Dark Matter: Evidence & Detection

Dark Matter 23%  
Atoms 4.6%  
Dark Energy 72%

NASA/WMAP

\[ E \sim O(10 \text{ keV}) \]

WIMP

\[ v \sim 230 \text{ km/s} \]

Direct Detection:
Elastic Scattering of WIMPs off target nuclei
\[ \rightarrow \text{nuclear recoil} \]

\[ E_R \sim O(10 \text{ keV}) \]
Where are we? Where do we go?

Experimental Results

WIMP Expectations

How do we get there?
WIMP Spectroscopy?

Assume the 2 events „seen“ by CDMS in 2009 would be WIMPs

*Science 327, 1619 (2010)*

What would existing LAr/LXe detectors see?

110 kg x 365 d x 50% acceptance

30 kg x 200 d x 50% acceptance
**DARWIN – Dark Matter WIMP Search with Noble Liquids**

- *R&D and Design Study* for a next generation noble liquid facility in Europe. Approved by ASPERA in late 2009
- Coordinate existing European activities in LXe and LAr towards a multi-ton Dark Matter facility
- Physics goal: probe WIMP cross sections well below $10^{-47}$ cm²
Science Goal
DARWIN is a Design Study for a next-to-next generation Dark Matter detection experiment based on LXe/LAr. Most technical requirements have not been defined yet. They are the outcome of the DARWIN study.
TPC Approach

- ionization/scintillation ratio ($S_2/S_1$) allows for electron recoil rejection
- 3D position reconstruction in TPC
- Multiscatter Rejection
- LAr: Pulse Shape Discrimination
DARWIN Consortium

ArDM, WARP, XENON + new Groups:
UZH (CH), INFN (I), ETHZ (CH), Subatech (F), Mainz (D), MPIK (D), Münster (D), Nikhef (NL), KIT (D), WIS (IS) + Columbia, Princeton, UCLA (USA)

Marc Schumann (U Zürich) – DARWIN

This talk presents contributions from many members

http://darwin.physik.uzh.ch
Structure

R&D and Design Study for
- Detector Infrastructure
- Light/Charge Readout
- Electronics/DAQ
- Underground / Shield Infrastructure
- Material Screening and Backgrounds
- Science Impact

The DARWIN proposal

Multiton LXe and/or LAr WIMP detector find best choice/design, exploit complementarity?
Optimal Ar / Xe Scaling

Optimization for 100 GeV/c² WIMP: Which scaling factor is required to give same number of events above threshold?
Realistic: Scaling Factor 2

Scaling factor 2:

Assumptions here:

- 20 t LAr → 10 t fiducial mass
- 8 t LXe → 5 t fiducial mass

in a Cerenkov water shield
Sensitivity vs. Background

calculations use already achieved values for background, acceptance energy threshold (10 keVr / 30 keVr), and background rejection (99.5% / 3x10^{-7})

Challenges:
- Background must be 10³ lower than now
- Kr85 must be reduced down to 1 ppt level
- pp-neutrino background (ER)?

Challenges:
- background is dominated by Ar39
- depleted Ar gives factor ~25 reduction
- need >10x better PSA rejection (even with depleted Ar)
Sensitivity vs. Background

Challenges:
- Background must be $10^3$ lower than now
- Kr85 must be reduced down to 1 ppt level
- pp-neutrino background (ER)?

Marc Schumann (U Zürich) – DARWIN
Laboratory and Shield

Backgrounds are currently studied for 2 sites:

- **LSM (F)**
  - ULYSSE

- **LNGS (I)**

Several shielding options:

- Compact liquid scintillator
- Cerenkov water shield
R&D: Light Readout

• **Photodetectors**
  (a) large area PMTs
  - low radioactivity
  - high QE, high collection efficiency
  - operation at cryogenic temperatures
  (b) hybrid detectors with large cathode and solid state e-multiplier (QUPID)
  - extremely low radioactivity
  - for LXe and LAr

• **UV light collection**
  (a) co-doping of Ar with Xe (→ shift light emission)
  (b) LAr: wavelength shifters, coating of light sensors
  (c) surface properties of materials (reflection, diffusion)
  (d) 4 geometry: challenges? Light guides?

„Classic“ Approach:
The same photosensors detect S1 (light) and S2 (charge) signal.
R&D: Photosensors

**QUPID** for LXe and LAr
Quartz Photon Intensifying Detector
- developed by UCLA group (Arisaka/Wang)
- very low radioactivity
  APD, quartz, no voltage divider
- ongoing tests and R&D at UCLA

Hamamatsu
R11410 / R11065
3“ PMT, high gain
LXe/LAr operation
low radioactivity

Marc Schumann (U Zürich) – DARWIN
R&D: Scintillation Properties

\[ L_{\text{eff}}(E_{\text{nr}}) = \frac{LY(E_{\text{nr}})}{LY(E_{\text{ee}} = 122 \text{ keV})} \]

new measurement @ Columbia:
\textit{arXiv:1104.2587 (2011)}

\( \text{LY}=20 \text{ PE/keV} \)

LXe response to low \( E_{\gamma} \) @ UZH

\( \text{LY}=20 \text{ PE/keV} \)

@ 122 keV
R&D: Charge Readout

- **Idea:**
  - good position resolution for signal / background discrimination
  - charge cloud in TPC is very localized (<1 mm)
  - large scale charge readout structures can keep this information
  - cost

**Goal:** Investigate and develop new concepts for readout of ionization produced by keV energy events, independent of scintillation readout.

- **Approach:**
  (a) Large cryogenic LEM / THGEM / Micromegas for noble liquids
      → charge amplification in holes
  (b) Gaseous PMTs without dead zone
      → MgF$_4$ window because of quencher
  (c) CMOS pixel detector coupled to electron multipliers (GridPix)
      → low radioactivity is possible
Summary

• **DARWIN**: a multiton LXe/LAr detector to explore cross sections below $10^{-47}$ cm²
• design study approved by ASPERA, timeline 2010 — end 2012
• outcome will be a proposal for the DARWIN facility

**Technical Challenges:**
- lowest background
- lowest threshold
- high discrimination
- large number of channels
- high sensitivity (QE)
- large area sensors

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