Charge Channels

PA, PB, PC, PD

-3V, 0V, 1 cm

7.6 cm
CDMS II at low energies

- Ionization Energy [keVee]
  - T1Z5
  - Multiples
  - Singles
  - Run 123 Nuclear Recoils
  - Run 124 Nuclear Recoils
  - Run 125 Nuclear Recoils
  - Run 126 Nuclear Recoils
  - Run 127 Nuclear Recoils
  - Run 128 Nuclear Recoils

- Total Phonon Energy [keV]
  - ER band
  - NR band (+2σ)

charge energy (scaled to keVee) vs phonon energy
CDMS II at low energies

Recoil Energy [keVee] vs Recoil Energy [keVnr]

- Charge energy (scaled to keVee)
- Recoil energy (scaled to keVee or keVnr)
CDMS II at low energies

Recoil Energy $[\text{keVee}]$

Ionization Energy $[\text{keVee}]$

- T1Z5
- Multiples
- Singles
- Run 123 Nuclear Recoils
- Run 124 Nuclear Recoils
- Run 125 Nuclear Recoils
- Run 126 Nuclear Recoils
- Run 127 Nuclear Recoils
- Run 128 Nuclear Recoils

Reduced yield at top and bottom surfaces

Guard ring
Inner electrode

Recoil Energy $[\text{keVnr}]$

- 2.7
- 5
- 7.3
- 9.6
- 11.9
CDMS II at low energies

Recoil Energy [keVee]

Ionization Energy [keVee]

Reduced yield at top and bottom surfaces

Near-complete sidewall trapping

Guard ring

Inner electrode

+3
CDMS II at low energies

Recoil Energy [keVee]

Ionization Energy [keVee]

Recoil Energy [keVnr]

Timing can tell us position...

...but timing fails below ~10keV.
The CDMS II Exposure


Detector
- T1Z2
- T1Z5
- T2Z3
- T2Z5
- T3Z2
- T3Z4
- T3Z5
- T3Z6

Bin #
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Run 123
Run 124
Run 125
Run 126
Run 127
Run 128

01/2007
07/2007
01/2008
07/2008

Detector-Specific Live Periods
Excluded Due to Cf Calibration
Preparation

±2σ NR bands defined for each run for each detector
If we conservatively choose a $5$ keV$_{nr}$ threshold,

...we can assume constant trigger efficiency.
Preparation

Test:
Do cut efficiencies vary with a one-year period?

Tight limits placed on efficiency modulation; efficiencies were then assumed constant.
CDMS II Modulation

Candidate Event Rate vs. Time

DC rates (in green), detector by detector
Candidate Event Rate vs. Time

DC-subtracted, detector by detector before combining residuals
CDMS II Modulation

Candidate Event Rate vs. Time

DC-subtracted, detector by detector before combining residuals

Residual Rate, WIMP Cand. 5 to 11.9 [keVnr]
Testing of $[R_{\text{mod}}, \phi]$ models

predicted rate for $[\text{det } d, \text{ bin } \beta ]$

$$\mu_{\beta d} = \left\{ \Gamma_d + R_{\text{mod}} \cos [\omega (t_{\beta} - \phi)] \right\} [\text{exposure } \beta_d]$$

DC Mod. Rate Mod. Rate Phase

poisson likelihood of data

$$\ell = \prod_{\beta, d} e^{-\mu_{\beta d}} \left( \mu_{\beta d} \right)^{n_{\beta d}}$$

Feldman-Cousins scan of model space
(marginalizing out the 8 DC rates $\Gamma_d$)
space of \([R_{\text{mod}}, \phi]\) models

5.0-11.9 keVnr

\[\pi/2 (\sim \text{Apr.1})\]

\[\pi (\sim \text{Jul.1})\]

\[3\pi/2 (\sim \text{Oct.1})\]

\[0.175\]

\[0.35 \text{ [keVnr kg day}^{-1}\]

Expected Phase for a Simple Halo

\[0 \text{ (Jan.1)}\]
space of $[R_{\text{mod}}, \phi]$ models

$\pi/2$ (â¼ Apr.1)

Expected Phase for a Simple Halo

CoGeNT

$\pi$ (â¼ Jul.1)

$3\pi/2$ (â¼ Oct.1)

0.175

0.35 [keVnr kg day]$^{-1}$

5.0-11.9 keVnr
space of $[R_{\text{mod}}, \phi]$ models

5.0-11.9 keVnr

Expected Phase for a Simple Halo

CoGeNT
CDMS

$\pi$ ($\sim$Jul.1)

$\pi/2$ ($\sim$Apr.1)

$3\pi/2$ ($\sim$Oct.1)

0.35 [keVnr kg day$^{-1}$]

0.175

(Jan.1)
space of \([R_{\text{mod}}, \phi]\) models

\(5.0-11.9\ \text{keVnr}\)

\(R_{\text{mod}} < 0.06\ \text{[keVnr kg day]}^{-1}\) (99% CL)

inconsistent with CoGeNT (>98% CL)
R_{mod} vs Energy (at a particular $\phi$)

106-day phase (CoGeNT Best-Fit)
$R_{\text{mod}}$ vs Energy (at a particular $\phi$)

152.5-day phase (Simple Halo Model)
$R_{mod}$ vs Energy (at a particular $\phi$)

152.5-day phase (Simple Halo Model)

Question from the audience:
Can we believe the nuclear recoil energy scale?
Phonon energy: two components

Charge Drift
Luke Phonons
Primary Phonons

Phonon Signal
= Primary + Luke
Phonon energy: two components

Phonon Signal = Primary + Luke

At 3V running in Ge...

Luke = Yield x Primary

Electron Recoils: Primary | 1.0 x Primary
Phonon energy: two components

\[
\text{Phonon Signal} = \text{Primary} + \text{Luke}
\]

At 3V running in Ge...

\[
\text{Luke} = \text{Yield} \times \text{Primary}
\]

Electron Recoils:

- Primary: 1.0 x Primary

Nuclear Recoils:

- Primary: \sim 0.2 x Primary
How to define a NR energy scale:

**STEP 1:** Calibrate using ER lines
How to define a NR energy scale:

**STEP 1:**
Calibrate using ER lines

**STEP 2:**
Scale from ER to NR
Conclusions

Between 5.0-11.9 keVnr,

$R_{mod} < 0.06 \text{ [keV}_{nr}\text{ kg day}]^{-1}$ (99% CL)

Inconsistent with CoGeNT (>98% CL)

→ Relative energy scales well known
→ Same target material
→ No dependence on halo model
extra slides
The Collar-Fields Maximum-Likelihood Analysis

Background model critique

**Surface event** distribution unmotivated energy: expect the low-yield rate to increase faster than the high-yield rate at low energies yield: no reason to think surface yield constant in energy

**Zero charge** distribution should not be fit in such a model (these events follow the *measured* charge noise dist.)

Looking at the multiple-detector events

**Singles**
**Multiples**
selecting only ±1σ nuclear recoil band
A ‘spike’ seen by Kelso et al. may be dependent on the choice of energy bins

Kelso, Hooper, & Buckley 1110.5338v1
The tighter nuclear recoil yield band, defined as 
-0.5σ to +1.25σ
The ‘candidate’ events were selected from WIMP-search data, ignoring pulse shape.
Interpretation of CDMS II at Low Energies

Sidebands for background estimate:
- 1.3 keV line
- Compton
- Surface
- 2σ zero charge band
- Zero-charge

Expected background spectra:
- Event rate (keV⁻¹kg⁻¹day⁻¹)
- Recoil energy (keV)
Blue Region: Hooper et al., PRD 82 123509 (2010)
$m_\chi = 7$ GeV/c$^2$ (90% CL) $\sigma_{SI} \sim 7 \times 10^{-41} - 2 \times 10^{-40}$ cm$^2$

CoGeNT (background model subtracted)

CDMS II (no background subtraction)

all detectors (coadded)

best detector
WIMP-nucleon $\sigma_{SI} [cm^2]$

WIMP Mass [GeV/c$^2$]

CDMS Soudan
10keV threshold

DAMA/LIBRA

CoGeNT

These Results

Xenon10
arXiv:1104.3088

Xenon100
arXiv:1104.2549

DAMA/LIBRA, light blue CoGeNT region, and combined region:
Hooper et al., PRD 82 123509 (2010)