Astroparticle Physics I: Experiments for direct WIMP detection

R.N. Caballero - IMPRS A&A retreat 2011, Hamburg
• Part I (Nicolas): Experiments for direct detection of WIMPs

• Part II (Jana): Cosmic Rays Observations

• Part III (Cherry):
  • Astroparticle physics and pulsars
Weakly Interacting Massive Particles (WIMPs)

- Interaction through weak force
- Mass: $1 \text{ Kev} \leq M \leq 300 \text{ TeV} \ (\sim 100 \text{ GeV})$
  $(M_{\text{H}_2}=1\text{GeV}, \ M_{\text{U}} \sim 240 \text{ GeV})$
- Velocity (Galactic WIMPs): $\sim 300 \text{ km s}^{-1}$
Weakly Interacting Massive Particles (WIMPs)

- Principle: WIMP/detector particle elastic collision
- Energy transfer to medium
- Important: cross-sections, expected event rates
- Tests with neutron collisions
Cryogenic Dark Matter Search (CDMS)

• Direct Detection: WIMP interaction with fermions in detector


• Cross-section (elastic scattering with fermions, today)
  \(10^{-38} \text{ cm}^2\)

• Event Rate \(\sim 0.1 \text{ kg}^{-1} \text{ day}^{-1}\)

\(\Rightarrow\) Needs:
Large detector mass,
Extremely low rate of background noise (low T)
Cryogenic Dark Matter Search (CDMS)

The CDMS experiments:

Detector: Cryogenic Ge/Si crystals

Cryogen: $^3\text{He}/^4\text{He}$ Dilution Refrigerator (5-10 mK)

Physical Quantity Measured: Energy deposited in crystal by interaction

Means of Measurement: Change in conductivity of
Cryogenic Dark Matter Search (CDMS)

The CDMS experiments:

Detector: Cryogenic Ge/Si crystals
Cryogen: $^3\text{He}/^4\text{He}$ Dilution Refrigerator (5-10 mK)

Physical Quantity Measured: Energy deposited in crystal by interaction

Means of Measurement: Change in conductivity of
Cryogenic Dark Matter Search (CDMS)

Detector: Cryogenic Ge/Si crystals

Cryogen: $^3\text{He}/^4\text{He}$ Dilution Refrigerator (5-10 mK)

Physical Quantity Measured: Energy deposited in crystal by interaction

Means of Measurement: Change in conductivity of
Cryogenic Dark Matter Search

The CDMS experiments:

- **Detector:** Cryogenic Ge/Si crystals
- **Cryogen:** $^3$He/$^4$He Dilution Refrigerator (5-10 mK)

**Physical Quantity Measured**: Energy deposited in crystal by interaction

**Means of Measurement**: Change in conductivity of Refrigerator (5-10 mK)

... Energy deposited in change in conductivity of...
Cryogenic Dark Matter Search (CDMS)

The CDMS experiments:
- Detector: Cryogenic Ge/Si crystals
- Cryogen: $^{3}$He/$^{4}$He Dilution Refrigerator (5-10 mK)
- Physical Quantity Measured: Energy deposited in crystal by interaction
- Means of Measurement: Change in conductivity of
Cryogenic Dark Matter Search (CDMS)
Cryogenic Dark Matter Search (CDMS)

(1) WIMP collides with detector nucleus
Cryogenic Dark Matter Search (CDMS)

(1) WIMP collides with detector nucleus
(2) Vibration: Phonons propagation through crystal
Cryogenic Dark Matter Search (CDMS)

1. WIMP collides with detector nucleus
2. Vibration: Phonons propagation through crystal
3. Some phonons reach the detector surface
Cryogenic Dark Matter Search (CDMS)

(1) WIMP collides with detector nucleus
(2) Vibration: Phonons propagation through crystal
(3) Some phonons reach the detector surface
(4) Phonons absorbed by Al collector fins
Cryogenic Dark Matter Search (CDMS)

(1) WIMP collides with detector nucleus
(2) Vibration: Phonons propagation through crystal
(3) Some phonons reach the detector surface
(4) Phonons absorbed by Al collector fins
(5) Phonon energy $\rightarrow$ to quasi-particles=$e^-$ in super-conducting Cooper pair/ pair breaks
Cryogenic Dark Matter Search (CDMS)

(1) WIMP collides with detector nucleus
(2) Vibration: Phonons propagation through crystal
(3) Some phonons reach the detector surface
(4) Phonons absorbed by Al collector fins
(5) Phonon energy → to quasi-particles=$e^-$ in super-conducting Cooper pair/ pair breaks
(6) $e^-$ migrate to W strip
Cryogenic Dark Matter Search (CDMS)

1. WIMP collides with detector nucleus
2. Vibration: Phonons propagation through crystal
3. Some phonons reach the detector surface
4. Phonons absorbed by Al collector fins
5. Phonon energy $\rightarrow$ to quasi-particles=$e^-$ in super-conducting Cooper pair/ pair breaks
6. $e^-$ migrate to W strip
Cryogenic Dark Matter Search (CDMS)

1. WIMP collides with detector nucleus
2. Vibration: Phonons propagation through crystal
3. Some phonons reach the detector surface
4. Phonons absorbed by Al collector fins
5. Phonon energy → to quasi-particles=$e^-$ in super-conducting Cooper pair/ pair breaks
6. $e^-$ migrate to W strip
7. Excess current pushes W from superconductor state back to conductor ⇒ dramatic change in the W electrical resistance
Directional Recoil Identification from Tracks (DRIFT)

- Direct Detection: WIMP interaction with low pressure gas molecules in detector (e.g. CF₄ /CS₂ mixture)

Needs:
Large detector mass,
Extremely low rate of background noise (low T)
Directional Recoil Identification from Tracks (DRIFT)
Directional Recoil Identification from Tracks (DRIFT)

(1) WIMP collides with target gas nucleus $\rightarrow$ nucleus recoil
Directional Recoil Identification from Tracks (DRIFT)

(1) WIMP collides with target gas nucleus $\rightarrow$ nucleus recoil
(2) Recoil nucleus/molecule ionises gas (CF$_4$)
Directional Recoil Identification from Tracks (DRIFT)

1. WIMP collides with target gas nucleus → nucleus recoil
2. Recoil nucleus/molecule ionises gas (CF$_4$)
3. Path of free $e^-$ in the gas
Directional Recoil Identification from Tracks (DRIFT)

(1) WIMP collides with target gas nucleus → nucleus recoil
(2) Recoil nucleus/molecule ionises gas (CF$_4$)
(3) ⇒ Path of free e$^-$ in the gas
(4) Free e$^-$ are attached by electronegative CS$_2$ molecules ⇒ CS$_2^-$ ions track
Directional Recoil Identification from Tracks (DRIFT)

1. WIMP collides with target gas nucleus → nucleus recoil
2. Recoil nucleus/molecule ionises gas (CF₄)
3. ⇒ Path of free e⁻ in the gas
4. Free e⁻ are attached by electronegative CS₂ molecules ⇒ CS₂⁻ ions track
5. Applied E field makes CS₂⁻ ions drift to the readout plane
Directional Recoil Identification from Tracks (DRIFT)

1. WIMP collides with target gas nucleus → nucleus recoil
2. Recoil nucleus/molecule ionises gas (CF₄)
3. Path of free e⁻ in the gas
4. Free e⁻ are attached by electronegative CS₂ molecules ⇒ CS₂⁻ ions track
5. Applied E field makes CS₂⁻ ions drift to the readout plane
6. Large mass of ion (vs e⁻ mass) ⇒ the original track structure maintained
Directional Recoil Identification from Tracks (DRIFT)

(1) WIMP collides with target gas nucleus → nucleus recoil
(2) Recoil nucleus/molecule ionises gas (CF$_4$)
(3) ⇒ Path of free e$^-$ in the gas
(4) Free e$^-$ are attached by electronegative CS$_2$ molecules ⇒ CS$_2^-$ ions track
(5) Applied E field makes CS$_2^-$ ions drift to the readout plane
(6) Large mass of ion (vs e$^-$ mass) ⇒ the original track structure maintained
(7) High directional sensitivity
WIMP Argon Programme (WARP)

Dark matter detection through scintillation:

Detector: cryogenic noble liquid (Ar, Xe)
Allows ionisation & scintillation detection

Cryogen: external liquid Argon bath (~ 87 K)

Physical Quantity Measured: energy deposited in medium by recoil

Means of Measurement: Scintillation light
WIMP Argon Programme (WARP)
WIMP Argon Programme (WARP)

(1) WIMP collides with target gas nucleus → nucleus recoil
WIMP Argon Programme (WARP)

1. WIMP collides with target gas nucleus → nucleus recoil
2. Recoil nucleus/ excitation-ionisation of atoms
WIMP Argon Programme (WARP)

1. WIMP collides with target gas nucleus → nucleus recoil
2. Recoil nucleus/excitation-ionisation of atoms
3. De-excitations, re-combinations ⇒ primary scintillation signal
WIMP Argon Programme (WARP)

1. WIMP collides with target gas nucleus → nucleus recoil
2. Recoil nucleus/ excitation-ionisation of atoms
3. De-excitations, re-combinations ⇒ primary scintillation signal
4. Applied E field ⇒ free e⁻ go to gas
WIMP Argon Programme (WARP)

1. WIMP collides with target gas nucleus → nucleus recoil
2. Recoil nucleus/excitation-ionisation of atoms
3. De-excitations, re-combinations ⇒ primary scintillation signal
4. Applied E field ⇒ free e⁻ go to gas
5. e⁻ accelerated, collide with gas atoms ⇒ secondary scintillation signal
WIMP Argon Programme (WARP)

1. WIMP collides with target gas nucleus → nucleus recoil
2. Recoil nucleus/ excitation-ionisation of atoms
3. De-excitations, re-combinations ⇒ primary scintillation signal
4. Applied E field ⇒ free e⁻ go to gas
5. e⁻ accelerated, collide with gas atoms ⇒ secondary scintillation signal
6. primary/secondary are dependent on the nature of the kind of impinging particle.
Results so far
Also, Axions are searched...

CAST (CERN)

ADMX (Washington)
Thanks!