The LUX Dark Matter Search
Objectives and Status

The Large Underground Xenon (LUX) dark matter search experiment is currently being deployed at the Homestake Laboratory in South Dakota. We will highlight the main elements of design which make the experiment a very strong contender in the field of direct detection, as well as an easily scalable concept. We will also present its potential reach for supersymmetric dark matter detection, within various timeframes ranging from 1 year to 5 years or more.
Summary

- The LUX Experiment
  - Collaboration
  - Particularities of LUX Design
  - Backgrounds and Sensitivity

- Operations Status
  - LUX 0.1 @ CWRU
  - LUX 1.0 @ Homestake Surface Facility
  - LUX 1.0 @ Homestake -4850 Davis Lab

- Outlook and LUX-ZEPLIN Program
  - LZ3
  - LZ20
  - SUSY Dark Matter Sensitivity

www.luxdarkmatter.org
# The LUX Collaboration

Collaboration meeting, Homestake, March 2009

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<tr>
<th>Brown</th>
<th>Xenon10, CDMS</th>
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<tr>
<td>Richard Gaitskell</td>
<td>PI, Professor</td>
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<td>Simon Fiorucci</td>
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<td>Luiz de Viveiros</td>
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<td>Jeremy Chapman</td>
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<td>Carlos Hernandez Famil</td>
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<td>David Malling</td>
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<td>Robert Lanou</td>
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<td>George Solidel</td>
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<td>Thomas Stufl</td>
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<td>Dan Akreli</td>
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<td>Alexander Bolozytya</td>
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<td>Mike Dragowski</td>
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<td>Kevin Lesko</td>
<td>Senior Physicist</td>
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<td>Yuen-Dat Chan</td>
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<td>Brian Fujikawa</td>
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<tr>
<td>Adam Bernstein</td>
<td>PI, Leader of Advanced Detectors Group</td>
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<td>Dennis Carr</td>
<td>Eng. Mech. Assoc</td>
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<td>Steven Dazeley</td>
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<td>Kareem Kazkaz</td>
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<td>Carter Hall</td>
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<td>James White</td>
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<td>Robert Webb</td>
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<td>Tyana Stieger</td>
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<td>Richard Landers</td>
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<th>University of South Dakota</th>
<th>Majorana, CLEAN-DEAP</th>
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<td>Dongming Mai</td>
<td>Professor</td>
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<td>Sidney Cahn</td>
<td>Lecturer/Research scientist</td>
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<td>Susie Bedikan</td>
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Formed in 2007, fully funded DOE/NSF in 2008

S. Fiorucci - Brown University
LUX Design – Detector Overview

- Thermosyphon
- Feedthroughs
- Water Shield
- Time Projection Chamber
- Inner Titanium cryostat
- Superinsulation
- Titanium cryostat
- 350 kg liquid xenon
- Anode and electron extraction grids
- Cathode
- Photomultiplier Tubes
- Xenon recirculation and heat exchanger
LUX Design – Double Phase LXe TPC

- Can measure single electrons and photons
- Charge yield reduced for nuclear recoils
- Good 3D imaging
  - Reject multiple scatters
  - Eliminate edge events to take advantage of Xe self shielding

Animation by LLNL
LUX Design – Water Tank

- Water Tank: \( d = 8 \text{ m}, \ h = 6 \text{ m} \)
  - 300 tonnes, 3.5 m thickness on the sides
  - Inverted steel pyramid (20 tonnes) under tank to increase shielding top/bottom

- Cherenkov muon veto

- Ultra-low background facility
  - Gamma event rate reduction: \( \sim 10^{-9} \)
  - High-E neutrons (>10 MeV): \( \sim 10^{-3} \)

Flux attenuation in water (normalized to number of incoming particles)

- Rock Gammas
- Rock Neutrons
- Mu Neutrons

Inverted steel pyramid
LUX Design – Thermosyphon

- Closed loop of LN$_2$ condensation/evaporation
- Cold LN$_2$ bath on top
  - Safe deported cooling
  - No danger from power failure
- 1 main thermosyphon for rapid cooling
  - Provides 1 kW cooling power
  - Allows circulation at ton/day scale
- 2 secondary thermosyphons
  - Mounted on cold Cu head
  - $\sim$0.2 kW cooling power
  - Ensure stable operation
- Technology readily scalable to multi-ton detectors
LUX Design – Heat Exchanger

- Xe is constantly recirculated at rate ~250 kg/day
  - x10 compared to Xenon10

- Heat exchanger transfers heat from incoming Xe gas to outgoing Xe liquid
  - 97% efficient
  - 1200 kg cooled with 5 l/d LN$_2$ (10 W)
LUX Design – Active Volume

- 350 kg of liquid Xe
  - Active volume: h=59cm, d=49cm
- Light collection ~2.0 phe/keVr
  - 2x better than Xe10
  - Analysis threshold down to < 3 keVr

- 122 PMT R8778
  - 2” diameter
  - 175 nm, QE > ~30%
  - U/Th ~9/3 mBq/PMT

- Dodecagonal field cage + PTFE reflectors
  - Cu PMT holding plate

Design by J. White

S. Fiorucci - Brown University
LUX Design – Cryostat

- Inner vessel: 100 kg
  - Rated 60 psig / vacuum
- Outer vessel: 130 kg
  - Rated 45 psig / 30 psi
- Total det mass: ~2.4 t
  - + 350 kg of LXe

- Ultra-low radioactivity inner and outer Titanium cryostats (high strength, low mass)
  - Activity <0.4 mBq/kg in U+Th
  - Cryostats separated by vacuum + superinsulation film
  - Inner cryostat covered with Cu radiation shield

- Cosmogenic activation of Ti at Homestake altitude gives $^{46}$Sc (89 d)
  - Equilibrium level ~15% of LUX ER background budget, ~5% after 130 days underground
LUX Acquisition System

- Struck ADC boards run on "Pulse Only Digitization" mode (POD)
  - Average event size (122 PMTs, 700 µs): 60 kB
    - Comparison Xe10 equivalent: ~17 MB
  - Max event rates (100% livetime):
    - Calibration « multi-event » mode: 1.2 kHz
    - Background « single event » mode: 300 Hz

- Trigger through custom DDC-8 logic boards
  - Dedicated 8 channel 14 bit ADCs, sync with DAQ
  - S1/S2 pulse recognition capability
  - Can trigger on either or any combination of both

Run requirements:
- S1&S2 trigger mode
- S1 on Ch1 in coincidence with S1 on Ch2
- S1 on Ch1 between 15400 and 88800 mVns
- S1 on Ch2 between 5580 and 32880 mVns

DDC-8DSP

1. FPGA (XCS3D3400A)
2. FX2-LP (USB 2.0)
3. Analog Input Channels
4. ADCs
5. Analog passive filters
6. Analog active filters
7. NIM-IN
8. NIM-OUT
9. NIM-Timestamping
10. External Clock
11. Spy Channel
12. HDMI
13. USB Connector
14. JTAG Connector
15. VME Connector (POWER +5V)
16. External Power (+5V)
LUX Backgrounds and Signals

- **Goal:** < 1 NR event / 100kg / 300 days (50% accept.)

- **Expected ER background** ~260 $\mu$dru
  - PMT contribution dominant / external sources ($10^{-4}$)
  - $^{85}$Kr < 2 ppt (~10% of LUX ER background budget)
  - 350 kg = full advantage of Xe self-shielding

- **Expected NR background** < 500 ndru$_r$
  - Neutrons mostly from (alpha,n) on PMTs
  - Subdominant to gammas after ~99.5% ER discrimination

- **Strength of LUX** is in the extremely low ER background in the fiducial volume

- **No single neutron scatter** (~1/20 event expected in entire set of 100 kg x 100 days)
LUX – SI Coupling WIMP Sensitivity

Graph showing the cross-section [cm$^2$] (normalised to nucleon) versus WIMP mass [GeV/c$^2$]. The graph includes data from various experiments:

- Zeplin-III
- Xenon10
- CDMS-II
- XMASS (2009)
- SuperCDMS (2013)
- LUX (2010)

The graph indicates that at 100 GeV/c$^2$, the cross-section is $7 \times 10^{-46}$ cm$^2$. The graph also highlights the sensitivity of LUX to the WIMP mass.
LUX 0.1 Program

- **Objectives**
  - Develop full-scale cryogenics + fluid system
    - In particular high-flow purification/circulation
  - System integration
    - Xe handling, Slow Control, Safety, DAQ, Electronics
  - Team integration

- **Achievements to date**
  - July 2008: LUX is funded
  - Detector designed and built
  - Cooldown and stable operation at LXe temperature
  - All PMTs tested and characterized
  - S1 and S2 light observed
  - 250 kg/d Circulation, 97% efficient heat transfer
  - $^{57}$Co data taken with full DAQ + Trigger system
LUX 0.1 Program

- Stainless steel prototype cryostat
  - Fully functional dual-phase detector
  - 4 R8778 PMTs (3 top, 1 bottom)
  - 0.5 kg active Xe region, 5 cm drift length
  - 60 kg LXe total, 270 kg Al displacer
    - 60% of full LUX cold mass

![Image of LUX 0.1 cryostat with a graph showing 436 phe and 12550 phe with a time of 3.4 µs.](image-url)
DUSEL @ Homestake

Davis Cavern
4300 m.w.e
$\Rightarrow$ 4 $\mu$/m$^2$/d

Surface Facility
LUX 1.0 – Surface Facility

- Full-scale test of LUX deployment
  - Liq/gas system
  - PMT testing
  - DAQ testing
  - S1 trigger efficiency
  - Xe purity

- Exact duplicate of the underground layout for all major systems

- 1 m thick water shield designed to allow limited real data taking, even at the surface
  - Expected Gamma rate ~70 Hz, Neutron rate ~30 Hz, Muon rate ~50 Hz
  - Natural detector limit: 175 Hz (PMT gain stability, < 10% event overlap)
  - Will require: S2 gating, reduced PMT gain

- Beneficial occupancy: End September 2009
Homestake - Access to level 4850

- Level 4850 dry and accessible at the end of May 2009
  - Slower than original schedule
- First assessment of Davis Cavern
  - Condition generally very good!
- Construction/excavation design completed
  - New 300’ access/safety tunnel to be excavated
  - Shared access with Majorana facility, also to be excavated

- Two storey, dedicated LUX 55’ x 30’ x 32’ facility, CL 100k
  - Includes CL 1k clean room, control room, counting facility

- Beneficial occupancy: Spring 2010
LUX-ZEPLIN (LZ) Program

- New collaborators from Zeplin III and US institutions
  - Imperial College, London
  - STFC Rutherford Appleton Lab
  - ITEP, Moscow
  - Moscow Engineering Physics Institute
  - LIP, Coimbra
  - University of Edinburgh
  - UC Santa Barbara
  - LBNL

- Several phases: 3 t, 20 t from 2009 → 2018+

- DUSEL Program at Homestake L7400
LZ Program

- **LZ3**: 3 tonnes detector in Davis water shield (SUSEL)
  - Proposal start: Sept 2009
  - Bigger 3" PMTs already in testing. Goal ~1 mBq/PMT

- **LZ20**: 20 tonnes detector, part of ISE for DUSEL
  - "ultimate" direct detection experiment

Requirements

- Mechanics, safety: LUX 350kg will demonstrate
- Light collection: current understanding 20t scale ok
- Xe purity: LZ20 requires $< 10^{-14} \text{ Kr/Xe, } < \sim \text{mBq Rn}$
  - state of art already demonstrated (SNO, Borexino) + Xe much easier to purify
  - work in progress to achieve high reliability

Backgrounds

- Goal: $< 2$ neutron events / 3,000 tonne.days (before acceptance cut)
- PMT background already improved by x2 compared to 2" tubes improvement by x10 likely in near future (currently XMASS has $< 1 \text{ mBq/PMT}$)
- Cosmogenic backgrounds still subdominant at -4850 ft for 20 tonne scale
LZ Program – LZ20, ultimate search?

- Electron Recoil signal limited by p-p solar neutrinos
  - Subdominant with current background rejection
- Nuclear Recoil background: coherent neutrino scattering
  - $^8$B solar neutrinos
  - Atmospheric neutrinos
  - Diffuse cosmic supernova background
- LZ20 reaches this fundamental limit for direct WIMP searches

LZ20 also sensitive to $\beta\beta0\nu$ decay in natural xenon up to lifetimes of $\sim 1.3 \times 10^{26}$ years!
- Projections based on
  - Known background levels
  - Previously obtained $e^-$ attenuation lengths and discrimination factors

- 100 kg x 300 days

LZ3 (constr: 2010-2011, ops: 2012-2013)
- 1,500 kg x 500 days

- 13,500 kg x 1,000 days

- Fiducial volumes selected to match < 1 NR event in full exposure
Conclusions

- LUX Xe TPC builds on established technology, with some upgrades
  - Full advantage of Xe self-shielding at this size (and higher)
  - Effective, cheap, scalable water shield against gammas, neutrons and muons (veto)
  - Efficient, remote cryogenics
  - Very low radioactivity, high strength titanium cryostat

- First stage LUX 0.1 is already running since Summer 2008
  - Most subsystems already tested and perfected

- Fast-paced physics campaign:
  - Deployment at Surface Facility in September 2009
  - Deployment in dedicated Davis Lab in Spring 2010
  - Sensitivity reach with 100 live days: $7 \times 10^{-46} \text{ cm}^2 @ 100 \text{ GeV/c}^2$
    - x100 better than current SI limits
  - Nest stage LZ3 proposal by Fall 2009
  - LZ20 DUSEL S4 proposal submitted January 2009

- LUX/Brown has a postdoc position opening!