A Known Unknown: Directly Detecting the Missing Mass of the Universe

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see information (and copy of talk) at
http://particleastro.brown.edu/
http://cdms.brown.edu/  http://xenon.brown.edu/
Rick Gaitskell, Introduction

- Particle Astrophysics Group, Dept of Physics, Brown University
  - Brown Faculty for 4 years (Associate Professor). Previously at University College, London / UC Berkeley, Center for Particle Astrophysics / Oxford University
  - 15 years searching for Dark Matter in the form of WIMPs
    - CDMS I/II Cryogenic Dark Matter Search Experiment
      - Currently is most sensitive WIMP search
    - XENON: Next generation search experiment (Deploy Fall 2005)
The geocentric pre-Copernican Universe in Christian Europe. At center, Earth is divided into Heaven (tan) and Hell (brown). The elements water (green), air (blue) and fire (red) surround the Earth. Moving outward, concentrically, are the spheres containing the seven planets, the Moon and the Sun, as well as the "Twelve Orders of the Blessed Spirits," the Cherubim and the Seraphim. German manuscript, c. 1450.

From Joel Primack, UC Santa Cruz
Confession

>95% of the Composition of the Universe is still unknown
Known Unknowns

• “As we know,
  There are known knowns.  
  There are things we know we know. 
  We also know
  There are known unknowns. 
  That is to say 
  We know there are some things 
  We do not know. 
  But there are also unknown unknowns, 
  The ones we don't know 
  We don't know."

• -- Donald Rumsfeld, Secretary of Defense, 
  February 12, 2002, Department of Defense news briefing
Introduction

• --> 1990’s For many a “known known” was that $\Omega_{\text{Total}} = 1$
  - This being matter dominated, $\Omega_m = 1$
• We have had to revise this view partially: $\Omega_{\text{Total}} = 1$, but $\Omega_m \sim 0.3$
  - Dark Matter now has to share the shadows with Dark Energy
  - Indeed it is convenient to split into 3 Dark Problems
    • Baryonic Dark Matter - Mostly known
    • Non-Baryonic Dark Matter - Known Unknown
    • Dark Energy - Only God knows, right now
• It has been a Problem in Cosmology that astrophysical assumptions often need to be made to interpret data/extra parameters
  - Now many independent/increasingly precise techniques are being used
  - This now enables disentanglement of “Gastrophysics”
• Ultimately new solutions will be related to Fundamental/Particle Physics
  - Non-baryonic dark matter - New Particles - SUSY, neutrinos, baryogenesis
  - Dark Energy - Gravity / Extra Dimensions
\[ \Omega \quad \text{(Plot assumes Hubble Constant 70 km/s / Mpc (h \sim 0.7))} \]

Structure Formation washed out by relativistic particles (WMAP significantly lowers limit)

\[ \Omega \text{CMB photons} \sim 10^{-5} \]

Plots shows consensus in 2000

By 2004 Error bars have shrunk!

\[ \Omega_{\text{Total}} = \Omega_m + \Omega_{\Lambda} = 1.02 \pm 0.02 \]
\[ \Omega_m = 0.27 \pm 0.02 \]
\[ \Omega_{\Lambda} = 0.73 \pm 0.04 \]
\[ \Omega_b = 0.046 \pm 0.001 \]
\[ \Omega_{\nu} < 0.0076 \]

\[ \rho_c = \frac{3H_0^2}{8\pi G} \approx 1.19h^2 \text{ GeV}^{-2}\text{m}^{-3} \]

\[ \Omega_x = \frac{\rho}{\rho_c} \]
**WMAP/CMB: 1st Year data: Best fit cosmological model**

Greg Tucker (Brown)

\[
\begin{align*}
\Omega_{\text{tot}} &= 1.02 \pm 0.02 \\
\Omega_m &= 0.27 \pm 0.04 \\
\Omega_b &= 0.044 \pm 0.004 \\
\Omega_{\Lambda} &= 0.73 \pm 0.04 \\
 h &= 0.71 \pm 0.04 - 0.03
\end{align*}
\]

consistent with data from
HST Key project
weak lensing
D measurements
LSS (2dFGRS/SDSS)
Type Ia SN

\[
\lambda \sim k^1
\]

\[
\theta \sim t^1
\]

\[
z = 1000
\]

**Observer**

**Last scattering surface**

**Cold Dark Matter theory**

**Data**

- WMAP
- CBI
- ACBAR

**COBE >7 deg**

**WMAP**

**Foreground-cleaned WMAP map from Tegmark, de Oliveira-Costa & Hamilton, astro-ph/0302496**

Greg Tucker (Brown)
Differing models of Universe varying $\Omega_\Lambda$ and $\Omega_m$ while $\Omega_\Lambda + \Omega_m = 1$.
Dark Matter Dynamical Evidence: Individual Galactic Halos

Spiral Galaxies

Doppler shifts of 21-cm H emission line data

\[ F_{\text{centripetal}} = F_{\text{gravity}} \]

\[ \frac{m v_r^2}{r} = \frac{G m M_{\text{total}}(r)}{r^2} \]

\[ v_r = \sqrt{\frac{G M_{\text{total}}(r)}{r}} \]

\[ \frac{M(r)}{r} \rightarrow \text{const} \quad (r \gg r_{\text{core}}) \]

A self gravitating ball of ideal gas at a uniform temperature would have such a profile (e.g. see J Binney and S Tremaine, Galactic Dynamics, Princeton UP, 1988)

\[ M_{\text{dark}} \geq 10 M_{\text{stars}} \]

However, mass from summing all galactic halos only set lower limit \( \Omega_m > 0.02 \)

NEED TO PROBE LARGER SCALES INTER-GALACTIC
Inter-Galactic Scales

1920’s Hubble establishes (using Cepheid variable stars) that spiral nebulae (M31) well outside Milky Way

Subsequent surveys: Average Galaxy spacing ~1 Mpc

- How far out do the galactic dark halos extend?

It is apparent that the spatial distribution of galaxies shows range of structure

- Small Clusters e.g. “Local Group” MW + M31 (Andromeda, 0.8 Mpc) + ~12 smaller galaxies (include Large / Small Magellanic Clouds)
- Rich Clusters e.g. Virgo or Coma clusters, 1000’s galaxies in few Mpc

1 pc = 3.26 light-years
Galactic Velocity Dispersion in Clusters

- Velocities of galaxies in galactic clusters
  - 1936 Fritz Zwicky - first measurement => Dark Matter
    - Measured Velocity Dispersion via Doppler Redshift of 8 galaxies in Coma Cluster
    - Velocities too high to be provided by gravitational potential from luminous matter alone ($m_{\text{lum}} \approx 0.5\%$ of required)
  - Expect Virialized Velocities
    \[ \langle KE \rangle = -\frac{1}{2} \langle PE \rangle \]
  - Modern Results - similar (earlier data did have syst.)
Measurement of Cluster Mass by Strong Lensing

- If the deflection angle is large there are multiple images - strong lensing
- Requires close alignment of source and center of lens distn e.g. CL0024+1654
  - Foreground galaxy cluster z=0.39 (false yellow = Near Infrared)
  - Background galaxy source z=1.6 (blue, color due to star formation, young galaxy)
    - Einstein Ring ~100 kpc radius @ z=0.39
  - Mass Distribution deconvolved from Hubble Image (galaxies=spikes, DM=hump dominant mass)
Dark Matter Halo Simulations

- Dark Matter Halo Sim $z=10 \rightarrow 0$
  - Non-linear, hence numerics
  - Each point is $\sim 10^9 \, M_{\text{sun}}$
  - Galaxy is $\sim 10^{11} \, M_{\text{sun}}$

- Understanding smaller scale structure inside galactic halos
  - remains a challenge for both observation and simulation

J. Diemand, J. Stadel and B. Moore, U. Zurich
http://krone.physik.unizh.ch/~diemand/clusters/
(Λ)CDM Best Fits Observed Halo Structure

- **Cold Dark Matter**
  - Cold means at times of structure formation the particles are non relativistic
  - CDM simulations most closely map observed structure

- **Warm Dark Matter**
  - Compromise reasonably motivated in 1990’s to help fit Matter Power Spectrum, however, introduction of LCDM cosmology now makes this unnecessary

- **Hot Dark Matter**
  - e.g. Light Neutrinos
  - Streaming of relativistic particles washes out smaller scale structure
  - WMAP/LSS Provides hard upper limit
    \[ \Omega_\nu < 0.0076 \] (Spergel et al., 2003)
Summary of Evidence

- Concordance Model ($\Lambda$CDM) fits data extremely well
  - Seems probable that model will be around for sometime to come
  - Currently no good alternatives to it
    - Need to invent new ones!!

- >95% still unidentified, "Known Unknown"
  - General Properties known and allow precision fit of data
  - Concordance
  - Challenge will be discover physics that generates Dark Matter/Dark Energy
  - Why is Universe so & what created initial conditions?

$\Omega_{\text{Total}} = 1$
$\Omega_m = 1/3$
$\Omega_\Lambda = 2/3$
WIMPs - a Candidate for Non-Baryonic CDM

- A WIMP $\delta$ is like a massive neutrino: produced when $T >> m_\delta$ via annihilation through $Z$ (+other channels). Annihilation/pair creation maintain thermal equilibrium.

- If interaction rates high enough, comoving density drops as $\exp(-m_\delta/T)$ as $T$ drops below $m_\delta$: annihilation continues, production becomes suppressed.

- But, weakly interacting $\Rightarrow$ may freeze out before total annihilation if

  $$H > \Gamma_{\text{ann}} \sim n_\delta \langle \sigma_{\text{ann}} v \rangle$$

  i.e., if annihilation too slow to keep up with Hubble expansion

- Leaves a relic abundance:

  $$\Omega_\delta h^2 \approx 10^{-27} \text{ cm}^3 \text{ s}^{-1} / \langle \sigma_{\text{ann}} v \rangle_{\text{fr}}$$

  $\downarrow$

  if $m_\delta$ and $\sigma_{\text{ann}}$ determined by electroweak physics, then $\Omega_\delta \sim 1$
Direct Detection Astrophysics of WIMPs

• Energy spectrum & rate depend on WIMP distribution in Dark Matter Halo
  - “Spherical-cow” assumptions: isothermal and spherical, Maxwell-Boltzmann velocity distribution
  - $V_0 = 230 \text{ km/s}, \; v_{\text{esc}} = 650 \text{ km/s}$,
  - $\rho = 0.3 \text{ GeV/cm}^3$

• Energy spectrum of recoils is featureless exponential with $\langle E \rangle \sim 50 \text{ keV}$

• Rate (based on $\sigma_{n\chi}$ and $\rho$) is fewer than 1 event per kg material per week

“At any instant may contain ten 60-GeV WIMPs on average. 20 billion WIMPs may pass through each second.”

SUSY - Supersymmetry
What Nature has to Offer

What we hope for!
Dark Matter Experiments (Worldwide/affiliations) (Running/Active Collaboration)

>10 Experiments currently operating underground

- NaIAD
- ZEPLIN I
- ZEPLIN II
- ZEPLIN III
- DRIFT I
- CRESST II
- Edelweiss II
- France
- Germany
- HDMS/Genino
- Picasso
- Russia
- XMASS (DM)
- [LiF]
- Elegant V&VI
- US
- Canada
- IGEX
- Majorana (DM)
- ANAIS
- Rosebud
- Italy
- Cuoricino
- DAMA
- LIBRA
- Switzerland
- XeDAMA
- Italy
- Japan
- [LiF]
DM Direct Search Progress Over Time (->2004)

Gaitskell, Annual Reviews vol 54, 2004, in press
CDMS II Collaboration

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Sources of Background

Detectors must effectively discriminate between

- Nuclear Recoils (Neutrons, WIMPs)
- Electron Recoils (gammas, betas)

Use Ge and Si based detectors with two-fold interaction signature:

- Ionization signal
- Athermal phonon signal
Really Cool Detectors: ZIPs

- 250 g Ge or 100 g Si crystal
- 1 cm thick x 7.5 cm diameter
- Photolithographic patterning
- Collect athermal phonons:
  - XY position imaging
  - Surface (Z) event veto based on pulse shapes and timing

Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer edge

Z-sensitive Ionization and Phonon-mediated

1 μ tungsten
380μ x 60μ aluminum fins
Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil.

Most background sources (photons, electrons, alphas) produce electron recoils.

- 47k Photons (external source)
• Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil
• Most background sources (photons, electrons, alphas) produce electron recoils
• WIMPs (and neutrons) produce nuclear recoils
CDMS II Background Discrimination

- Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil
- Most background sources (photons, electrons, alphas) produce electron recoils
- WIMPs (and neutrons) produce nuclear recoils
- Detectors provide near-perfect event-by-event discrimination against otherwise dominant bulk electron-recoil backgrounds
CDMS II Background Discrimination

- Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil
  - Most background sources (photons, electrons, alphas) produce electron recoils
  - WIMPs (and neutrons) produce nuclear recoils
- Detectors provide near-perfect event-by-event discrimination against otherwise dominant bulk electron-recoil backgrounds
  - Particles (electrons) that interact in surface “dead layer” of detector result in reduced ionization yield
ZIP Z-Position Sensitivity Rejects Electrons

- Cut based on phonon-pulse risetime eliminates the otherwise troublesome background surface events
- >99% above 10 keV

![Graph showing Neutrons from $^{252}$Cf source and Surface-electron recoils (selected via nearest-neighbor multiple scatters from $^{60}$Co source) vs. (Single-scatter) photons from $^{60}$Co Source]
CDMS II at Stanford and at Soudan

• 2001-2002 run at shallow site
  ◆ 28 kg day exposure of 4x 250g Ge detectors (and 2x 100g Si detectors)
  ◆ 20 nuclear-recoil candidates consistent with expected neutron background *PRD 68:082002 (2003)*

  ![Graph showing Log(10) of Muon Flux vs Depth(meters water equivalent)](image)

  - 200 Hz muons in 4 m² shield
  - 1 per minute in 4 m² shield

• 2003-2005 in Soudan Mine, Minn.
  ◆ Depth 713 m (2090 mwe)
  ◆ Reduce neutron background from ~1 / kg / day to ~1 / kg / year

- Kamioka (Japan)
- Sudbury (Canada)
- Mont Blanc (France)
- Baksan (Russia)
- Kolar (India)
- Orovil (USA)
- Soudan (USA)
- Gran Sasso (Italy)
- Boulby (UK)
- Frejus (France)
Experimental Setup in the Soudan Mine
Shielding from Backgrounds at Soudan

- Active scintillator veto, polyethylene and lead shielding, and radon purge reduce backgrounds from muons, neutrons and photons.
First Year of Running CDMS II at Soudan

• Installed two towers of 6 detectors each in 2003
• Ran “Tower 1” October 2003- January 2004
  - Same 4 Ge (1 kg) and 2 Si (0.2 kg) ZIPs run at Stanford
  - Results announced at last year’s APS

• Ran 12 detectors in 2 towers from 25 March- 8 August 2004
  - New results today
First Year of Running CDMS II at Soudan

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  ◆ Results announced at last year’s APS

• Ran 12 detectors in 2 towers from 25 March- 8 August 2004
  ◆ New results today
  ◆ Ge more sensitive to WIMPs since $\sigma_{n\chi} \propto A^2$
  ◆ Si more sensitive to neutrons
  ◆ Si sensitive to lower-mass WIMP

• I will discuss only results from the Ge detectors today
Analysis of 2nd Soudan Run of CDMS II

- Included 5 of 6 Ge and 4 of 6 Si detectors (others still blinded)
  - 1.25 kg of Ge, 0.4 kg of Si
  - 72 live-days WIMP-search data
- “Opened the box” on March 31, 2005
- Pre-designated “primary” analysis
  - Similar to timing cut used previously, but better rejection
- 4 “secondary” blind analyses with more sophisticated techniques, better rejection of backgrounds

See A. Reisetter, session K9
In Situ Calibrations for Setting Cuts “Blind”

Second run’s calibration data, prior to timing cuts

Blue points: electron recoils induced by a $^{133}$Ba $\gamma$ source
Yellow points: nuclear recoils induced by a $^{252}$Cf neutron source

After timing cuts, set to reject nearly all low-yield electron recoils

53% acceptance of neutrons

23x our WIMP-search background
WIMP-search data

Prior to timing cuts

After timing cuts, which reject most electron recoils

PRELIMINARY ESTIMATE: 0.37 ± 0.20 (sys.) ± 0.15 (stat.) electron recoils, 0.05 recoils from neutrons expected
Upper limits on the WIMP-nucleon cross section are $1.7 \times 10^{-43}$ cm$^2$ for a WIMP with mass of 60 GeV/c$^2$

- Factor of 2.3x below CDMS Soudan 1st run
- Factor 10 lower than any other experiment

Excludes large regions of SUSY parameter space under some frameworks

- Bottino et al. 2004 in yellow
- Kim et al. 2002 in cyan
- Baltz & Gondolo 2004 mSUGRA in red
Projected CDMS Sensitivity

Installed 3 additional towers in November

- Additional improvements
  - Cryogenics, backgrounds, DAQ
  - Currently commissioning
- 30 detectors in 5 towers of 6
  - 4.75 kg of Ge, 1.1 kg of Si to run through 2006
  - Improve sensitivity ×10
Current XENON Collaboration

Columbia University
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Brown University
Richard Gaitskell, Peter Sorensen*, Luiz De Viveiros*

University of Florida
Laura Baudis, David Day*

Lawrence Livermore National Laboratory
Adam Bernstein, Chris Hagmann and Celeste Winant+

Case Western Res. Univ. (group moved from Princeton)
Tom Shutt, John Kwong*

Rice University
Uwe Oberlack, Omar Vargas*

Yale University
Daniel McKinsey, Richard Hasty+, Angel Manzur*
Potential Signals from Interaction

**LXe Advantages:**
- size
- size
- even / odd
- temp
- yield / noise
disc.

Figure from G. Chardin
XENON Event Discrimination: Electron or Nuclear Recoil?

Within the xenon target:

- **Neutrons, WIMPs** => Slow nuclear recoils => strong columnar recombination
  - Primary Scintillation (S1) preserved, but Ionization (S2) strongly suppressed
  - **γ, e-, μ, (etc)** => Fast electron recoils =>
  - Weaker S1, Stronger S2

Ionization signal from nuclear recoil too small to be directly detected => extract charges from liquid to gas and detect much larger proportional scintillation signal => dual phase

Simultaneously detect (array of UV PMTs) primary (S1) and proportional (S2) light => Distinctly different S2 / S1 ratio for e / n recoils provide basis for event-by-event discrimination.

Challenge: ultra pure liquid and high drift field to preserve small electron signal (~20 electrons); efficient extraction into gas; efficient detection of small primary light signal (~200 photons) associated with 16 keVr
Sample Events from Xenon Detector

XeBaby two phase chamber response to neutrons (AmBe) and gammas (137Cs)

\[ V_C = 4.0 \text{kV}, \quad V_A = 4.0 \text{kV} \]

**Gamma event**

\(~30 \text{ ns decay time of Xe excitation}\)

\(\sim 1\mu\text{s shaping on Slow Digitizer}\)

**Nuclear Recoil event**

\(\sim 1\mu\text{s shaping on Slow Digitizer}\)
XENON10: A 3D Sensitive WIMP Detector

An array of 52 PMTs allows X-Y position reconstruction

10keV Nuclear Recoil Events near the detector edge

Edge events can be rejected based on reconstructed positions

Z position determined from electron drift time

Reconstructed event positions
XeBaby Test Rig

- **Fiducial volume**: $\varnothing = 4\text{cm}$, $h = 2\text{cm}$ ($\text{Xe} \sim 100\text{g}$)
- **2 PMTs** ($\varnothing = 5\text{cm}$ each)
- **Operated at Nevis Lab, Columbia University**

![XeBaby Diagram](image1)

**Source Position**

1x10^7 n/sec AmBe source

- Lead
- Liquid Xe
- Poly
- BC501A (dia. 4inch x 4inch)
- 130 degree
- 60cm
Event Discrimination (Using S2/S1 ratio)

AmBe Source
- Neutron spectrum peaked at 4MeV + 4.43MeV $\gamma$'s (suppressed with 10cm Pb shield)
- $V_C = 4$ kV/cm, $V_A = 3.5$ kV/cm

Inelastic Events:
- 40 keV (Xe129*) and 80 keV (Xe131*)

137Cs Source
- $V_C = 4$ kV/cm, $V_A = 4$ kV/cm
Features in Energy Spectrum

Features in AmBe Spectrum:

- Elastic Nuclear Recoils in Xe
- Inelastic Nuclear Recoils in Xe: 40keV (129Xe) and 80keV (131Xe)
- Gammas from Inelastic Nuclear Recoils in Teflon (F): 110keV and 200keV
S2/S1 Dependence on E-Field for n/γ Recoils

20050328T2052 - AmBe - Depth(>3us)+Quality Cuts - Vc=6.0kV

\[ \log_{10} S2 [\text{phe}] (\text{Ch1 Ch2}) \quad \text{p.e./keVee = 344} \]

\[ \log_{10} S1 [\text{phe}] (\text{Ch1 Ch2}) \quad \text{p.e./keVee = 1.97} \]

\[ \log_{10} \text{Cts/sec} \]

XENON_2005
Features in Energy Spectrum

§ Calibration Spectrum
§ 57Co: 122keV
§ Xe Activation Lines: 164keV (Xe131m) and 236keV (Xe129m)
  • Xe in chamber has been activated due to intermittent exposure to AmBe neutron for the previous 10 days
Rejection Power by S2/S1

Rejection power
(80% acceptance window)
~95% (with flat component)
>99% (by gaussian fit)

Flat component due to edge events
Non-uniform E-field; Charge trapped on PTFE

Improve with 3D detector
**XENON R&D: Dual Phase 3D XeTPC Prototype**

- Pulse Tube Refrigerator used to liquefy and maintain LXe at $-95.1 \pm 0.05 \, \text{C}$
- Array of 7 PMTs (Hamamatsu R9288) directly coupled to the Xe active volume
- Fast and Slow digitizers for direct and proportional light waveforms
- Drift Field $> 1\, \text{kV/cm}$; Extraction Field $> 10 \, \text{kV/cm}$
- Calibration with gamma (Co-57), alpha (Po-210) and neutron (AmBe) sources.
21 PMTs Array Details (XENON3)

- Hamamatsu R8520
- Developed for operation in LXe
- Metal Channel, compact ((2.5 cm)² x 3.5 cm)
- Square anode (good fill factor: 66.2%)
- Low background: \(^{238}\text{U} / ^{232}\text{Th} = 15 / 3 \text{ mBq}
- Quantum Efficiency: >20 % @178nm
XENON R&D Milestones: Summary

+ PMTs operation in LXe
+ > 1 meter $\lambda_e$ in LXe
+ CsI photocathode in LXe w/o Feedback
+ Operating ~few kV/cm electric field
+ Electron extraction to gas phase
+ Efficient & Reliable Cryogenic System
+ Electron/Alpha recoil discrimination
+ Nuclear recoil Scintillation Efficiency (10-55 keVr)
+ Nuclear recoil Ionization Efficiency
+ Electron/Nuclear recoil discrimination
+ Kr removal for XENON10
+ Electric Field / Light Collection Simulations
+ Background Simulations
+ Materials Screening for XENON10
+ Design of XENON10 System
+ Low Activity PMTs and Alternatives Readouts

Achieved
Achieved
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Achieved
In progress
Tools Developed_Done for XENON10
Tools Developed_Done for XENON10
on-going (Soudan_SOLO Facility)
In Progress
on-going
R&D Milestone: > 1 m Electron Attenuation Length

Continuous Circulation of Xe gas through high temperature metal getter to achieve high purity (<1ppb) of the liquid target a few days.

\[ Q(t) = Q(0) \exp\left(-\frac{t}{\tau}\right) \]

\[ \lambda = \nu \tau \]

![Graph and diagram showing electron lifetime and purification system with 1 kV/cm and \( \lambda \approx 1.2 \) m]
XENON10 Schematic of Detector and Shield Design

- Polyethylene (30cm, 2.2 tonnes)
- Pb (23 cm, 31 tonnes)
- Stainless Steel Cryostat (100 kg)
- Low Activity PMTs (Hamamatsu R8520-06-M4F)
- Copper (2.5cm)
- Teflon
- Xenon Gas
- Liquid Xenon – Inner Region (ø18 cm, h 15 cm, 12 kg)
- Liquid Xenon – Veto Region (thickness 5cm, 50 kg)
  (parameters used in Monte Carlo)
PMTs Gamma Background in XENON10

Gamma Background from PMTs (Hamamatsu R8520: $^{238}\text{U} / ^{232}\text{Th} / ^{40}\text{K} / ^{60}\text{Co} = 13 / 4 / 60 / 3 \text{mBq}$ is 4x below XENON10 target – can be further reduced to 40x with outer LXe Veto and multi-site events cut.

Inner Chamber Events (8 < E < 28 keV)

Energy Histogram

7 Inner PMTs → R8778: $^{232}\text{Th} - 4\text{mBq}; ^{238}\text{U} - 13\text{mBq}; ^{40}\text{K} - 60\text{mBq}; ^{60}\text{Co} - 3\text{mBq}

$^{238}\text{U} - 13\text{mBq}; ^{232}\text{Th} - 4\text{mBq}; ^{40}\text{K} - 60\text{mBq}; ^{60}\text{Co} - 3\text{mBq per Kg}$

Total: Inner Events = 21 mHz; Veto Events = 322 mHz; Non-veto Inner Events = 14 mHz

DRU Rates Averaged Over Range: 8 < E < 16 keV

Inner Chamber Events (8 < E < 28 keV)

Spatial Distribution

Non-vetoed Inner Events Only

7 Inner Top PMTs (Hamamatsu R8778)

XENON10 Target

XENON10 Target x0.1
XENON10 at LNGS: Gran Sasso National Laboratory

- Install Shield and Detector by Sep 2005
- Complete Calibration by Dec 2005
- Start physics run in Jan 2006
Dark Matter Goals

- Dark Matter Goals (labeled on figure)
  - **XENON10** - Sensitivity curve corresponds to 
    ~2 dm evts/10 kg/month
    - Equivalent CDMSII Goal for mass >100 GeV 
      (Latest 2004 CDMSII result is x10 above this level)
    - With only 30 live-days x 10 kg fiducial - Zero events - would reach 
      XENON10 sensitivity goal (90% CL), but we would like to do physics!
    - Important goal of XENON10 prototype underground is to 
      establish clear performance of systems
  - **XENON100** - Sensitivity curve corresponds to
    ~20 dm evts/100 kg/year
    - Background Simulations for XENON10 indicate it could reach b/g suppression necessary to reach this 
      sensitivity limit (would require some modest upgrade), but with 10 kg target would only give ~2 dm evts/ 
      10kg/year - no physics.
DM Direct Search Progress Over Time (2005)

Gaitskell, Annual Reviews vol 54, 2004