LUX
DARK MATTER SEARCH
Carter Hall
The Collaboration

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Hunting for WIMPs in parametric space

![Graph showing spin-independent cross section versus WIMP mass][1]

[1]: https://example.com/graph.png
Davis' neutrino detection apparatus one kilometer underground in the Homestake Gold Mine, Lead, South Dakota. The tank contains 400,000 liters of perchloroethylene.
Current Davis Cavity Dimensions:
55ft x 30ft x 32ft high

LUX Experiment with Low-Background Counting Facility (LBF)
De-watering almost complete!

Received yesterday, 10:54 am
Liquid target:
- Readily purified
- *Scalable to large masses*

Liquid scintillator: 14C fatal for dark matter
- Even in petroleum - 10-18
- 14C: U->a + rock -> n ->
  14N(n,p)14C

Xe, Ar, Ne(?)
- Xe: 165 K, \(\lambda=175\) nm
- Ar: 87.3 K, \(\lambda=128\) nm, 39Ar - 1 Bq/kg
- Ne: 27.1 K, \(\lambda=80\) nm, bubbles ->
  - slow charge drift

Signals: ionization & scintillation
- Single photons, electrons readily measured
Single Phase detectors

- Scintillation signal.
  - Cryogenic versions of Chooz, Kamland, Borexino.

- Rayleigh scattering:
  - Position reconstruction poor.
  - Need large volume to reject large rate of Rn-daughter background on surface.
  - Multiple-vertex events hard to distinguish.

- PMTs: highly radioactive
  - Self-shielding in large detector
  - LXe best for this

(XMASS: 800 kg total, 100 kg fiducial)

<table>
<thead>
<tr>
<th></th>
<th>$\lambda$ (nm)</th>
<th>$L_{\text{theory}}$ (cm)</th>
<th>$L_{\text{exp}}$ (cm)</th>
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<tbody>
<tr>
<td>Ne</td>
<td>78</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Ar</td>
<td>128</td>
<td>90</td>
<td>66</td>
</tr>
<tr>
<td>Xe</td>
<td>174</td>
<td>30</td>
<td>30-5</td>
</tr>
</tbody>
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(Seidel, Lanou, Yao, 2002)
Scintillation pulse shape discrimination

- Scintillation from excimer state:
  - $\text{Ar}^* + \text{Ar} \rightarrow \text{Ar}2^*$
  - Triplet (long lived)
  - Single (short lived)

- Discrimination of electron recoil backgrounds:
  - Nuclear recoils don’t populate triplet
  - No one knows why

- Ar system by far most favorable
Why Xenon?

- High Z $\rightarrow$ Self shielding $\rightarrow$ “Wall-less detector”
- Scintillation + ionization (+ phonons for SXe)
- Scintillation light wavelength good match for QE PMTs
- Low natural radioactivity
- Easy to purify
- Good gamma/neutron discrimination ($>10^2$)
- High atomic mass
  - Coherent scattering cross-section $\propto A^2$
  - Good WIMP energy transfer in the range of $\sim 100$ GeV/c$^2$
- Low cost ($\sim$ $1500$/kg)
WIMP Signals in a Dual-Phase Xenon Detector
UMD Liquid Xenon Lab

Liquid xenon detector R&D @ UMD

UMD Xenon condenser
Shielding Gamma Rays

Water, 2.6 MeV gammas

1 m water shielding

Liquid Xe, 2.6 MeV gammas

1 m liquid Xe
Single Scatters of MeV photons

- Dominant background in foreseeable future

- Rare

- Can approximate analytically:

\[ P(L) \approx \frac{L}{\lambda} e^{-\frac{L}{\lambda}} \]
Self-shielding effect

- Sensitivity vs volume greater than linear
Recombination - based discrimination

Electron recoils (Background)

Nuclear recoils (Signal)

T. Shutt, LBNL - Feb 10, 2009
Gamma/neutron discrimination

$^{133}$Ba Electrons

Electron recoil calibration (Case data, $^{133}$Ba at 2.0 kV/cm)

Nuclear recoil calibration (Case data, $^{252}$Cf at 2.0 kV/cm)

Recoil Energy (keVr)

Measurements above ground
XENON10 WIMP search data

- Blind Analysis
- 58.6 days, 5.4 kg fiducial
- ~50% acceptance of Nuclear Recoils
- 2-12keVee / 4.5-27 keVr
  - Assuming QF 19%
  - 4.5-27 keVr
- 10 events in the “box” after all primary analysis blind cuts
  - Calibration expectation: 7.0 +2.1-1.0 (gaussian)
  - Data: 5 ~gaussian; 5 non-gaussian

“Straightened ER Scale”
LUX Inspiration: Xenon 10 – New best limit in 2007

26 kg LXe

Cross-section [cm²] (normalised to nucleon)

WIMP Mass [GeV]

4 keVee event; S1: 8 p.e. => 2 p.e./keV

Hit pattern of top PMTs
**The LUX Concept**
- 100 kg fiducial dual phase xenon detector, 300 kg total xenon mass
- 2.5 m thick purified water shield

**The Physics Goal**
- Detect (or exclude) WIMPs with a cross section of $7 \times 10^{-46} \text{ cm}^2$
- about 100 times more sensitive than current limit

**Project Cost** = 2.8 M$
LUX Detector

- Xenon Temperature 170K
- Gas Pressure 1.5bar
- 350 Kg of Xenon
- Drift Field 0.5kV/cm
- Active region ø50cm x 50cm
Predicted WIMP rate = 4 events in 300 day for $7 \cdot 10^{-46}$ cm$^2$ @ 100 GeV
LUX Deployment Plan

- LUX-0.1 test unit - summer 2009
- DUSEL/SUSEL cavern renovation - late 2009
- Deployment LUX-1.0 in DUSEL/SUSEL - Dec 2009
- Run LUX-1.0 for ~ 1 year of 2009
Cryostat at Case 2007/2008
Thermosyphon cooling system

Thermosyphon principle of operation

\[ \frac{dQ}{dt} = k A \left( T_H - T_C \right) / L \]
Thermosyphon cooling system
Thermal conductivity $k = (\Delta W/\Delta T)(L/A) = 30$ kW/Km

- diamond: 1-2 kW/Km
- copper: 0.4 kW/Km
Thermosyphons at oil-pipeline in North Russia
Photomultiplier Tubes

Hamamatsu R8778: QE ~30%  Background < 50mBq

LUX-0.1 PMT ASSEMBLY

LUX-1.0 PMT ASSEMBLY
Installation LUX-0.1:
Aluminum filler to be replaced by LXe in LUX-1.0
Summary

- Existing Cryostat at Case can support large mass LXe operations
- LUX-0.1 test platform is under operation
- LUX-1.0 components – in production
- Kr-85 removing system updated to process 350 kg Xe in 2008
- By the end of the year LUX should be installed at Homestake gold mine
LZ20

- New collaboration between LUX, and ZEPLIN III.
  - ZEPLIN III: largest European LXe dark matter collaboration: UK, Portugal, Russia
- LZ3: 3 ton, at Sanford Lab
  - Proposals: Sept. 09.
- LZ20: proposed part of ISE for DUSEL
  - 20 ton LXe mass
  - “ultimate” direct dark matter detection experiment
LZ20 in Context

Searches Past, Present & Future

Plot updated from that in DM Review Article:

T. Shutt, LBNL- Feb 10, 2009