THE STATUS OF DIRECT DARK MATTER SEARCHES

Chamkaur Ghag
University College London
Outline

- Evidence and direct detection
- Current state of play
- The next crop
- Tonne scale experiments
Evidence for Dark Matter

Formation of Structure in the Universe

Dark Matter is required!

Angular scale

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!

Formation of Structure in the Universe

Dark Matter is required!
Evidence for Dark Matter

Formation of Structure in the Universe

Dark Matter is required!

Dark Energy

Dark Matter

Ordinary Matter

26.8%

4.9%

68.3%

Comparison of the growth term calculated for all the massless neutrinos (including \( \nu_\ell \)) and \( \nu_\jmath \) - 209, \( \nu_\ell \) - 133, \( \nu_\jmath \) - 133.
Dark Matter Properties

- No electromagnetic interaction
- No strong interaction
- Stable
- Neutrinos are too hot
- Likely weak interaction (WIMPs)
- One possibility is LSP of SUSY

\[ \chi = \alpha \tilde{B} + \beta \tilde{W} + \gamma \tilde{H}_1 + \delta \tilde{H}_2 \]

- If SUSY is wrong that won’t stop galaxies rotating too fast!
- Zoo of WIMP candidates - direct searches must be broadband
Dark Matter Properties

- No electromagnetic interaction
- No strong interaction
- Stable
- Neutrinos are too hot
- Likely weak interaction (WIMPs)
- One possibility is LSP of SUSY

\[ \chi = \alpha \tilde{B} + \beta \tilde{W} + \gamma \tilde{H}_1 + \delta \tilde{H}_2 \]

- If SUSY is wrong that won’t stop galaxies rotating too fast!
- Zoo of WIMP candidates - direct searches must be broadband

The existence of Dark Matter points to BSM physics
Dark Matter Searches

- **Collider**
  - Production

- **Indirectly**
  - Annihilation

- **Directly**
  - Scattering

See M. Gustaffson’s talk on indirect detection with Fermi - 5:30pm tomorrow
Direct Detection

- Weak elastic scatters
- ~tens of keV nuclear recoils
- Underground operation
- Background rejection

V. Chepel & H. Araujo 'Liquid noble gas detectors for low energy particle physics' arXiv:1207.2292

http://www.deepscience.org/contents/facilities_popup01.shtml

Graph: Integral rate, counts/kg/year vs. threshold recoil energy, keV

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Xe</th>
<th>Ge</th>
<th>Ar</th>
<th>Ne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mχ=100 GeV/c²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>σ_σ,SI = 10^-9 pb (10^-45 cm²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

V. Chepel & H. Araujo 'Liquid noble gas detectors for low energy particle physics' arXiv:1207.2292
Detector Technologies

- **dE/dx**
- **Phonons**
- **Charge**
- **Light**

**CDMS EDELWEISS**
**CUOPP PICASSO SIMPLE**
**CRESST ROSEBUD**
**DAMA LIBRA XMASS CLEAN ANAIS KIMS DEAP/CLEAN**
**LUX XENON WARP ArDM ZEPLIN DARKSIDE**
**DRIFT DMTPC GENIUS NEWAGE**
Current state of play
Current state of play (SD)

WIMP-Neutron

WIMP-Proton
Particle

S1

S2

E field

Drift time indicates depth

ionization electrons

UV scintillation photons (~175 nm)

Image by CH Faham (Brown)
Light (S1) and charge (S2) depend on recoil dE/dx
Fiducialisation

XENON100
XENON100

- LNGS
- 100x less bkgd than XENON10
- 62 kg target (34 kg fiducial)
- 99 kg LXe active veto
- 1” square PMTs
- 225 day WIMP run 2011-2012
- S.I. limit: $2 \times 10^{-47} \text{ cm}^2$

(1.0 ± 0.2) events expected
2 events observed
→ 26.4% probability that background fluctuated to 2 events
→ PL analysis cannot reject the background only hypothesis

No significant excess due to a signal seen in XENON100 data.
Next up!
ZEPLIN Programme

**ZEPLIN I**
- Single phase, 3 PMTs, 5/3.1 kg
- Run 2001-04
- Limit: $1.1 \times 10^6$ pb

**ZEPLIN II**
- Double phase, 7 PMTs, moderate E field, 31/7.2 kg
- Run 2005-06
- Limit: $6.6 \times 10^7$ pb

**ZEPLIN III**
- Double phase, 31 PMTs, high E field, 10/6.4 kg
- Run 2009-11
- Limit: $3.9 \times 10^8$ pb
- 350 kg LXe TPC
- Homestake Mine (Davis cavern 4850ft)
- 122 low bkgd PMTs and Ti cryostat
- Sensitivity reach x10 over XENON100
- Active water Cerenkov shield
- Fully assembled and tested in surface facility before underground deployment
Could surpass XENON100 sensitivity in 2013

see H. Araujo’s talk - Wed 9:30am, Track 4
EDELWEISS-III

- Laboratoire Souterrain de Modane
- 40 cryogenic germanium detectors
- Phonon-ionisation for discrimination
- 5 keV recoil threshold
- 24 kg fiducial mass
- Upgrading to 32 kg Ge in summer 2013
- 2 year WIMP run to begin by end 2013
- Sensitivity of few $\times 10^{-9}$ pb (depending on backgrounds)
DEAP-3600 & miniCLEAN

- SNOlab, Canada
- Single phase open volume, $4\pi$ PMT coverage
- No E-field (maximize phe/keVee)
- Pulse shape discrimination, $\sim$40 keV thresh.
- Active water shield
- MiniCLEAN (150 kg fiducial)
  sensitivity: 1E-45 cm$^2$
- DEAP-3600 (1 tonne fiducial)
  sensitivity: 1E-46 cm$^2$

see J. Walding’s talk - Wed 9:20am Track 3
DarkSide-50

- Based at LNGS, under construction
- Liquid Ar 2-phase TPC
- Low background science device (unlike DS-10)
- Neutron veto inside Borexino CTF
- Used underground (depleted) Ar target
- Adopts v. successful Xe technology
- PSD + S2/S1 discrimination
- 3D position reconstruction for surface background rejection (ala LXeTPCs)
- DarkSide-10 decommissioned last month
XMASS

- Based at Kamioka, Japan
- Single phase detector (no E-field so no S2’s)
- 100 kg Xe fiducial (800 kg active)
- $4\pi$ PMT coverage
- Unexpected background observed
- Performance severely compromised
- Undergoing refurbishment of PMTs
- Data taking to begin 2014
Acoustic Bubble Chambers

1st generation*: 10ml
2nd generation: 1L
3rd generation: 4.5L

SNOLAB, Ca

SIMPLE (Freon target)
COUPP (CF3I)
Directional Gas TPCs

**DRIFT-II/III**
- CS$_2$:CF$_4$ low pressure target (33 g fid.)
- MWPC readout for 3D track reconstruction
- 1 m$^3$ modules in Boulby Mine, UK
- DRIFT-IIe incorporates major modifications to improve backgrounds and track reconstruction
- DRIFT-III plans for 24 m$^3$

*see S. Sadler’s talk - tomorrow 3pm, Track 3*

**DMTPC**
- CF$_4$ target (10l prototype)
- 1 m$^3$ modules under development presently
- Charge *and* optical readout for background rejection
Next generation (tonne scale) Experiments
EURECA

European Underground Rare Event Calorimeter Array
The future European 1-tonne cryogenic dark matter search

Aim:        <10^{-10}pb
Detectors:  Cryogenic Ge (from EDELWEISS) and
            scintillator calorimeters (from CRESST)
Shielding:  Radiopure Cu, polyethelene,
            3m water tank with PMTs
Infrastructure:  Cryostat to cool 1-tonne target
Collaboration:  EDELWEISS, CRESST, new members

see X. Zhang’s talk - tomorrow 3pm, Track 4
Global convergence of CryoDetectors

phonon – ionization
Germanium

SuperCDMS
Soudan, 10kg
$5 \times 10^{-9}\text{pb}$

SuperCDMS
SNOLAB
200kg, $8 \times 10^{-11}\text{pb}$

MoU since 2009
Increasing collaboration towards common experiment

CRESST
Gran Sasso
CaWO$_4$
phonon – scintillation

LSM
Germanium
10 – 32 kg
$2 \times 10^{-9}\text{pb}$

150 – 1000 kg
$3 \times 10^{-10}\text{pb}$ to
$2 \times 10^{-11}\text{pb}$
DEAP/CLEAN

DEAP-1 (7 kg)  μCLEAN (4 kg)  MiniCLEAN (300 kg)  DEAP-3600 (3600 kg)  CLEAN(100T)


DEAP/CLEAN

O(10) tonne fiducial

future goal, 1E-47 cm² sensitivity

emphasis on scalability to 100T-scale, for dark matter and solar neutrino physics
DEAP/CLEAN

- Concept design: 140 tonne fiducial mass single phase detector with PMT readout, in SNOLAB Cryopit Hall
- technical design based on MiniCLEAN, DEAP3600 technology, R&D + MicroBooNE
- active Gd-doped veto
- same scale as MicroBooNE@FNAL, exploring similar cylindrical cryostat
- coordinated proposals to NSERC (CA), STFC (UK), DOE (US) planned for 2014
- UK group activities: detector design, background model, calibration R&D, technology synergy with LAr ν efforts
LUX-ZEPLIN (LZ)

Next-generation LXe experiment building on LUX and ZEPLIN programmes

- **Route to detection & study: a progressive programme**
  - UK-led ZEPLIN programme pioneered liquid xenon for WIMP searches
  - LUX (now with UK) about to turn on – expect leading sensitivity in 2013
  - LZ could discover at $10^{-11}$ pb or exclude at $10^{-12}$ pb with 3 year run

- **Experimental approach: a low risk and aggressive programme**
  - Background free strategy (self-shielding, modest discrimination assumed)
  - Two-phase Xe technology: high readiness level (ZEPLIN, XENON, LUX)
  - Teams with huge track record in DM searches
  - Much infrastructure inherited from LUX350

- **LXe provides exciting physics for light & heavy WIMPs (GeV-TeV)**
  - Since we do not yet know what BSM physics looks like!
Down-selects
Science Board Sub-Group convened in 2012 to review UK involvement in DDMS...

“...the UK undoubtedly possesses unique expertise and has the potential to secure significant leadership within the relatively large international collaborations currently forming…”

...and propose a coordinated strategy for supporting next generation DDMS experiments that could potentially position the UK for leadership

“...it should be made clear to the community that further consolidation of activities would be viewed as a strength of any proposal.”

spokesperson: H. Kraus, Oxford
DMUK ‘down-select’

- DMUK founded to focus UK effort and as a body in which we build on mutual strength
- DMUK groups currently active in selecting the UK ‘flagship’ DM experiment
- Selected experiment(s) should seek to absorb UK expertise across DMUK
- Next meeting: 15th April 2013
- Next generation experiment selection coupled to international partners and funding
U.S. ‘down-select’

- DOE conducting down-select in two phases: R&D and then Project
- From 13 proposals to DOE, 5 selected for R&D funds and continuation in the down-selection process:
  - LZ
  - SuperCDMS
  - DarkSide-G2
  - COUPP
  - ADMX (axion search)
- 2-3 of these Next Generation (‘G2’) experiments to be funded
- Pursuit of a wide-range of technologies is not expected
- Merging of the communities is expected after down-select
Summary

- The nature of Dark Matter remains one of the most fundamental questions today.

- Direct detection experiments have accelerated rapidly in sensitivity, with high technology readiness levels or advanced detector development for the Next Generation tonne scale devices.

- Tonne scale experiments have sensitivities ideally matched to probe the bulk of the favoured parameter space on timescales compatible with accelerator and indirect.

- DMUK making excellent progress in consolidating UK direct detection activity.
Back-up Slides
XENON1T

- High transparency electrodes
- Active LXe veto
- 1 kV/cm drift field with external field shaping rings
- No top array screening mesh
- Three interlocking PTFE panels
- Titanium cryostat and vacuum jacket
- 2 arrays of 121 high QE 3” photodetectors
- No charge insensitive regions below photocathode
The XENON100 photosensors

• 1-inch square R8520 Hamamatsu PMTs, optimized to work at LXe T and P, and of low-radioactivity (< 1 mBq/PMT in $^{238}$U/$^{232}$Th)

• Top array: 98 PMTs (23% quantum efficiency) in concentric circles to improve radial event position reconstruction, teflon holder

• Bottom array: 80 PMTs, closely packed, and of higher quantum efficiency (32-34% at 178 nm), for efficient S1 light collection

• LXe veto: 64 PMTs, 23% quantum efficiency
How much is here? canonical value: 0.3 GeV/cm³
Kinematical and chemical vertical structure of the Galactic thick disk II. A lack of dark matter in the solar neighborhood

C. Moni Bidin, G. Carraro, R. A. Mendez, R. Smith

We estimated the dynamical surface mass density Sigma at the solar position between Z=1.5 and 4 kpc from the Galactic plane, as inferred from the kinematics of thick disk stars. We extrapolate a dark matter (DM) density in the solar neighborhood of 0+-1 mM\_sun pc^{-3}. In particular, our results may indicate that any direct DM detection experiment is doomed to fail if the local density of the target particles is negligible.

On the local dark matter density

Jo Bovy, Scott Tremaine (IAS)

An analysis of the kinematics of 412 stars at 1-4 kpc from the Galactic mid-plane by Moni Bidin et al. (2012) has claimed to derive a local density of dark matter that is an order of magnitude below standard expectations. We show that this result is incorrect and that it arises from the invalid assumption that the mean azimuthal velocity of the stellar tracers is independent of Galactocentric radius at all heights; the correct assumption—that is, the one supported by data—is that the circular speed is independent of radius in the mid-plane. The data imply a local dark-matter density of 0.3 +/- 0.1 Gev/cm^3

A new determination of the local dark matter density from the kinematics of K dwarfs

Silvia Garbari, Chao Liu, Justin I. Read, George Lake

We apply a new method to determine the local disc matter and dark halo matter density to kinematic and position data for \textless;sim2000 K dwarf stars taken from the literature. We perform a series of tests to demonstrate that our results are insensitive to plausible systematic errors in our distance calibration, and we show that our method recovers the correct answer from a dynamically evolved N-body simulation of the Milky Way. We find a local dark matter density of (0.95+0.53-0.49 Gev cm^{-3}) at 90\% confidence assuming no correction for the non-flatness of the local rotation curve, and (0.85+0.57-0.50 GeV cm^{-3}) if the correction is included.
No impact of $L_{\text{eff}}$ below 3 keVnr

"standard" $L_{\text{eff}}$

$L_{\text{eff}}=0$ below 3 keVnr
The new XENON100 Limit

![Graph showing WIMP-Nucleon Cross Section vs. WIMP Mass. The graph includes data from various experiments such as DAMA/Na, CoGeNT, CDMS (2011), DAMA/I, SIMPLE (2012), CRESST-II (2012), EDELWEISS (2011), CDMS (2010), and XENON100 (2011). The XENON100 (2012) observed limit is indicated with a blue line and a 90% confidence level (CL). The expected limit for this run is shown with green and yellow shaded regions, representing ±1σ and ±2σ expected, respectively.](image-url)
What XENON100 sees...
A light mass WIMP...

\[ m_\chi = 8 \text{ GeV/c}^2 \quad \sigma = 1.0 \times 10^{-4} \text{ cm}^2 \]
A CRESST-like signal...

$m_x = 25 \text{ GeV/c}^2 \quad \sigma = 1.6 \times 10^{-40} \text{ cm}^2$