Looking for WIMPs: Dark Matter Relics from the Big Bang

Dan Akerib
Case Western Reserve University
and
CDMS Collaboration

Dark Matter: the Missing Mass Problem

Speed of orbits
→ Strength of Gravity
→ Missing Mass
Looking for Wimps  (KITP Teachers Conference 10/05/02)

Other ways to ‘see’ it – gravitational lens

Mass warps space,  
Lensing indicates  
strength of gravity  
→ dark matter!

What is it? Extraordinary stuff!

• Early Universe as Particle Factory
  ♦ Not enough protons and neutrons produced in the Big Bang
  Convert energy to mass

E=mc²

• A new type of particle: WIMPs = weakly interacting massive particles
  Massive: source of gravity  Weakly-interacting: not star forming
Still around?

Expanding Universe and Weak Interactions – annihilations stop

WIMPs in the Galactic Halo

WIMPs – the source of Mass in the Rotation Curves?

WIMP-Nucleus Scattering

Scatter from a Nucleus in a Terrestrial Particle Detector

Big Problem: weakly interacting. Expect less than one-a-day in a kilogram detector
In physics, we measure voltages...

Particle Detection

It’s simple – detected particle ionizes the gas, collect the charge...

Or detected particle produces a flash of light, which is converted to ‘photoelectrons’...

Or detected particle interacts with a nucleus, which ionizes the gas, which...

Or...

Background Radioactivity
It’s in the air: a practical demonstration

Before…

It’s in the air: a practical demonstration

During…
It’s in the air: a practical demonstration

After...

What nature has to offer

What you hope for!
Getting rid of the haystack

WIMPs ‘look’ different
Photons and electrons collide with electrons
WIMPs (and neutrons) collide with nuclei

\[ E_{\text{charge}} \]
\[ E_{\text{thermal}} \]

Background

Signal

Charge Yield

\[ E_{\text{recoil}} \]

\[ \text{Recoil Energy [keV]} \]

CDMS detectors

- Heat sensitive detectors sensitive to individual particle interactions.
- Operated near absolute zero ("cryogenic")
- Our experiment is called the Cryogenic Dark Matter Search (CDMS)

The detectors are cooled in special refrigerators using liquid nitrogen and liquid helium
Superconducting Films: Ultrasensitive Thermometers

Superconducting films that detect minute amounts of heat

\[ R_{\text{TE}} (\Omega) \]

\[ T_c \sim 80 \text{mK} \]

The Voltages We Measure

The voltages we measure include heat and charge.

\[ V_{\text{bias}} \]

SQUID array

Phonon D

R

feedback

Heat

Charge

Charge/Heat
CDMS Strategy

Lines of defense

- Underground site: hadrons, \( \mu \)
- Muon veto: cosmogenic \( \gamma, \beta, n \)
- Pb shield: \( \gamma, \beta \)
- Poly shield: \( n \)
- Recoil type: \( \gamma, \beta \)
- Multiple-scatters: \( n \)
- Position sensitive

CDMS Data 1999

The detectors were exposed for a period of several months. The circled blue dots could be WIMP candidates, but we believe most or all of them are due to neutrons.

Preparing a more sensitive experiment (CDMS II) to start running next year.
Looking for Wimps  (KITP Teachers Conference 10/05/02)

19

Neutrons: Single Scatters vs Multiple Scatters

Single-scatter nuclear-recoils are produced by WIMPs or neutrons.

Multiple-scatter nuclear-recoils are only produced by neutrons.

4 multiple-scatters are observed – more than enough to account for 13 single-scatters.

Limits on WIMP Size*

To quantify our non-detection of WIMPs for comparison with other experiments and theoretical predictions, a statistical analysis is performed. For each possible WIMP mass, we determine the largest WIMP size* that could have gone undetected in the data. The regions above the U-shaped curves are ruled out by various techniques.

The shaded/dotted regions are predictions from particle physics theories.

*Technically, these are point-like particles – by “size” we really mean a measure of the probability they will scatter from a nucleus. This probability is quantified by an effective “cross sectional” area.
Looking for Wimps  (KITP Teachers Conference 10/05/02)

Daniel Akerib, Case Western Reserve University

DAMA NaI Experiment

100x detector mass of CDMS, but living with the ‘haystack!’
58,000 kg-days exposure (4 years)

See annual modulation signal!

Interesting Times…

CDMS after background subtraction

Amplitude of DAMA’s modulation predicts significantly larger signal than observed in CDMS – only 1/1000 chance of a statistical fluctuation

The best simultaneous fit is shown in red – too small to explain DAMA’s amplitude but too large to go unseen in CDMS.

DAMA 4 year data set
Looking for Wimps  (KITP Teachers Conference 10/05/02)

CDMS II in the Soudan Mine

Depth of 2000 mwe reduces neutron background from ~1 / kg / day to ~1 / kg / year

The CDMS II Apparatus

- Eventually we will build 7 stacks of 6 detectors each and install them in the Soudan Mine
The CDMS II Apparatus (cont’d)

The Soudan Mine refrigerator includes a low-radioactivity ‘clean room’ shielded environment (partially shielded in the photo).

Working at Soudan

Let's go to the video!

Starring CWRU graduate students

Don Driscoll
Gensheng Wang

Production and Editing
Kevin Barron  Craig Kunimoto

of KITP

Credits by yours truly…
Looking ahead: curves, curves, and more curves

WIMP-Nucleon Cross-Section [cm$^2$]

WIMP Mass [GeV/c$^2$]

The CDMS Collaboration

...at a recent collaboration meeting, 2000 feet underground
The CDMS Collaboration

Case Western Reserve University
D.S. Akerib, D. Driscoll, S. Kamat,
T.A. Perera, R.W. Schnee, G. Wang
Fermi National Accelerator Laboratory
M. Crisler, R. Dixon, D. Holmgren
Lawrence Berkeley National Lab
R.J. McDonald, R.R. Ross,
A. Smith
Nat'l Institute of Standards & Tech.
J. Martinis
Princeton University
T. Shutt
University of Minnesota
P. Cushman, L. Duong, A. Riesetter
Santa Clara University
B.A. Young

Stanford University
L. Baudis, P.L. Brink, B. Cabrera,
C. Chang, T. Saab, W. Ogburn
University of California, Berkeley
S. Armel, V. Mandic, P. Meunier,
W. Rau, B. Sadoulet, A. Lu
University of California, Santa Barbara
D.A. Bauer, R. Bunker, D. O. Caldwell,
C. Savage, H. Nelson, J. Sander,
R. Mahapatra, R. Nelson, S. Yellin
University of Colorado at Denver
M. E. Huber
Brown University
R.J. Gaitskell, J.P. Thompson,
M. Attisha

And with support from the US Department of Energy and the National Science Foundation

The Soudan Mine: Northern Minnesota

QUIZ:

- What season is it?
- Which one of us is British?
- Which one of us went to Russia last year?
  (That's a whole different story...)
Thank you…

visit us on the web at cdms.cwru.edu

Missing Mass: the Search for WIMPs

The Cryogenic Dark Matter Search (CDMS) Collaboration

Case Western Reserve University
Fermi National Accelerator Laboratory
M. Crisler, R. Dixon, D. Holmgren
Lawrence Berkeley National Lab
R. J. McDonald, R. R. Ross, A. Smith
Nat’l Institute of Standards & Tech.
J. Martinis
Princeton University
T. Shutt
University of Minnesota
P. Cushman, L. Duong, A. Riesetter
Santa Clara University
B. A. Young

Stanford University
L. Baudis, P. L. Brink, B. Cabrera, C. Chang, T. Saab, W. Ogburn
University of California, Berkeley
S. Armel, V. Mandic, P. Meunier, W. Rau, B. Sadoulet, A. Lu
University of California, Santa Barbara
University of Colorado at Denver
M. E. Huber
Brown University
R. J. Gaitskell, J. P. Thompson, M. Attisha
The plan for today

- A little astrophysics
- A little particle physics
- Our experiment to look for dark matter
- Along the way…
  - What is particle-astrophysics?
  - What is it like to pursue a career in science?
- Please stop and ask questions!

ZIP Detectors

- Z-sensitive Ionization and Phonon Detectors

Technology involves Transition Edge Sensors (TES), trapping of quasiparticles, and SQUID arrays
- Position information (xy and z) due to collecting phonons on faster time scale
Looking for Wimps  (KITP Teachers Conference 10/05/02)

The CDMS I Experiment

The thermal measurement requires that the detectors be ultra-cold. They are maintained at a temperature of 10 milli-Kelvin by a dilution refrigerator. Because the rate for WIMP scattering is so low, the experiment must also be carefully designed for background suppression: high-purity materials with low radioactivity, shielding against external radiation, an underground site to reduce the flux of cosmic radiation, and a veto to detect residual cosmic rays.

CDMS Refrigerators

In our lab at CWRU, open... closed... and in the Soudan Mine.

The Soudan refrigerator includes a low-radioactivity shielded environment (partially shielded in the photo).
Looking for Wimps (KITP Teachers Conference 10/05/02)

Working at Soudan

[Image of people working in a laboratory setting]

[Image of two people standing in front of a large cylindrical object]
Looking Ahead

The next step for CDMS

- Larger array & longer exposure
- Second generation detectors with event positions
- Deeper site for further reduction in cosmic-ray background

Soudan Mine, Northern Minnesota
2300' depth

MINOS
CDMS II
Soudan II

Sensitivity goals of future experiments