Deep Underground Labs and the Search for Dark Matter

Sujeewa Kumaratunga

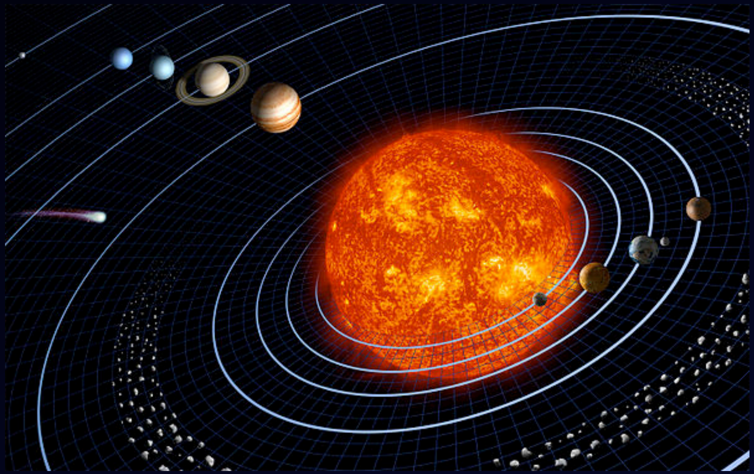
Outline

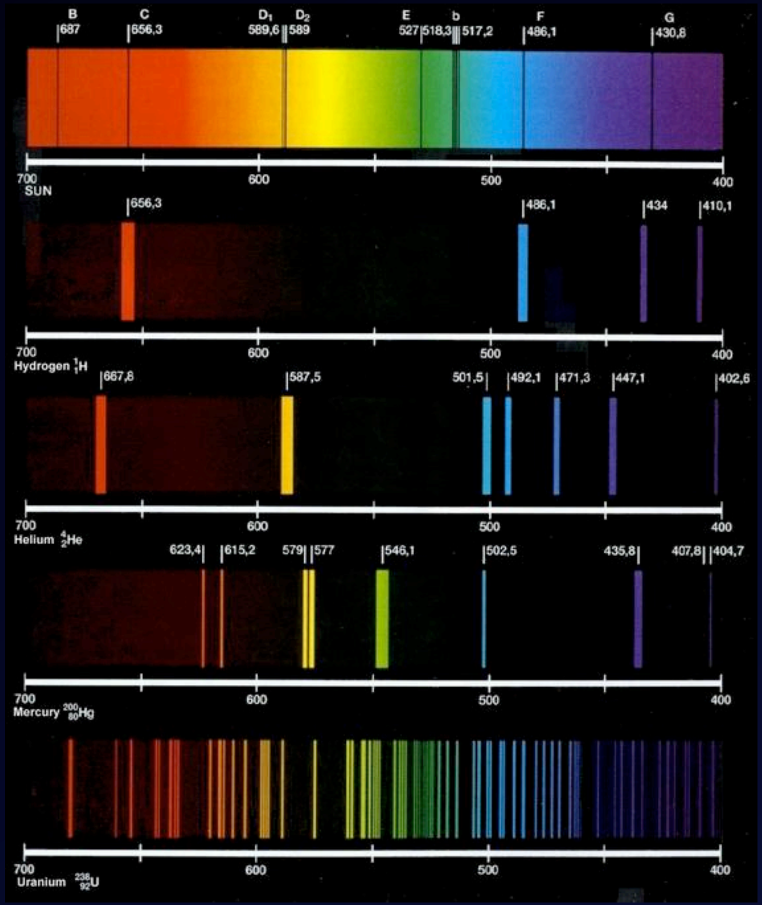
- Dark Matter, a brief history
- Underground Labs, SNOLab
- PICASSO : Project In CAnada to Search for Supersymmetric Objects
- CDMS : Cryogenic Dark Matter Search
- Status of Dark Matter Experiments

Dark Matter, a brief history

Measuring the Mass of Galaxies

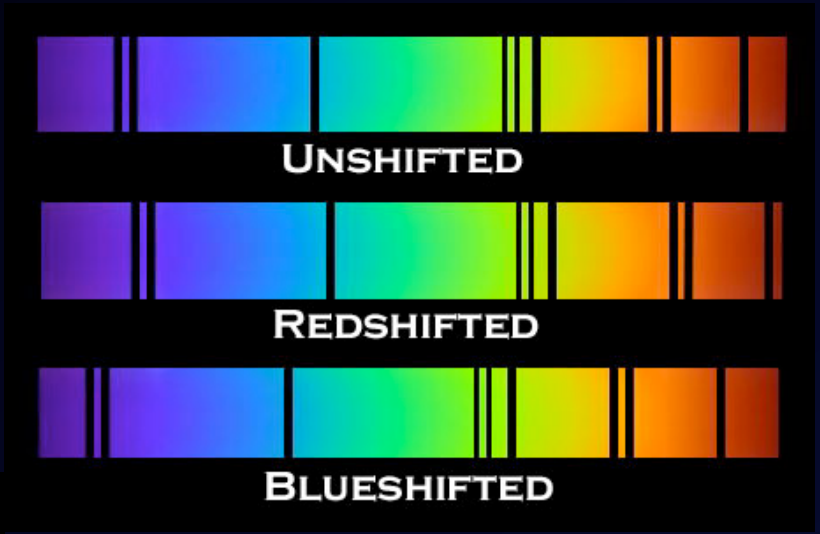
- 2 ways to measure mass of a galaxy:
  - a) by looking at how much light it emits

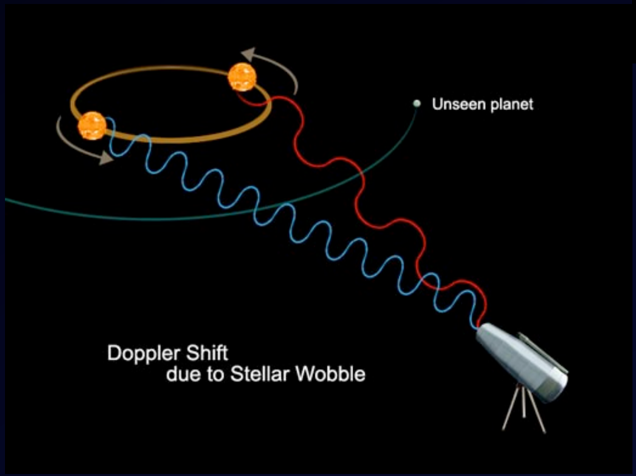




Measuring the Mass of Galaxies

- b) by looking at the velocity : measure Doppler shift (how much the wavelength shifts when the star is moving) to calculate velocity and from that calculate the kinetic energy and from that calculate the potential energy from 2<KE> = <PE>





redshift = moving away from us
blue shift = moving towards us

First Evidence for Dark Matter
Coma cluster anomalies

In the beginning… well… in 1933…

- Zwicky measured the mass of 8 galaxies in the Coma cluster
- With two methods
- Found that the second method gave higher mass than the first
- => if the galaxies were actually rotating that fast, then they would be flying apart

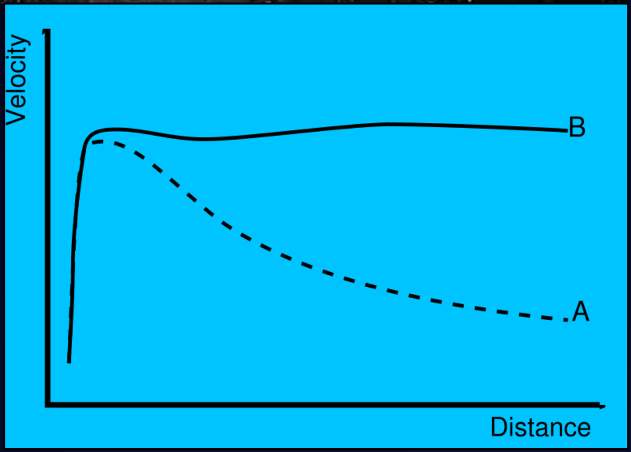
Fritz Zwicky, 1937

Fritz Zwicky postulates Dark Matter meaning something not luminous

Another Evidence for Dark Matter
Galactic Rotational Curve Anomalies

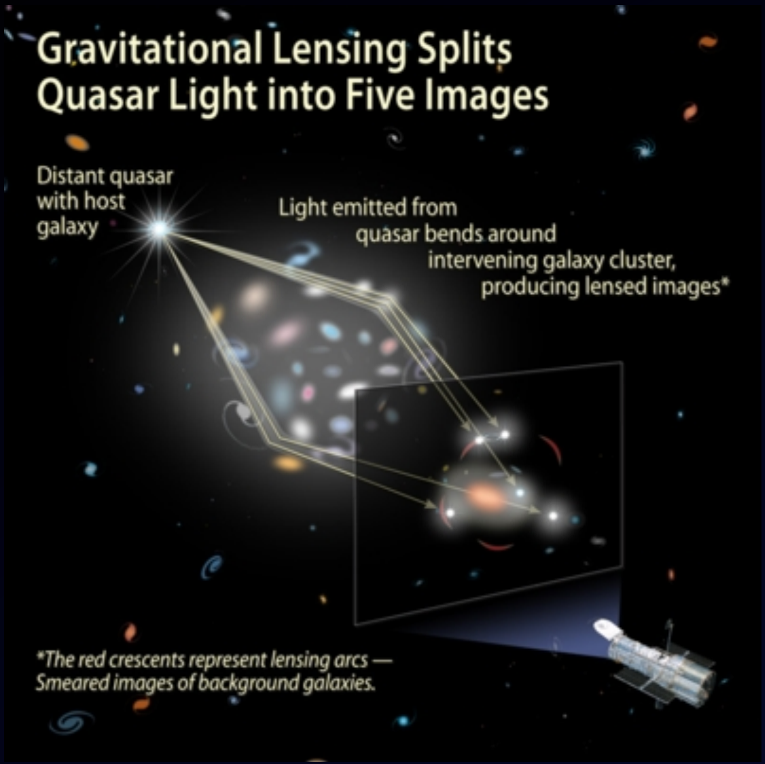
Vera Rubin, 1950

- Observed bodies far away from the galactic center had same speeds as those near the center (curve B)
- Against Newton's laws; We'd expect velocity (v) and distance to galactic center (r) to be proportional
- $v^2 \propto \frac{1}{r}$ (curve A)



Dark Matter in the outskirts of galaxies?

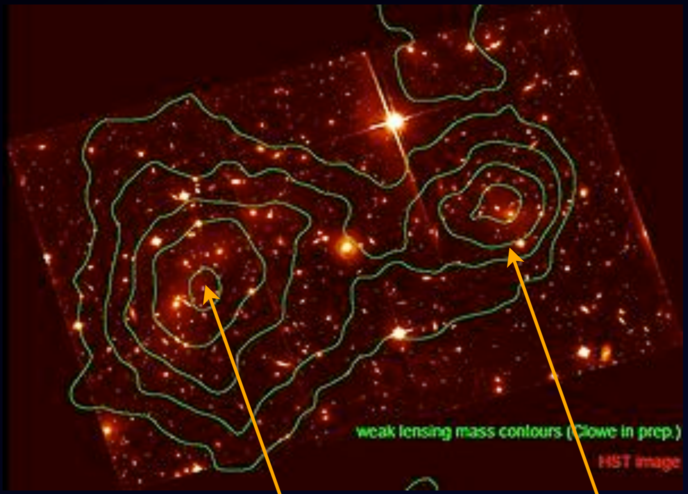
More Evidence for the Existence of Dark Matter
Gravitational Lensing



- First postulated by Orest Chwolson (1924), made famous by Albert Einstein (1936) in his general theory of relativity.
- Light from far away bright objects is bent by large masses producing multiple identical images
- First observed in Twin QSO in 1979 - one quasar that appeared as two images.

First Best Evidence of Dark Matter
Bullet Cluster

2006
first best
evidence
for
Dark Matter

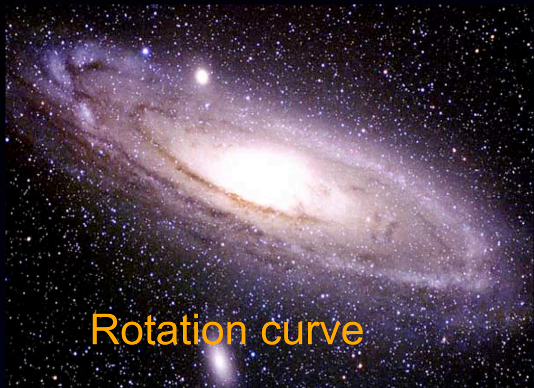


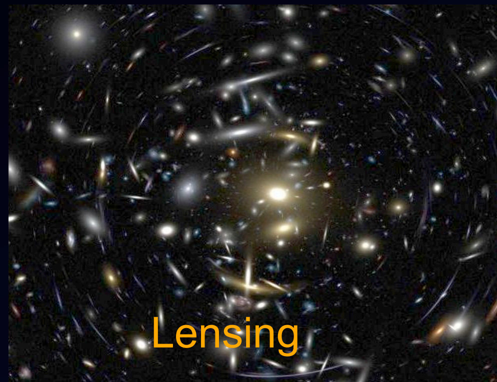
largest gravitational effects

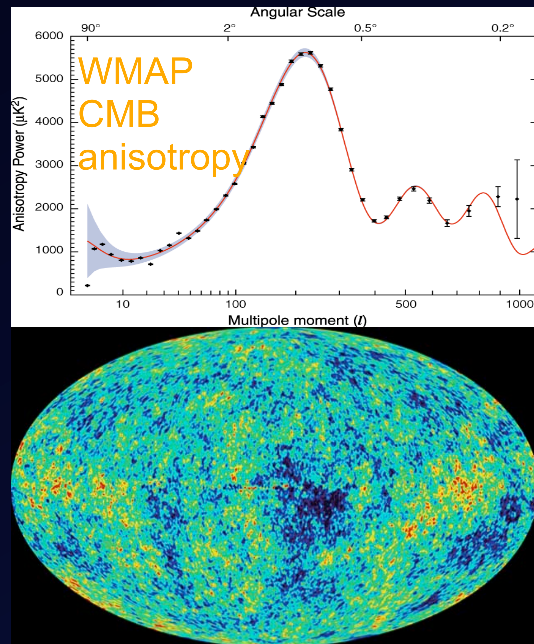
- Two clusters of galaxies collided 150 million years ago; the gas slowed down and remained near the collision center.
- The gas accounted for most of the visible mass, so expect today, to see larger gravitational lensing effects from around the collision center.
- But when Chandra mapped the gravitational lensing contours, the largest effect was in fact offset from this collision

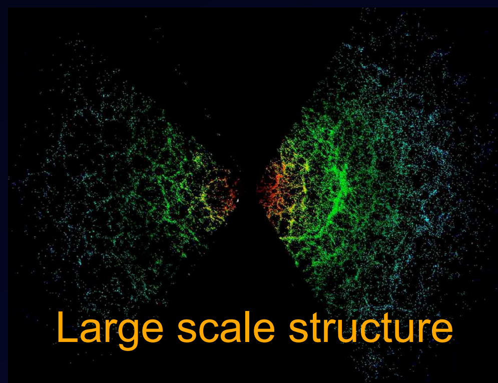
Other Evidence for the existence of Dark Matter

(lots more, but you don't want to stay here all day)









What causes all these Anomalies?

- Modified Newtonian Dynamics (MOND)? No; Bullet cluster disproves this and also F=ma has been tested at 10^{-15} ms^{-2}.
- Neutrinos? Not enough. So maybe they make some of the missing matter, but not the majority.
- Primordial black holes? No, we do not see them - they are supposed to explode after some (long) time, and we see none exploding this way.
- Non-baryonic (not made of protons, neutrons etc) dark matter particles? Most probably.

cool, but not enough

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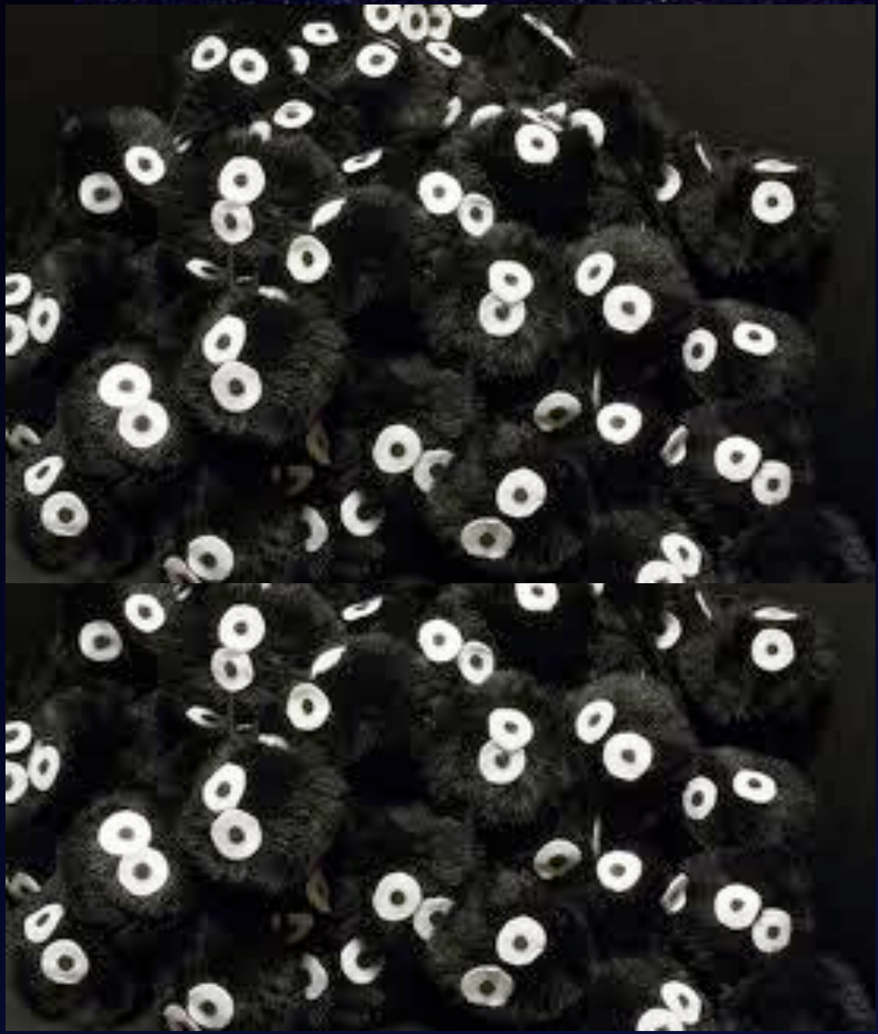


WIMPs - Could They be the Explanation?

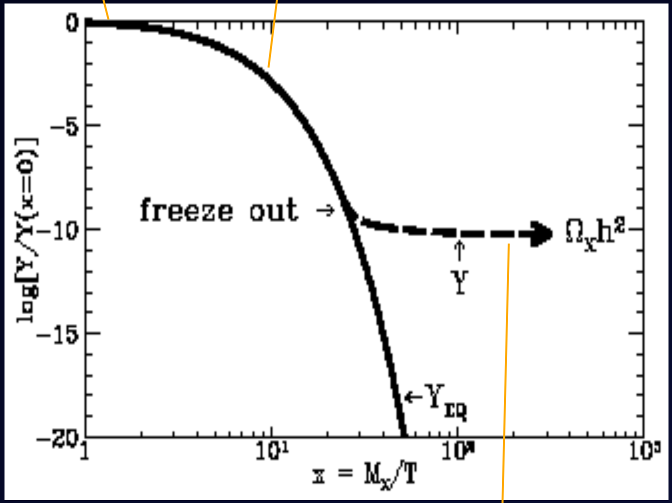
WIMP
(Weakly Interacting Massive Particles)
denoted by χ
are non-baryonic particles

WIMPs - Could They be the Explanation?

- Produced in the early universe from $e^+ + e^- \rightarrow \chi + \bar{\chi}$
- They annihilate with the reverse reaction $\chi + \bar{\chi} \rightarrow e^+ + e^-$
- As long as temperature, T > Mχ , then, WIMP number density, Υ, is constant.
- Annihilation stops when WIMPS are too sparse; mean free time of annihilation is smaller than the Hubble age of the universe
- WIMP number density constant after that: freeze-out

χ's produced & annihilated; T>>>Mχ

χ's production stopped, annihilation continues; T<Mχ

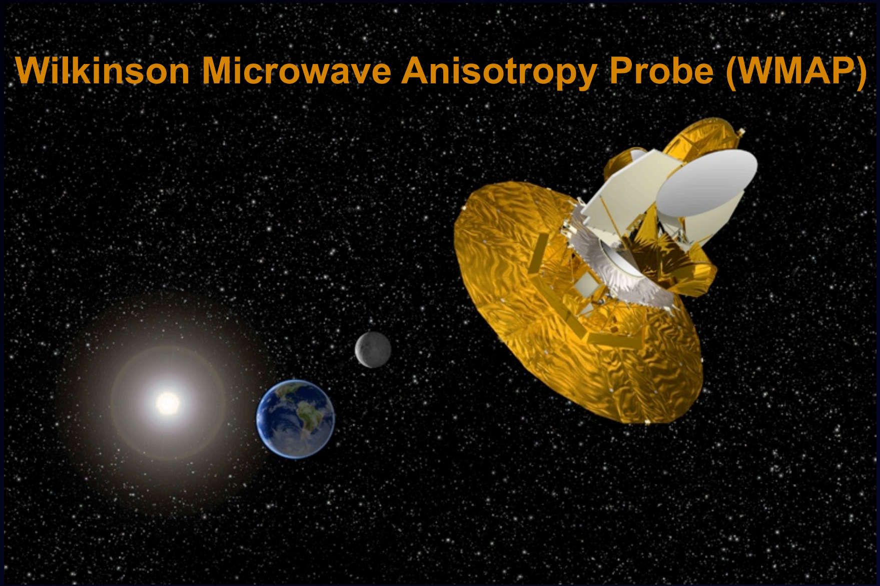


Freeze out; T<<<MX

Smoking Gun for Existence of WIMPs

$$\textit{WIMP relic abundance today} = \Omega_X h^2 \approx \frac{10^{-37}\,cm^2}{\sigma_a}$$

Determining m_X and σ_A from electroweak theory, we expect $\mathbf{\Omega_X = 0.3}$



WMAP RESULTS (2009):

Ω_{tot} = 1.02±.02

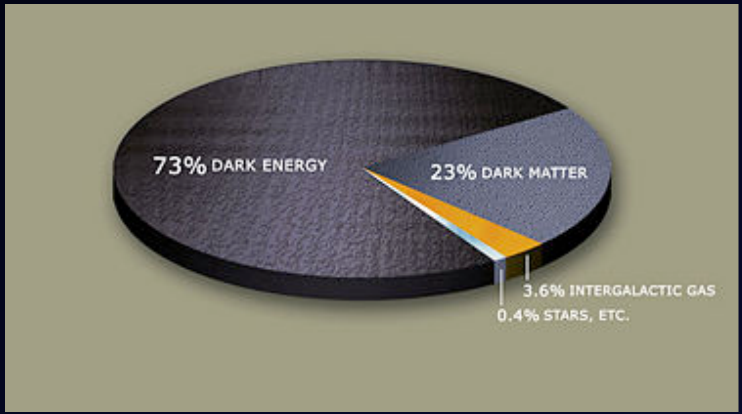
Ω_b = 0.04 ±0.004

$\boxed{\Omega_X = 0.27 \pm 0.04}$ ← **Observed same as predicted**

Ω_Λ = 0.73 ±0.04

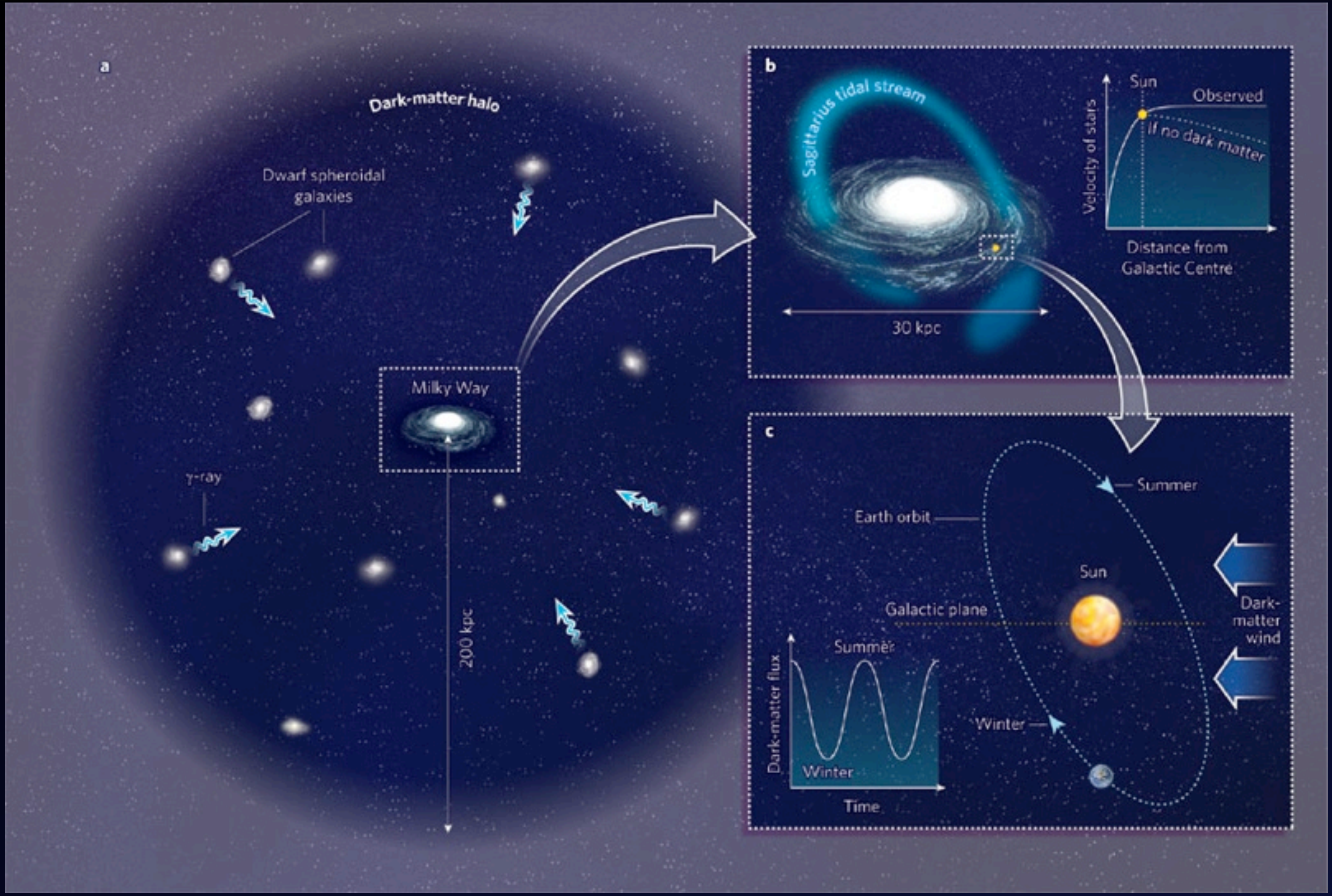
Standard Model for Astro-Particle Physics

- Dark Energy – biggest part
- Cold Dark Matter
  - WIMPs (Weakly Interacting Massive Particles), Axions
- Baryonic matter – stars, gas, MACHOs, etc

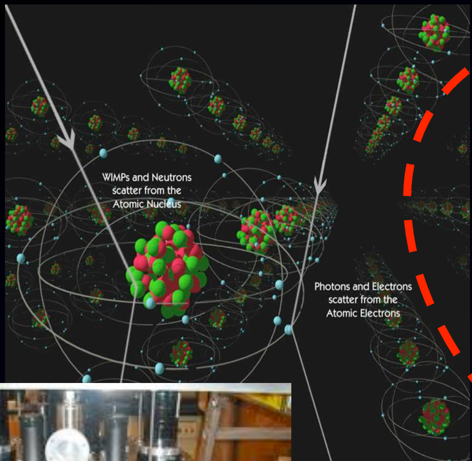


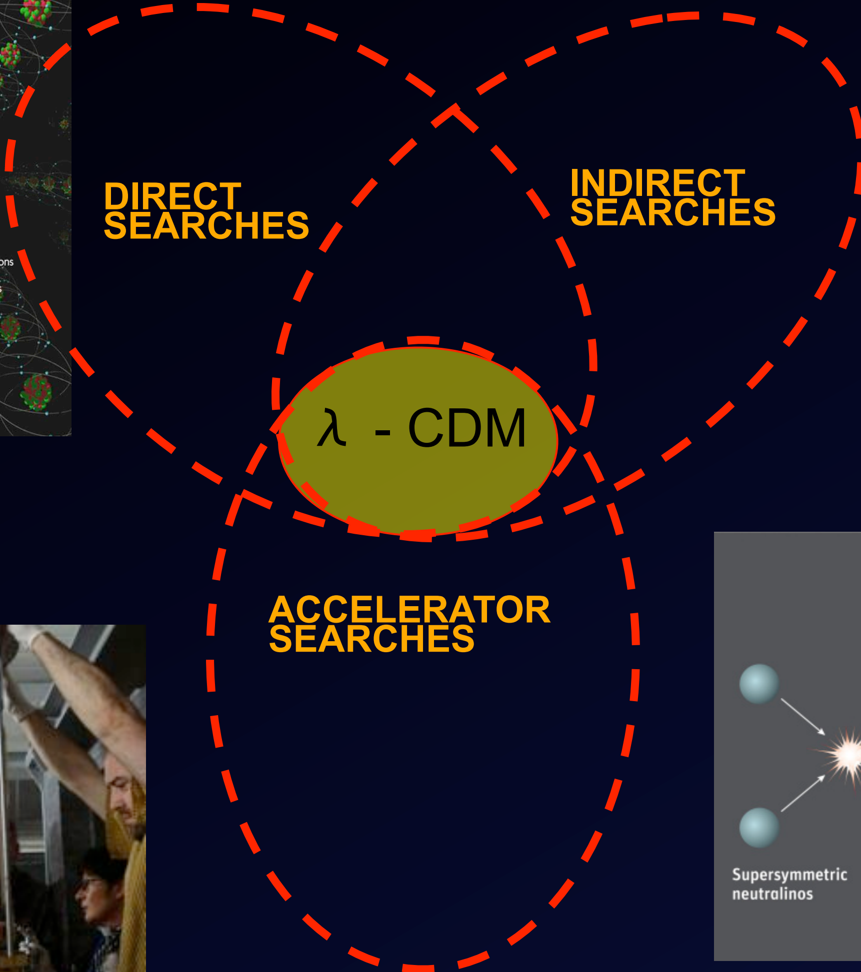
χ (neutralino) can be lightest stable super-symmetric particle – LSP
neutral particle
interaction with matter electro-weak
can provide relic population from early Big Bang

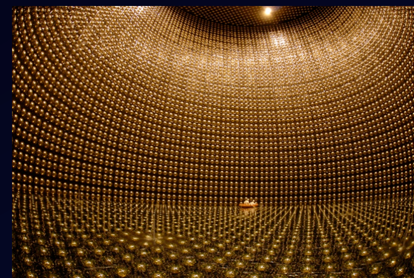
We are Surrounded by a Dark Matter Halo

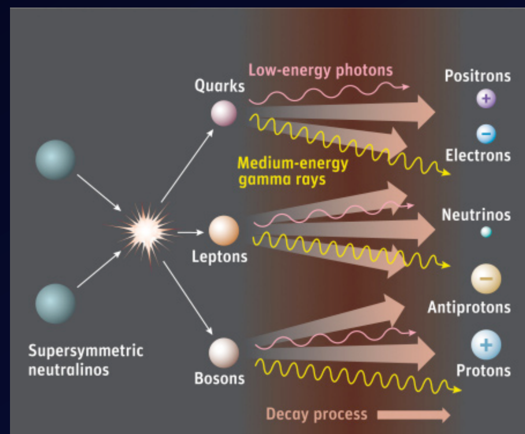


How to Detect Dark Matter









How to Detect Neutralinos

- Weakly Interacting particles
  - Deposit a few (1-100) keV (so about 50 trillion of these interactions in 1 second, will be like a 100W light bulb)
  - No electric charge deposited

$\equiv$

- Minimize background
  - Go underground: shield from Cosmic Rays (about 100 passing through your body every second right now)
  - Use water boxes to shield radioactivity
  - Carefully purify ingredients to remove radioactive U/Th

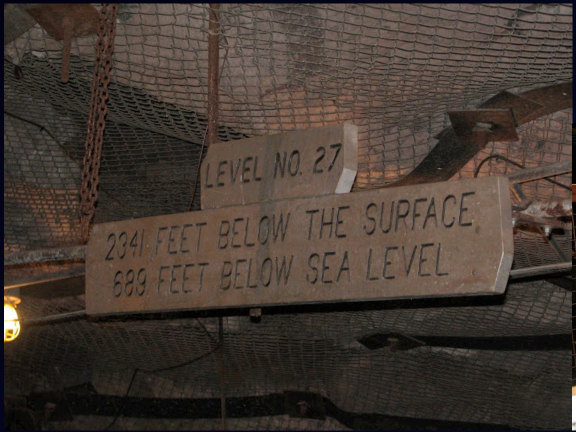
Underground Labs

very low background, shield ourselves from cosmic rays, so go underground

slide from Nigel Smith, SNOLab

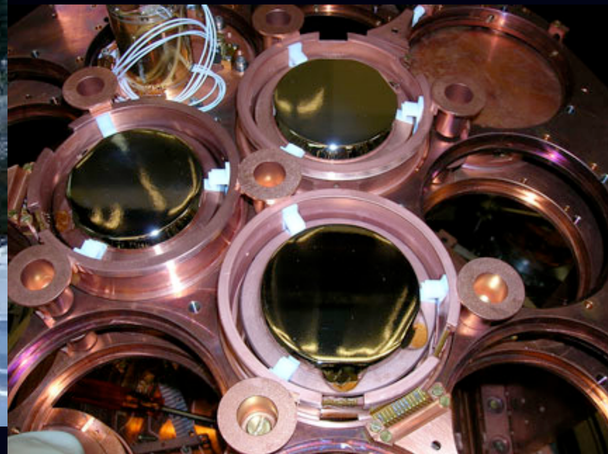
Underground Labs

2100m underground,
in Canada, Ontario
PICASSO experiment



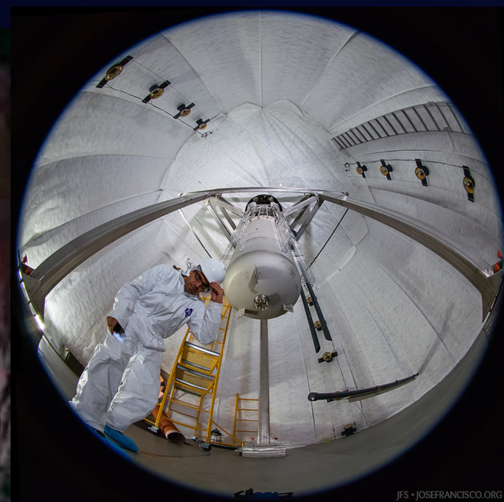
714m underground, in
USA, Minnesota
CDMS experiment

Underground Labs

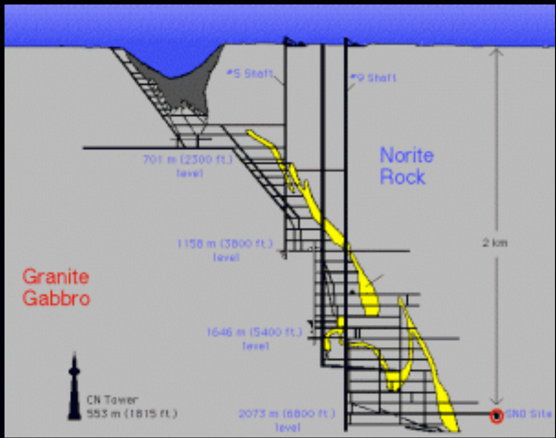


2934m underground,
in France
Edelweiss experiment

1600m underground,
in USA South Dakota
LUX experiment



SNOLab



Canada's very own, in Sudbury, ON

6800ft (~680 floors) underground

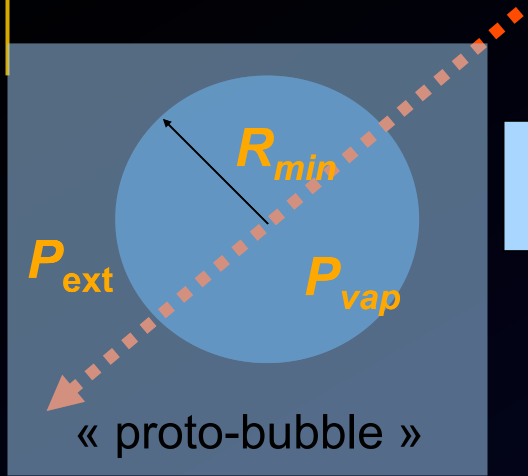
low cosmic ray rate: 1 muon in a square meter every 3 days (50 million times less than the surface)

PICASSO

Project In
CAnada to
Search for
Supersymmetric
Objects

A Spin Dependent Direct Dark Matter Search

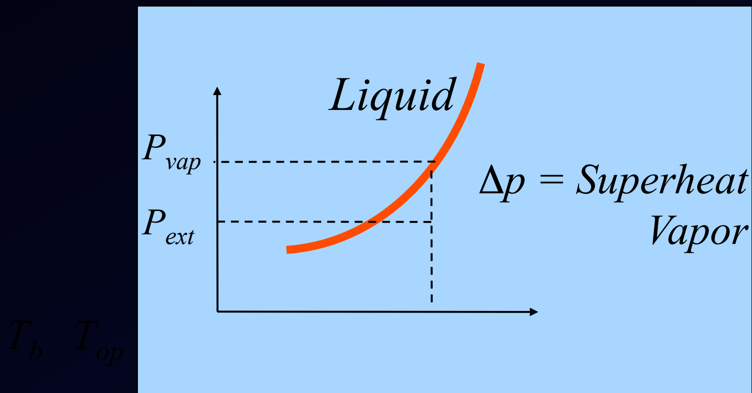
The Seitz Theory of Bubble Chambers



$$E_{dep} = \frac{dE}{dx} \times R_{\min} \geq E_{\min}$$

$$R_{\min} \equiv \frac{2\gamma(T)\varepsilon}{\Delta P(T)} \qquad E_{\min} \equiv \frac{16\pi}{3\times\eta} \frac{\gamma^3(T)}{(\Delta P(T))^2}$$

$\Delta P(T)$ = superheat
γ (T) = Surface tension
ε = critical length factor
η = energy convers. efficiency



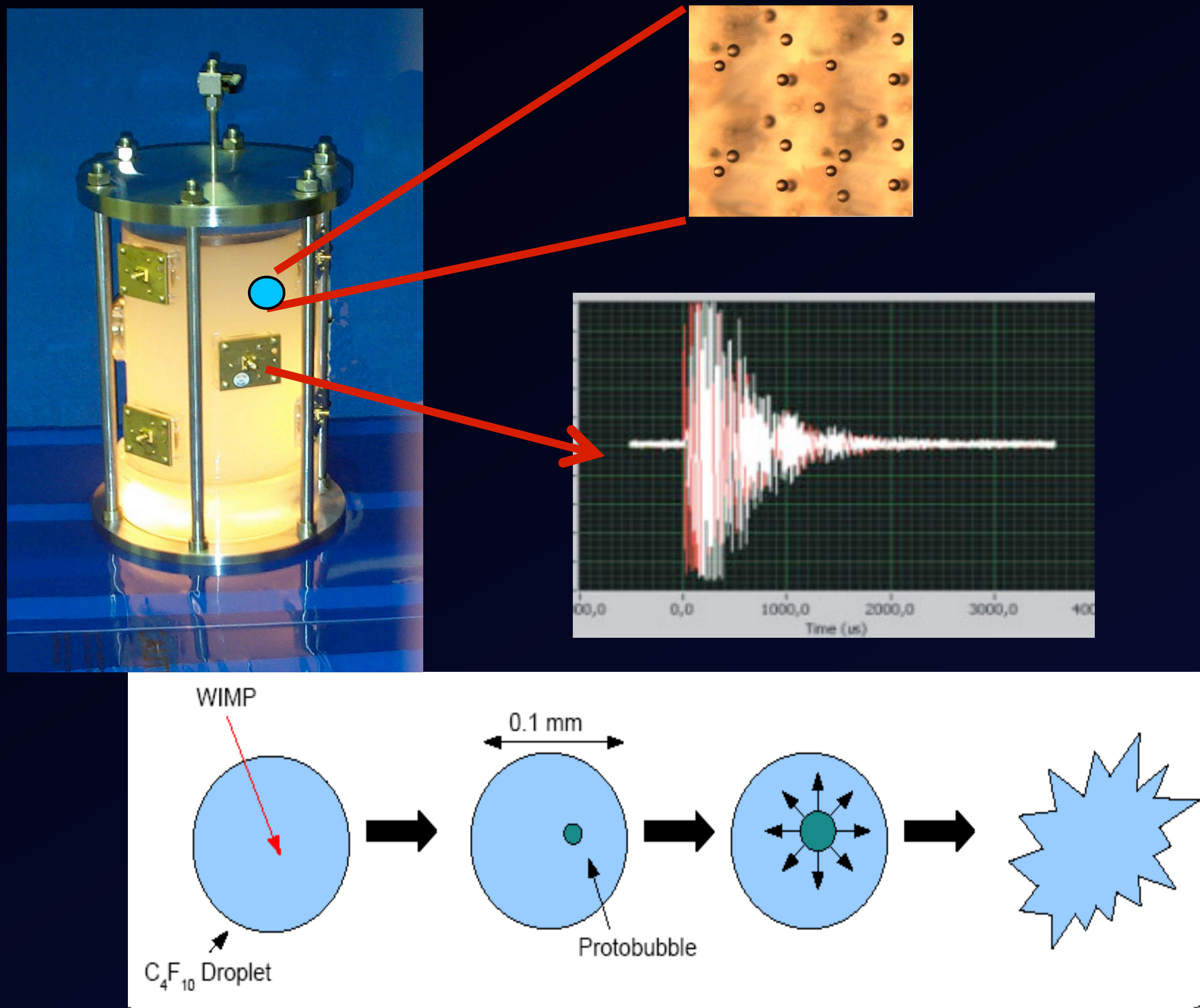
A bubble forms if a particle deposits enough energy, E_{min}, within a radius R_{min}

see cloud chamber in the TRIUMF lobby for similar set up.

F. Seitz, Phys. Fluids I (1) (1958) 2

PICASSO Detectors

- **Super heated C_4F_{10} droplets**
  - 200um,
  - held in matrix in polymerized gel
  - act as individual bubble chambers
- **When ionizing particle deposits energy**
  - F^{19} recoils
  - Creates nucleation centre in superheated liquid.
  - Bubbles grow, turning entire C_4F_{10} droplet to vapor



Monday, February 18, 2013

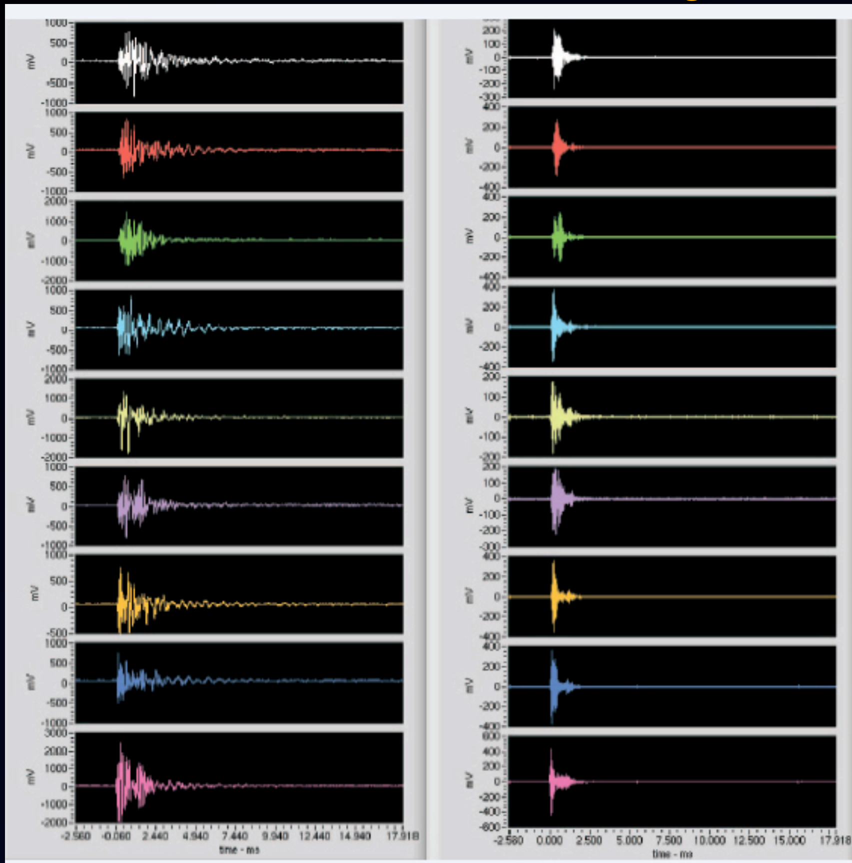
PICASSO Experiment Status

- Detectors:
  - 32 detectors, 9 piezos each
  - total active mass of 2248.6g
  - 1795.1g of Freon mass
  - Temperature & Pressure control system
- 40 hr data taking
- 15hr re-compression

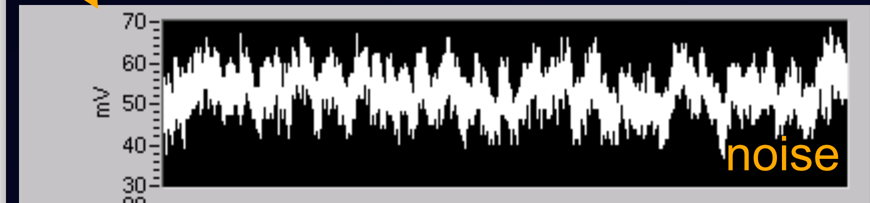
PICASSO events

raw signal

high pass filtered signal



different amplitude scales



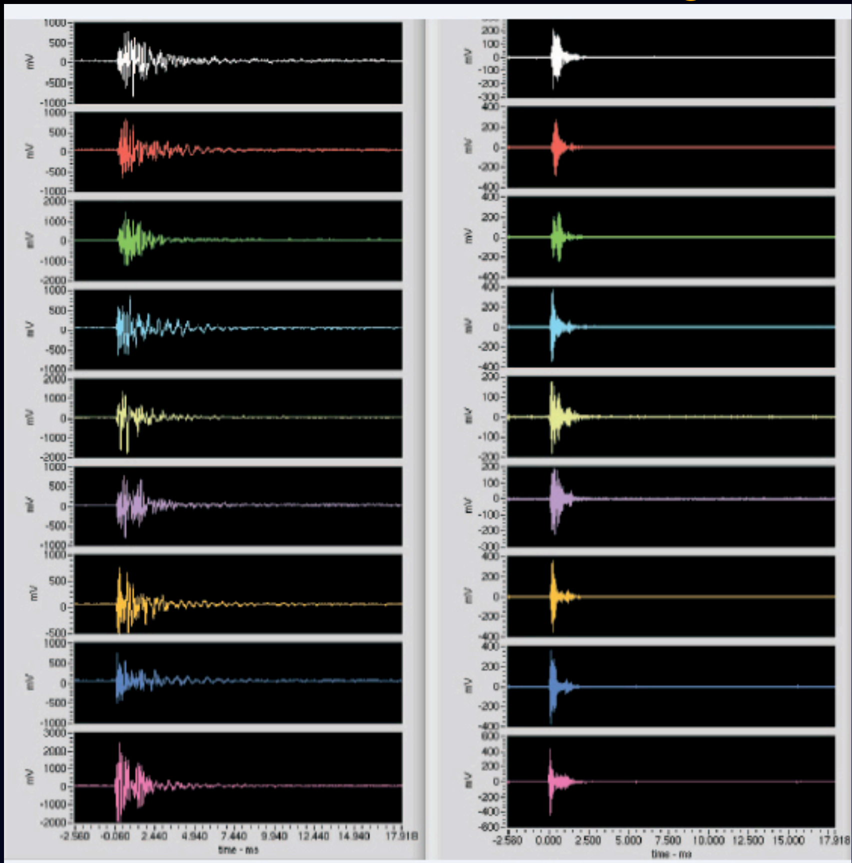
Two Discrimination Variables:

1. **Energy Variable**
2. **Frequency Variable**

PICASSO events

raw signal

high pass filtered signal



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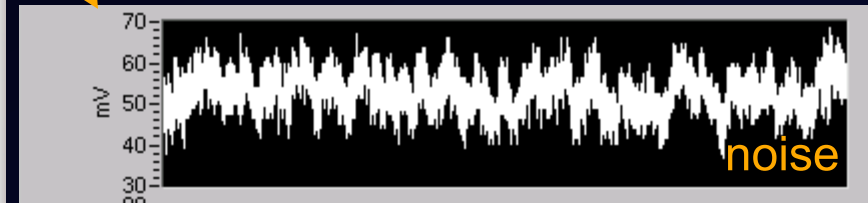

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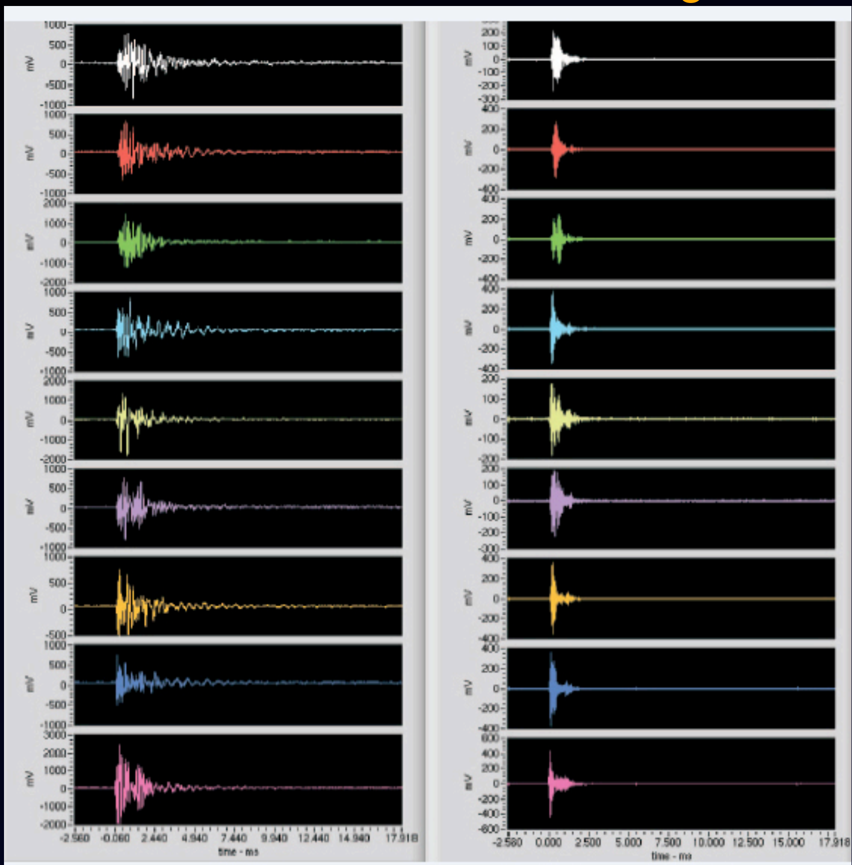

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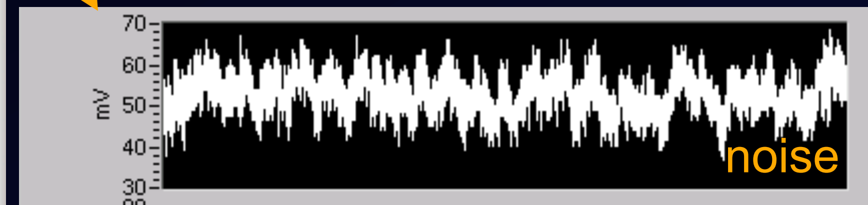

Two Discrimination Variables:

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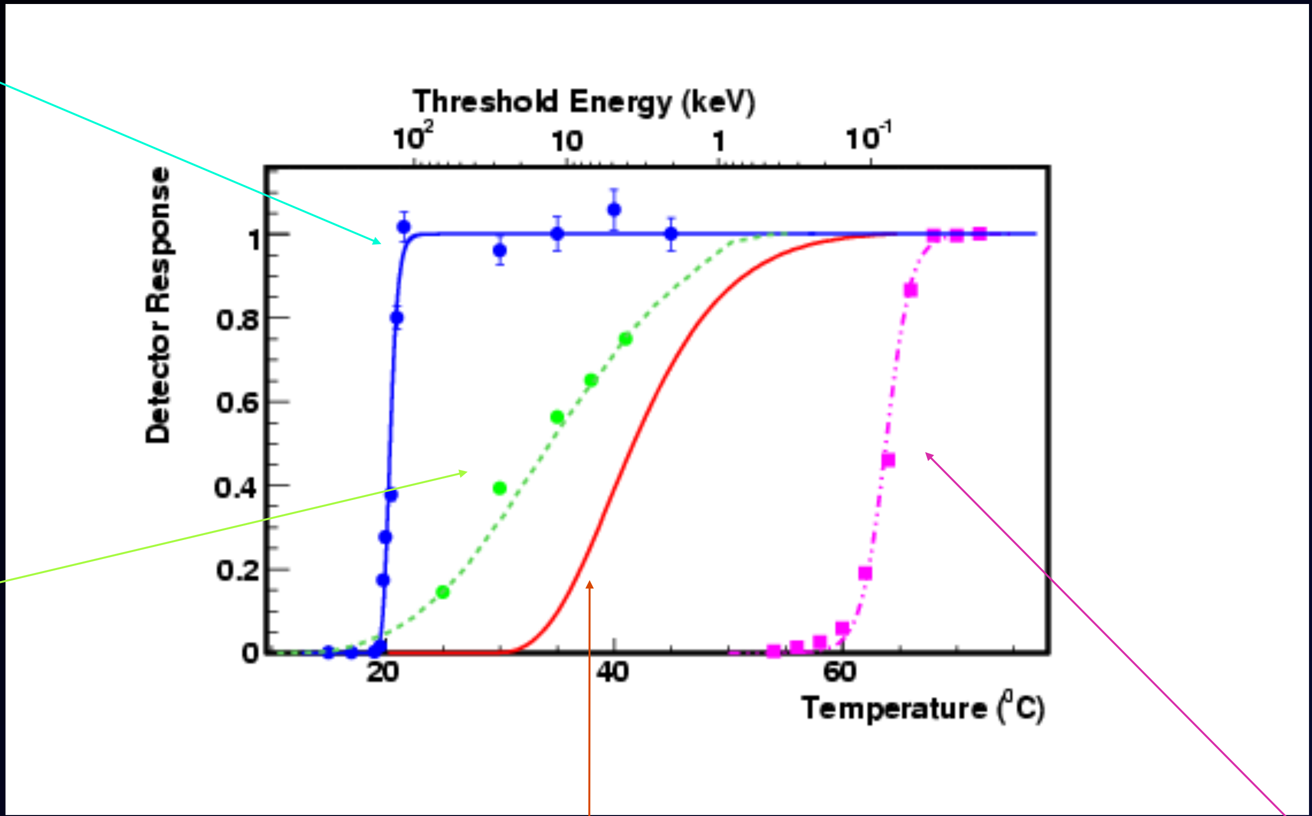
PICASSO Detector Responses

α - particles from ^{226}Ra spike

Alphas (from radioactive impurities) are the biggest background.

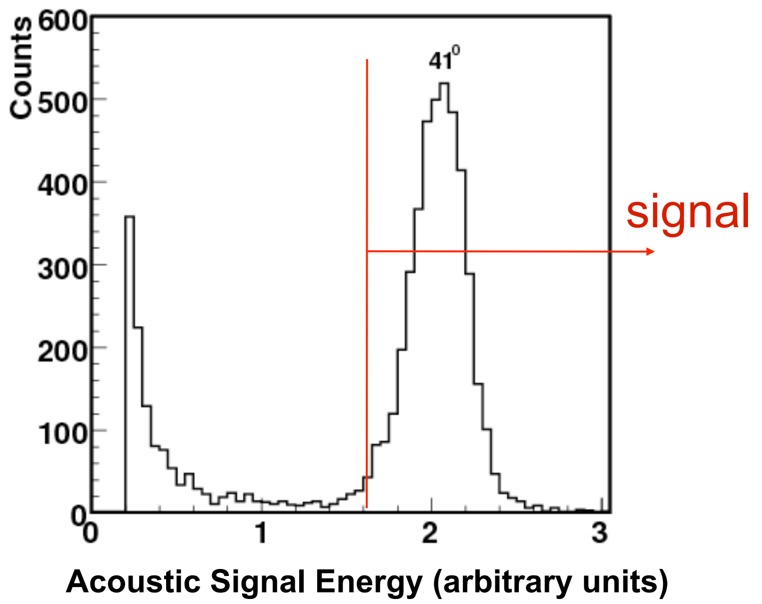


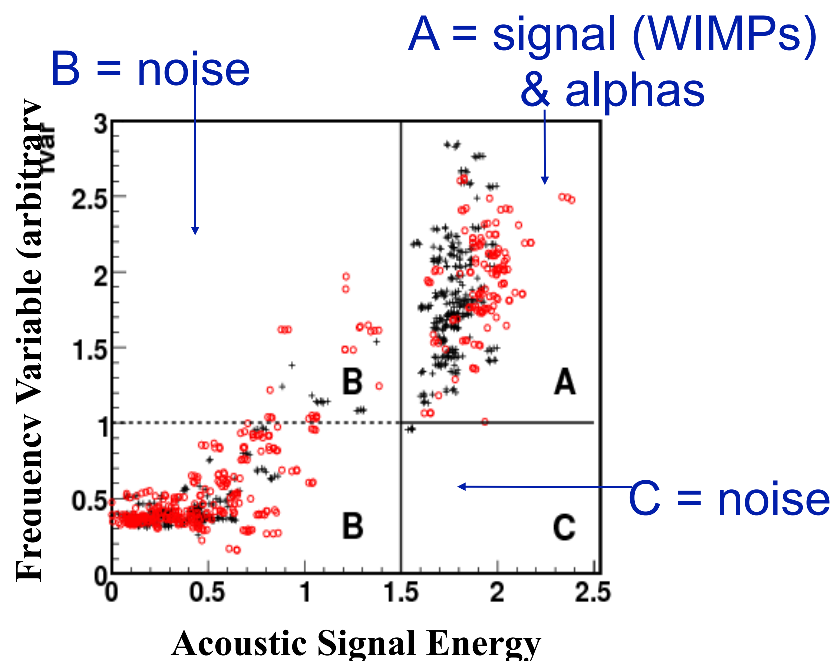
Neutrons from AcBe source (data +MC)

Recoil nuclei from 50 GeV /c^2 WIMP

γ's from ^{22}Na & MIP's

Discriminating Variables





**** Neutron calibration run

Signal and noise well separated

Another Dark Matter Experiment : CDMS

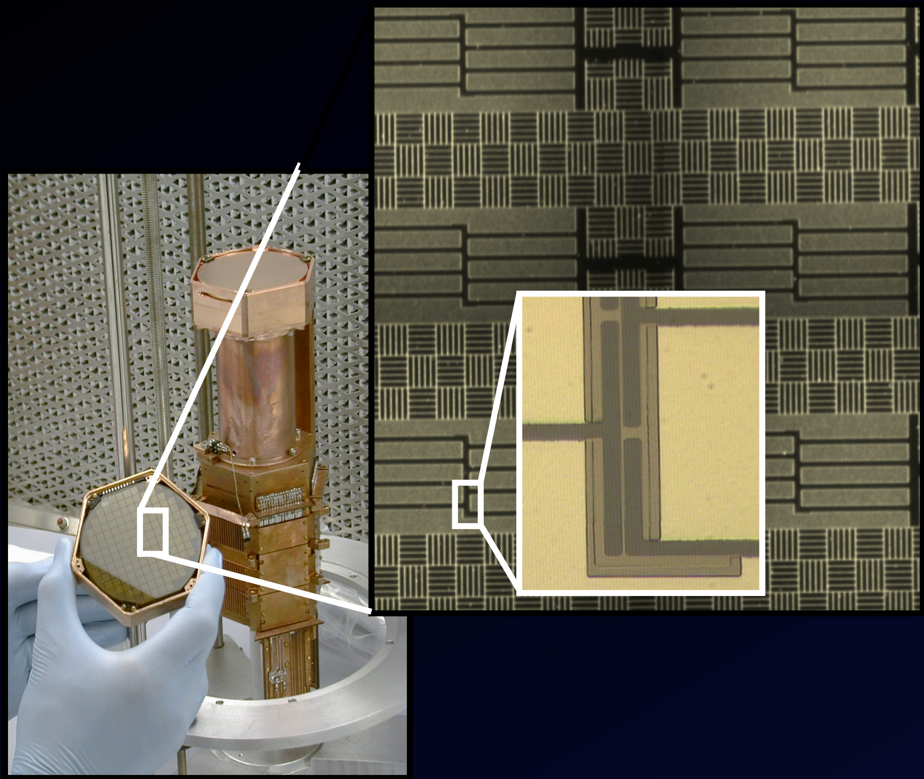
Cryogenic **D**ark **M**atter **S**earch

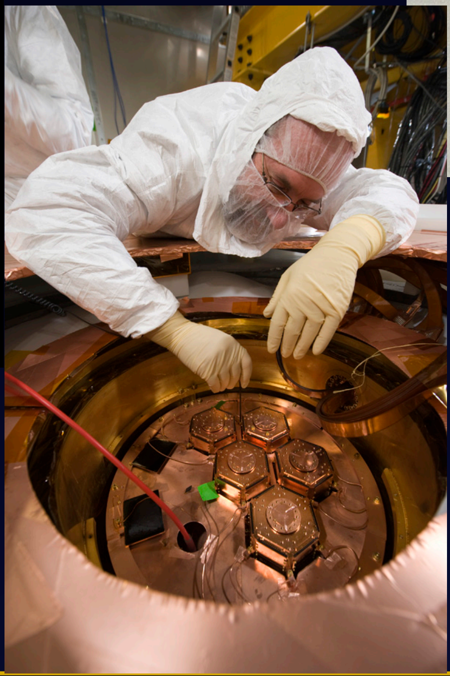
began in my old mine, in Soudan, MN, 714m underground, now also moving to SNOLab

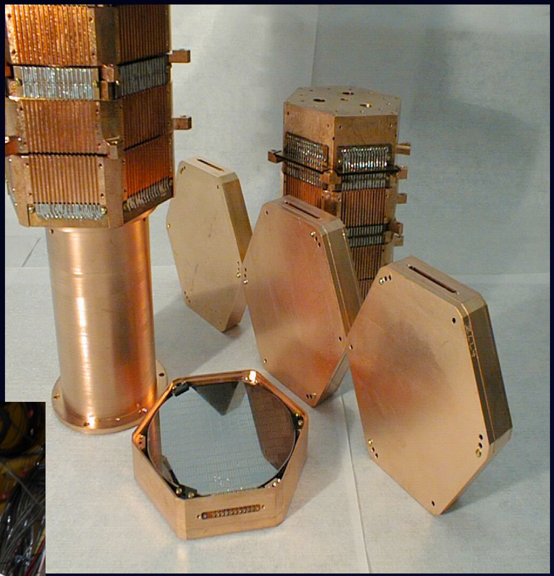
CDMS Detection Technique

- WIMPS will produce a vibration (they are massive) but will not produce a charge when it interacts (they are electrically neutral).
- Cool detector so (close to) nothing is vibrating in a natural state; temperature 40mK (about 1/7000ths of the temperature of a cold winter day in Vancouver): tiny sensors detect tiny vibrations, phonons.
- Use Germanium, Silicon (transistor, solar cell material) to detect charge: grid on one side of disk measures electric charge.
- biggest background is from electrons coming from photons

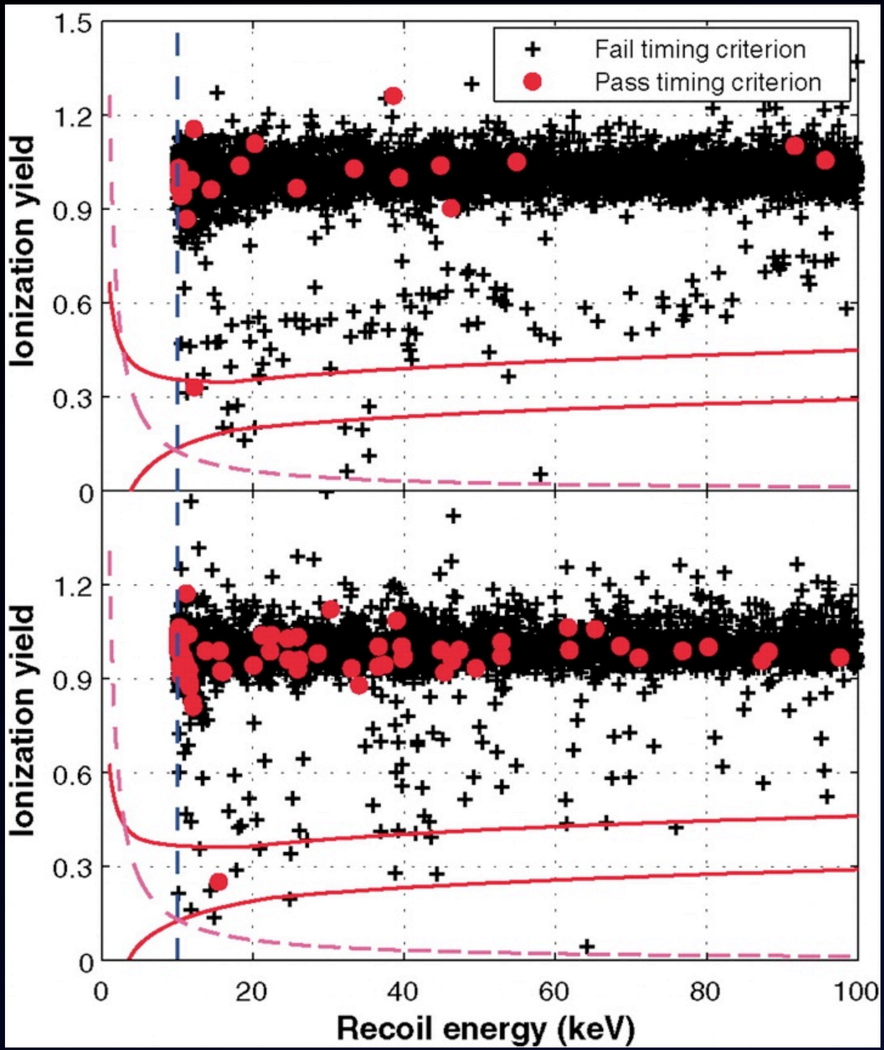
CDMS Detectors







CDMS Data

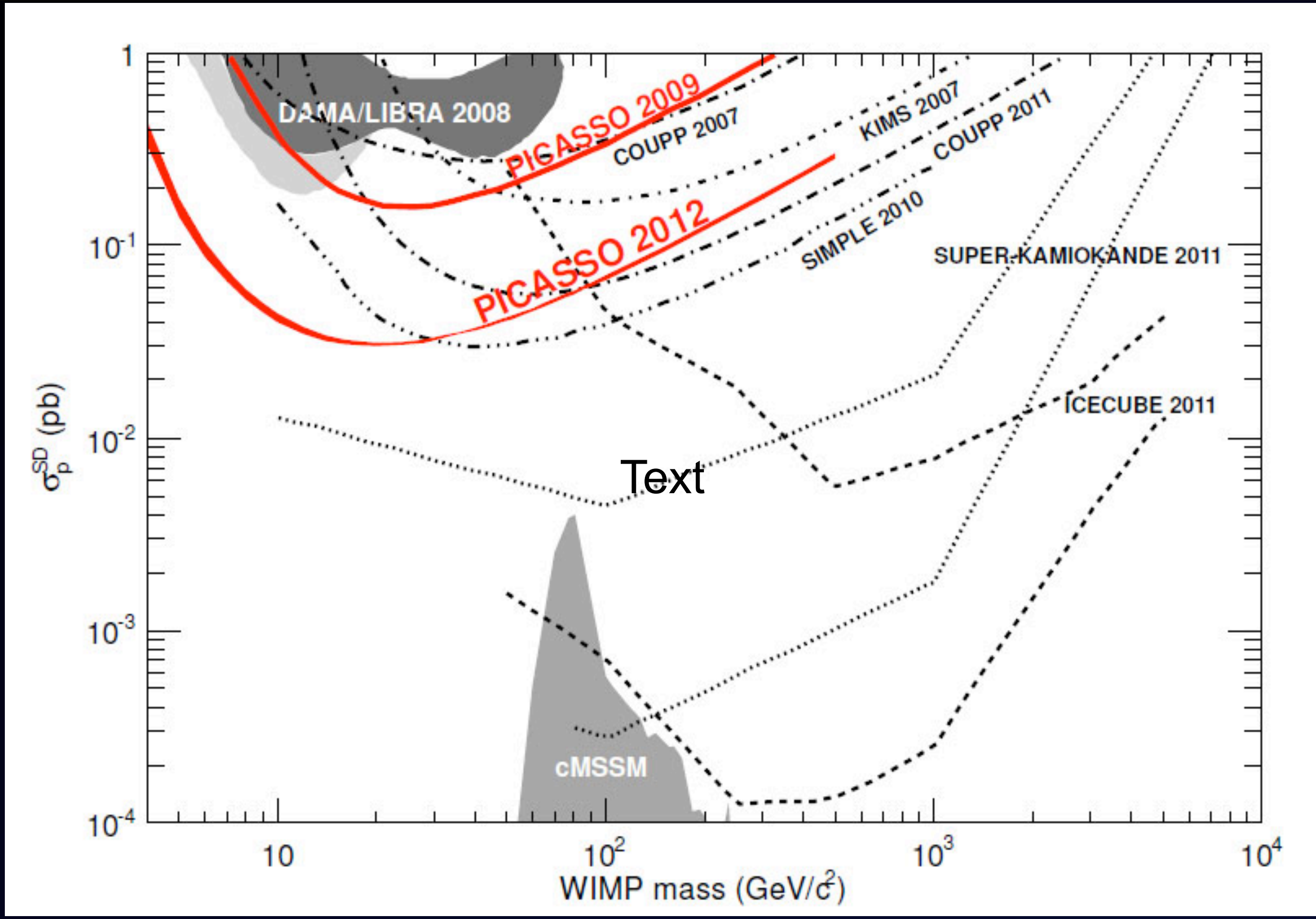


The band around 0.3 ionization yield is the acceptance of WIMPS (from neutron calibration)

- 2 candidate events
- they expected 0.9 +/- 0.2
- not statistically significant to claim discovery

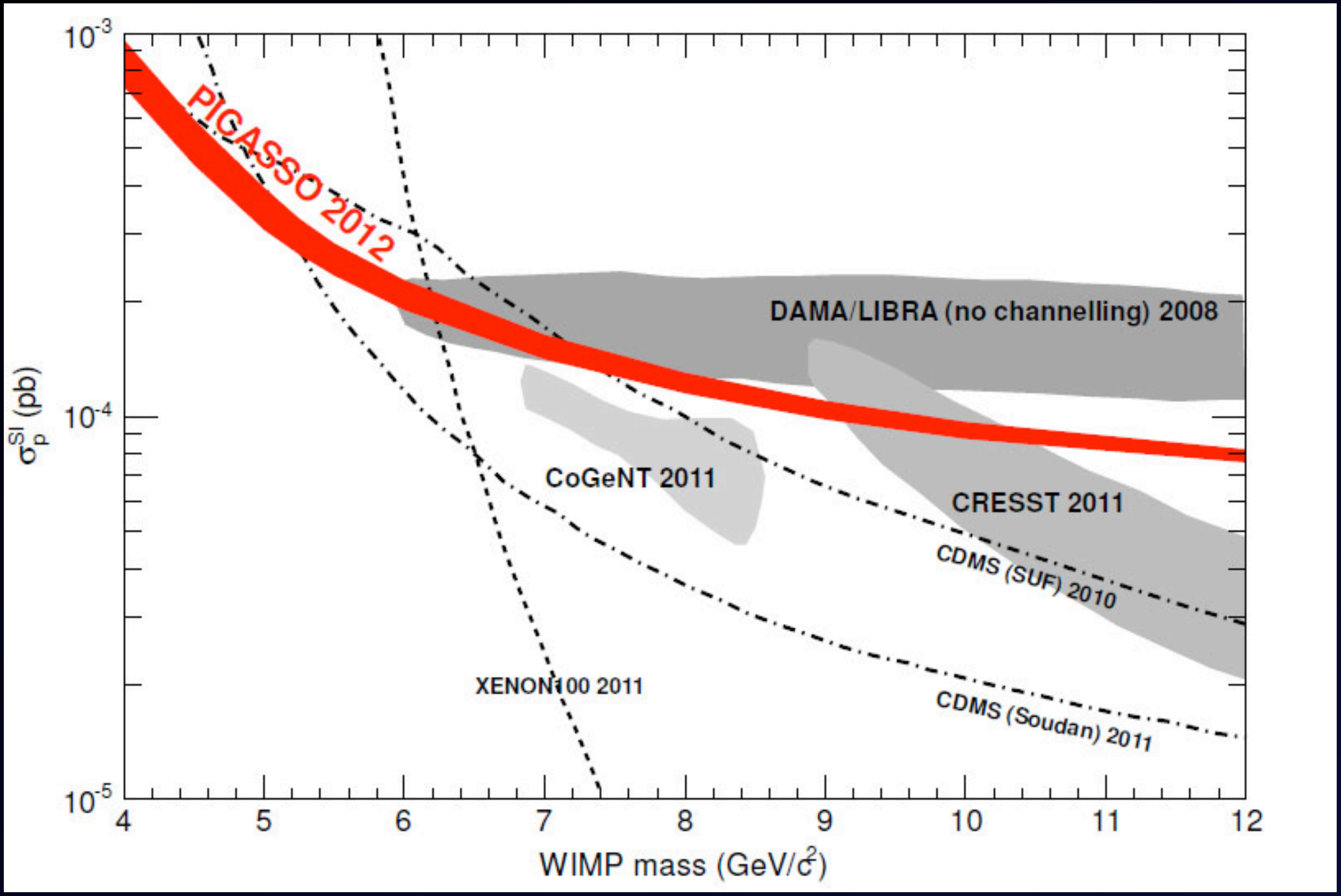
Status of Dark Matter Experiments

Results of Spin-dependent Experiments



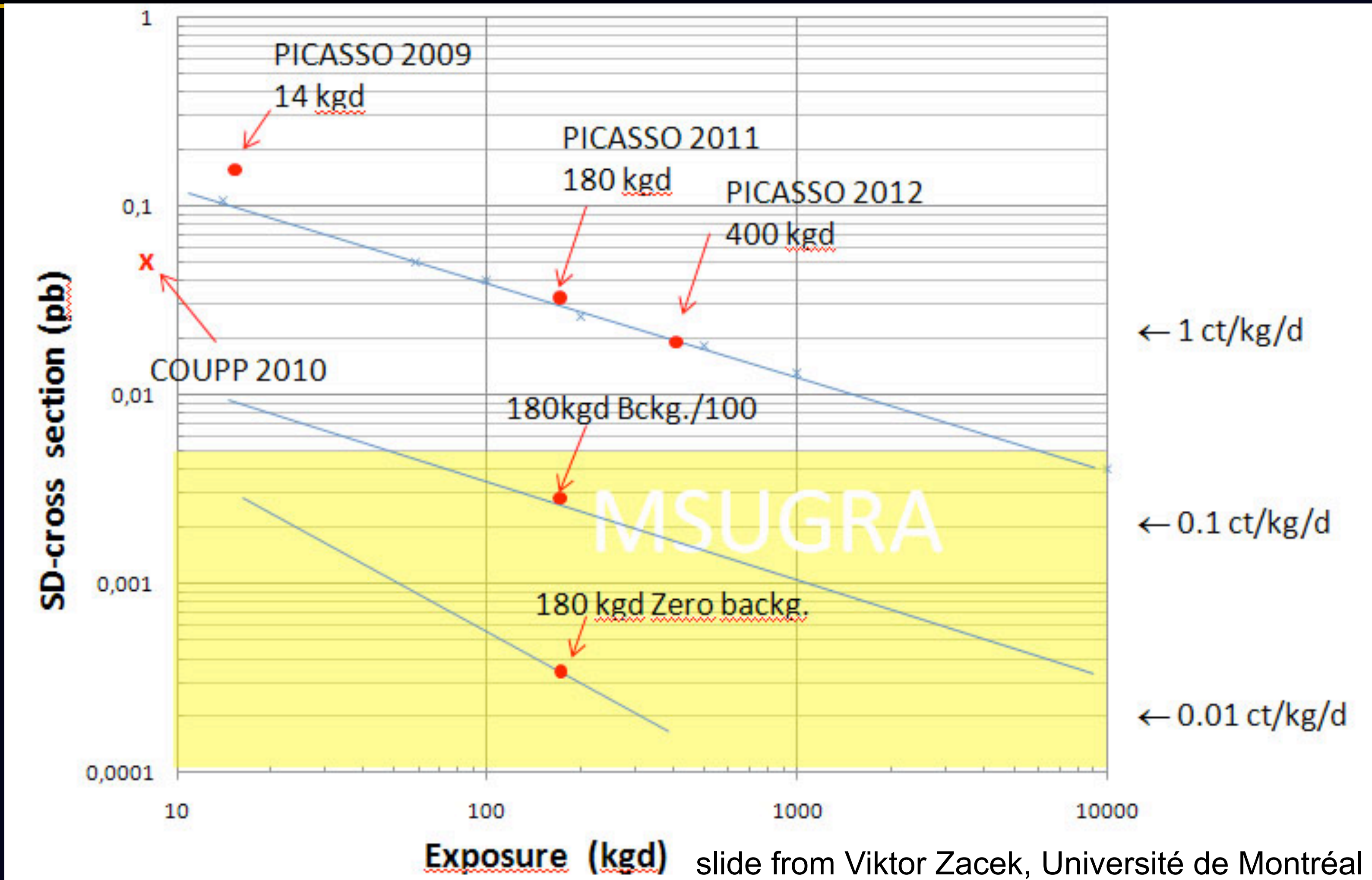
PICASSO Collaboration,
Phys.Lett.B711:153-161,2012

Results of Spin-independent Experiments



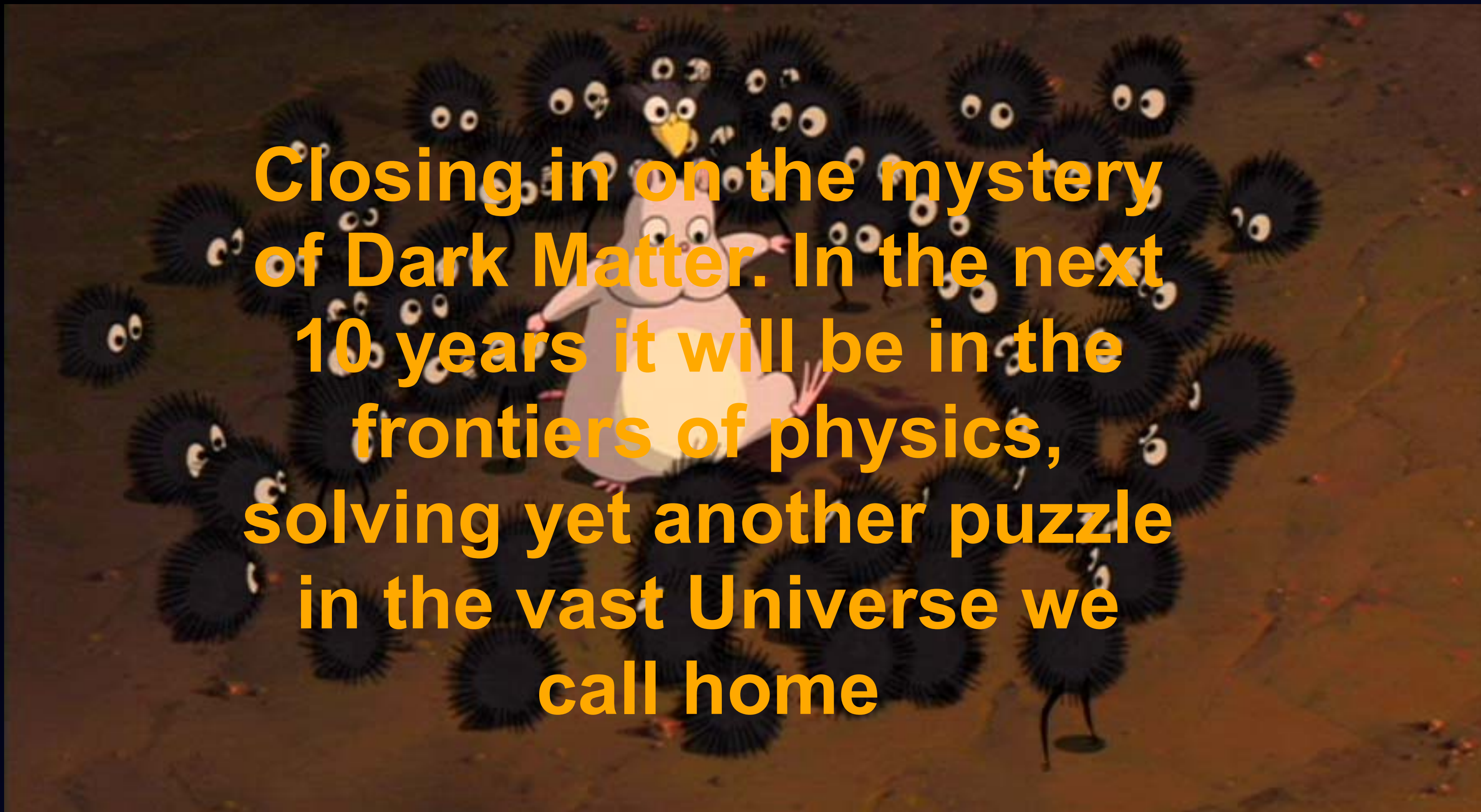
PICASSO Collaboration, Phys.Lett.B711:153-161,2012

Status of Dark Matter Experiments and their Theory



slide from Viktor Zacek, Université de Montréal

Closing in on the mystery of Dark Matter. In the next 10 years it will be in the frontiers of physics, solving yet another puzzle in the vast Universe we call home



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