Direct detection and the neutrino floor

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Outline

• Neutrino backgrounds

• Mapping the neutrino floor

• Strategies

Based on
C.A.J. O'Hare, J. Billard, E. Figueroa-Feliciano, A. Green & L. Strigari [1505.08061]
C.A.J. O'Hare [1604.03858]
C.A.J. O'Hare & A. Green [in prep.]
Neutrino backgrounds

Solar

Diffuse supernova background

Atmospheric
Neutrino backgrounds

Coherent neutrino-nucleus scattering rates on a Xenon target:

- Solar
- Supernova
- Atmospheric

Recoil energy [keV]

Recoil rate [ton^{-1} year^{-1} keV^{-1}]

8B neutrinos
6 GeV WIMP
Complete Xenon neutrino floor

CAJ O'Hare [1604.03858]
Neutrino flux uncertainty

“floor” depends on flux uncertainty used in calculation

SI discovery limit @ 6 GeV [cm²]

F. Ruppin et al [1408.3581]

CDMSlite (2015)

Xenon100 (2012)

LUX (2013)

8B Flux uncertainty:

- 1%
- 2%
- 5%
- 10%
- 20%

Exposure [ton-year]

TeVPA Sep 2016

Ciaran O'Hare
Neutrino floor calculation with uncertainties placed on:
- Local density, $\rho_0$
- Solar rotation speed, $v_0$
- Escape velocity, $v_{esc}$

- 1 ton-year
- 10 ton-years

Low: $\sigma_{\rho_0} = 0.01 \text{ GeV cm}^{-3}$
  $\sigma_{v_0} = 10 \text{ km s}^{-1}$
  $\sigma_{v_{esc}} = 10 \text{ km s}^{-1}$

Med: $\sigma_{\rho_0} = 0.05 \text{ GeV cm}^{-3}$
  $\sigma_{v_0} = 40 \text{ km s}^{-1}$
  $\sigma_{v_{esc}} = 40 \text{ km s}^{-1}$

High: $\sigma_{\rho_0} = 0.1 \text{ GeV cm}^{-3}$
  $\sigma_{v_0} = 60 \text{ km s}^{-1}$
  $\sigma_{v_{esc}} = 50 \text{ km s}^{-1}$

No uncertainties

TeVPA Sep 2016
Strategies for the neutrino floor

- Need detectors >100 tons to probe below neutrino saturation
- Improving neutrino flux calculations/measurements can *delay* onset of floor
- What about target complementarity? F. Ruppin *et al* [1408.3581]

[Plots stolen from J. Billard]

**SD (proton) discovery limit @ 6 GeV [cm²]**

- Xe
- Xe+Ge
- Xe+Ge+Si

**SI discovery limit @ 6 GeV [cm²]**

- X 3
- X 50
Strategies for the neutrino floor

- Use distinguishing features of dark matter signal:
  - Annual modulation J. Davis [1407.1052]
  - Direction dependence P. Grothaus et al [1406.5047], CAJ O'Hare et al [1505.08061]
Directional signatures

- Sun does not coincide with peak WIMP direction at any time
- It should be possible to distinguish the two signals with direction:

**Sep. 6\textsuperscript{th}**
Max. separation between WIMP and neutrinos

**Feb. 26\textsuperscript{th}**
Min. separation between WIMP and neutrinos

\[ \text{0 - 1.6 keV} \quad \text{1.6 - 3.3 keV} \quad \text{3.3 - 5 keV} \]

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Directional detection

e.g. Low pressure gas time projection chamber

- **3D readout**: full recoil track \((x, y, z)\)
- **2D readout**: projection on anode \((x, y)\)
- **1D readout**: projection along drift direction \((z)\)
Comparing readout strategies

Evolution of discovery limit @ 6 GeV as a function of detector mass:

CAJ O'Hare et al [1505.08061]
Comparing readout strategies

![Graph comparing WIMP-nucleon cross section vs. WIMP mass](image)

- CDMSlite (2015)
- LUX (2012)
- Exposure = 10 tons x 1 year

- Counting
- Time
- Energy

1D, 2D, 3D
Hemispherical detector
(preliminary)

Can only measure directionality down to hemispheres

Stationary:

Solar ν recoils scatter 0 - 90 deg. from Solar direction → always have hemisphere with no Solar ν background
Hemispherical detector
(placeholder)

Detector mass [ton]

SI discovery limit at 6 GeV [cm^{-2}]

Energy+Time only

Hemisphere directional (stationary)

Hemisphere directional (Solar tracking)

Full 3D directional
Summary

Neutrino floor not the final limit to direct detection searches

• There are various strategies for probing below the floor
  ➔ Better neutrino flux estimates
  ➔ Larger detectors
  ➔ Target complementarity
  ➔ Annual modulation
  ➔ Directional detection
Strategies for the neutrino floor

- >100 ton detectors
- Target complementarity (SI)
- Target complementarity (SD)
- Directionality: 3D, 2D, 1D, Hemisphere(?)
- Better flux measurements

NB: “difficulty” axis somewhat subjective
Bonus slides
Coherent neutrino-nucleus scattering

\[ \frac{d\sigma}{dE_r} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r) \]

\[ \frac{dR}{dE_r} = \int_{E_\nu^{\text{min}}}^{\infty} \frac{d\sigma}{dE_r} \times \frac{d\phi}{dE_\nu} dE_\nu \]

Differential event rate

**Cross-section**
- Flavour-blind neutral current
- Standard model

Neutrino flux
Neutrino floor with different speed distributions

- Dashed: 1 ton-yr
- Solid: 10 ton-yr

\[ f_{SHM}(v) \propto e^{-v^2/v_0^2} \]
\[ f_{DPL}(v) \propto \left[ \exp \left( -\frac{v_{esc}^2 - v^2}{kv_0^2} \right) - 1 \right]^k \]
\[ f_{Tsallis}(v) \propto \left[ 1 - (1-q)\frac{v^2}{v_0^2} \right]^{1/(1-q)} \]
\[ f_{Mao}(v) \propto e^{-v/v_0} \left( v_{esc}^2 - v^2 \right)^p \]

[ between 0 and \( v_{esc} \) ]

CAJ O'Hare [1604.03858]
Projected angular pdfs

3D readout:

2D readout:

1D readout:
Sense recognition

CAJO, Billard, Green, Figueroa-Feliciano, Strigari arXiv:1505.08061

![Graph showing WIMP-nucleon cross section vs. WIMP mass]

- **3D no sense recognition**
- **3D**
- **2D no sense recognition**
- **2D**
- **1D no sense recognition**
- **1D**

- **$E_{th} = 0.1 \text{ keV}$**
  - **$M = 0.1 \text{ ton}$**
- **$E_{th} = 5 \text{ keV}$**
  - **$M = 10^4 \text{ ton}$**
Angular resolution

CAJO, Billard, Green, Figueroa-Feliciano, Strigari arXiv:1505.08061

\[ E_{th} = 0.1 \text{ keV} \quad M = 0.1 \text{ ton} \]

\[ E_{th} = 5 \text{ keV} \quad M = 10^4 \text{ ton} \]