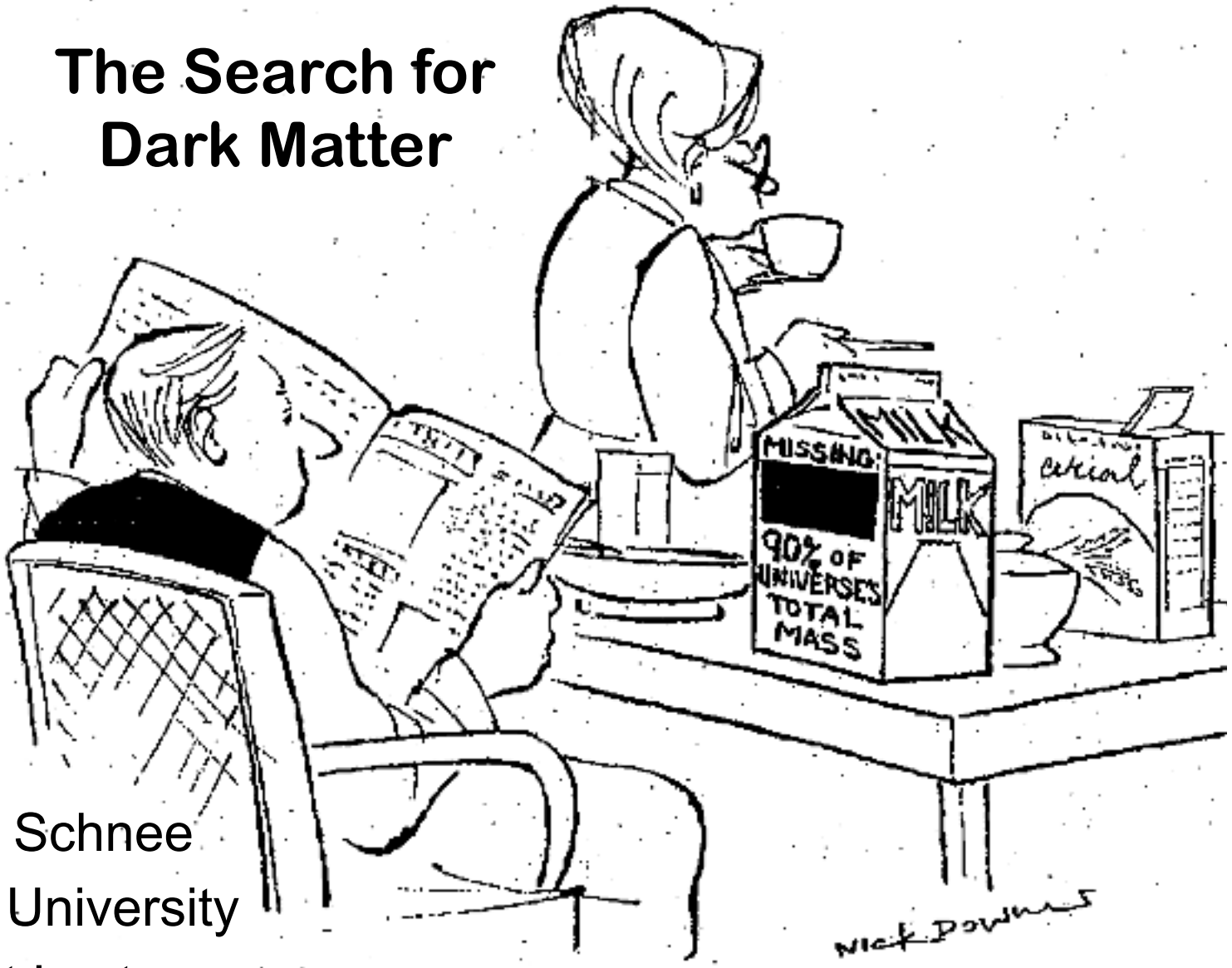
What's the Matter in the Universe?

The Search for Dark Matter

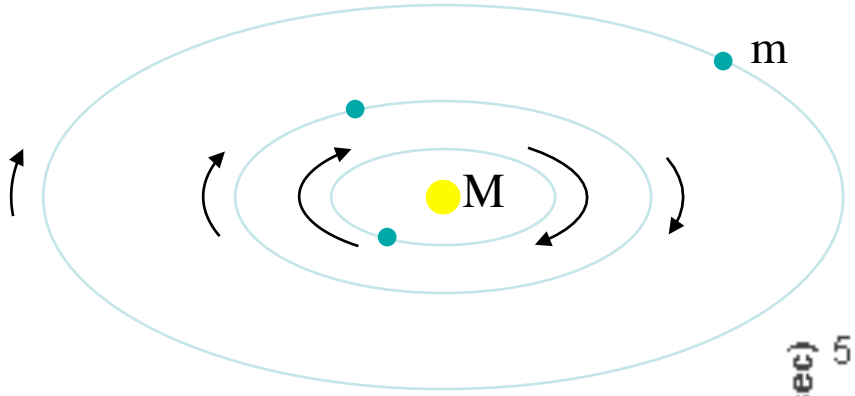


Richard Schnee
Syracuse University

Quarknet Lecture

July 13, 2012

Is there Mass where there is no Light?



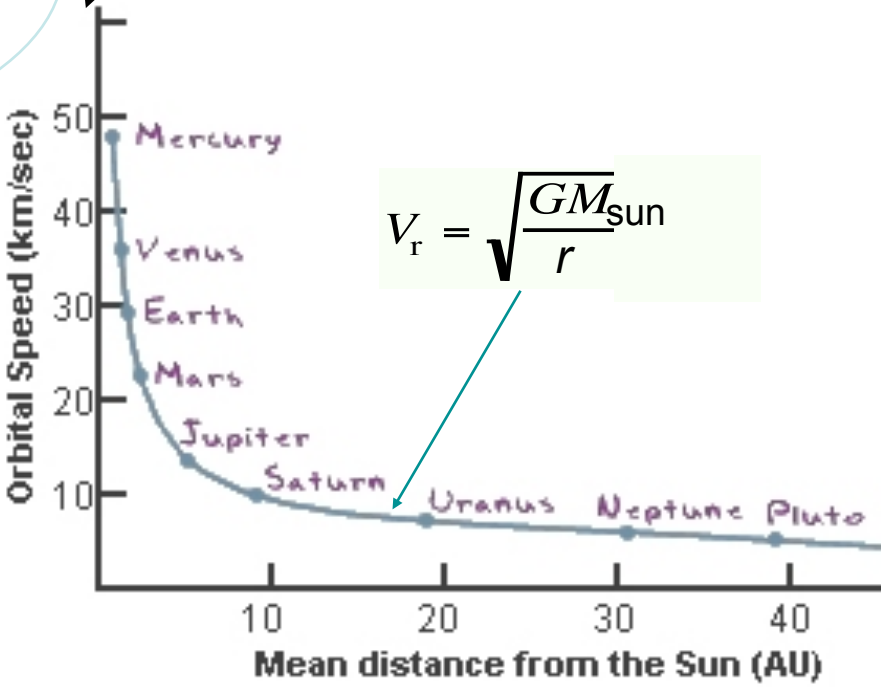
$$F_{\text{centripetal}} = F_{\text{gravity}}$$

$$\frac{mV_r^2}{r} = \frac{GmM_{\text{total}}(r)}{r^2}$$

$$V_r = \sqrt{\frac{GM_{\text{total}}(r)}{r}}$$

If mass of solar sytem is where the light is, $M(r)$ is constant, so $v = k / \sqrt{r}$

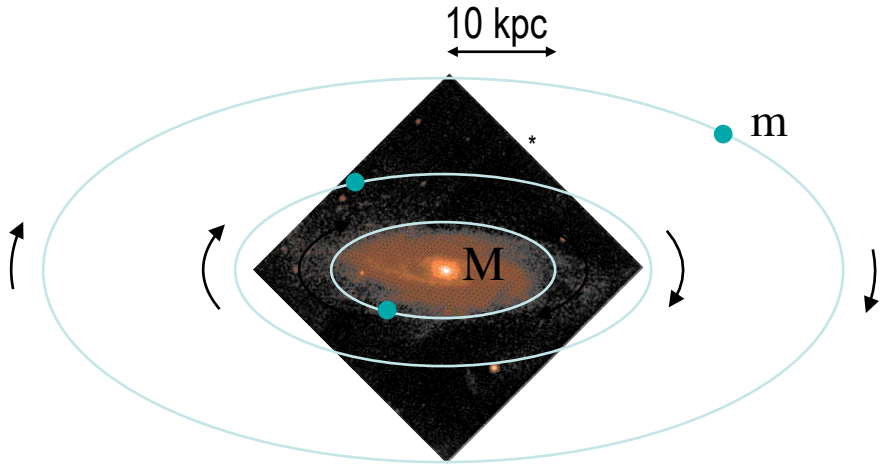
Solar system



$$V_r = \sqrt{\frac{GM_{\text{sun}}}{r}}$$

In the solar system, >99.7% of the mass is where the light (i.e. the sun) is. The (dark) planets don't count for much…

Is there Mass where there is no Light?



$$F_{\text{centripetal}} = F_{\text{gravity}}$$

$$\frac{mV_r^2}{r} = \frac{GmM_{\text{total}}(r)}{r^2}$$

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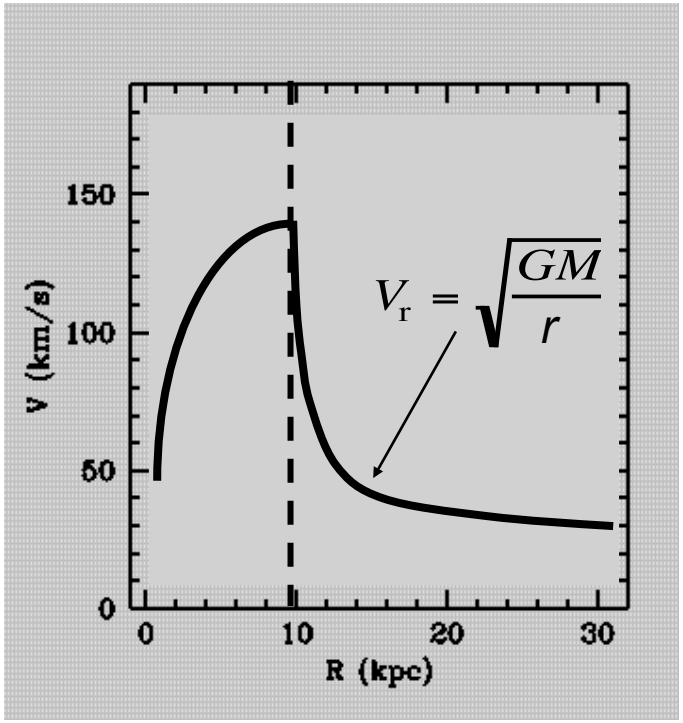
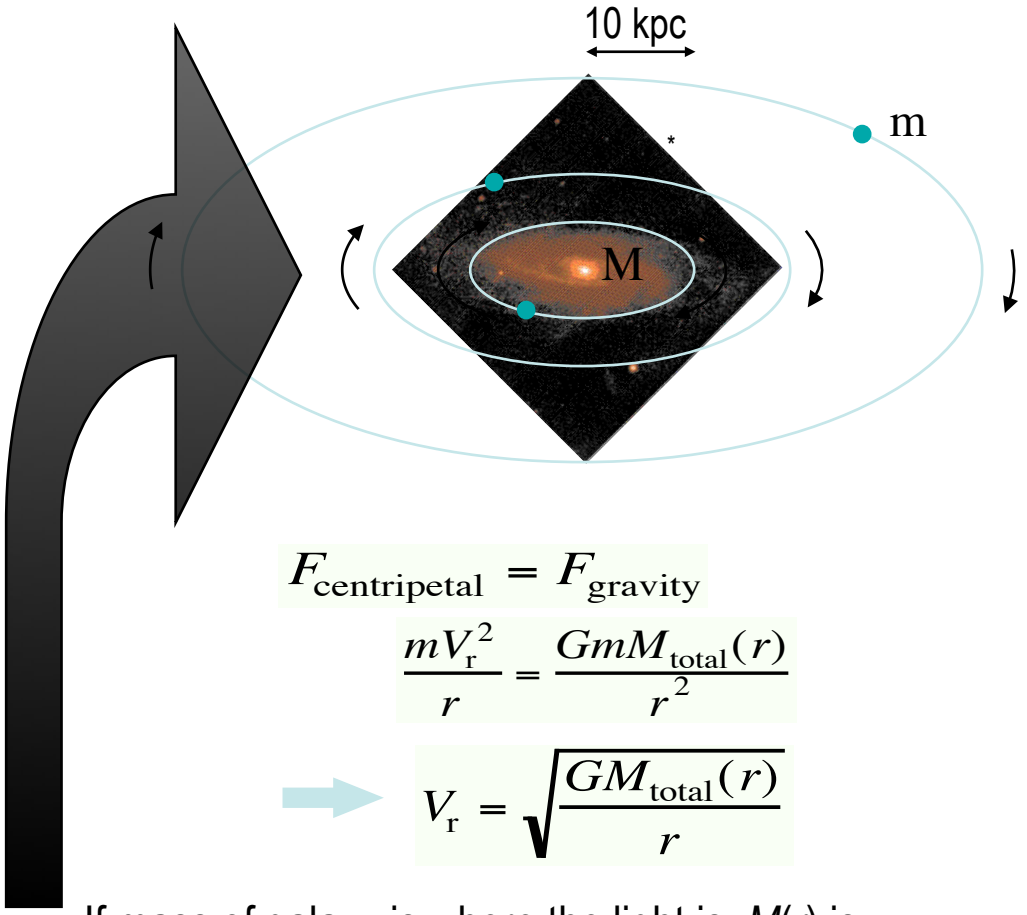
If mass of galaxy is where the light is, $M(r)$ is constant for $r > r_{edge}$, so $v = k / \sqrt{r}$

Galaxy



* Galaxy image from DSS2 5" x 5"

Is there Mass where there is no Light?



Galaxy

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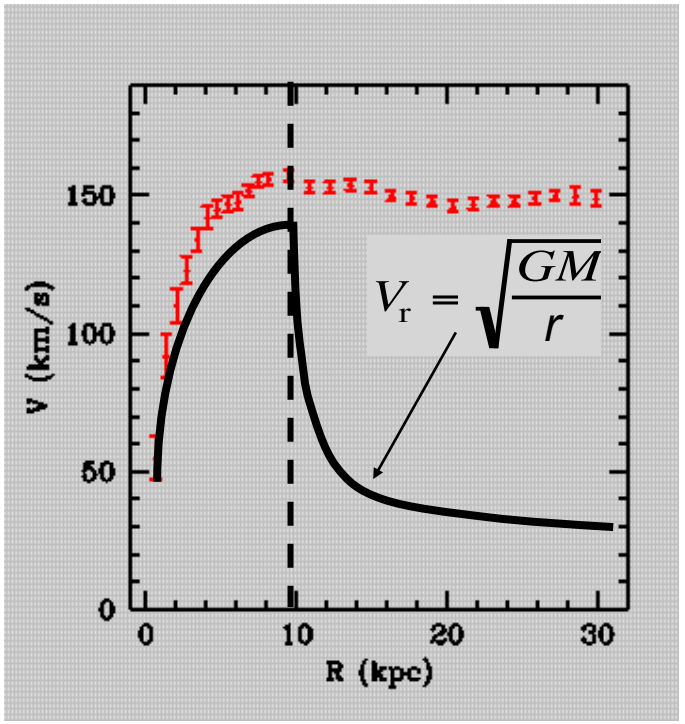


§

If mass of galaxy is where the light is, $M(r)$ is constant for $r > r_{edge}$, so $v = k / \sqrt{r}$

Must be mass where there is no light:

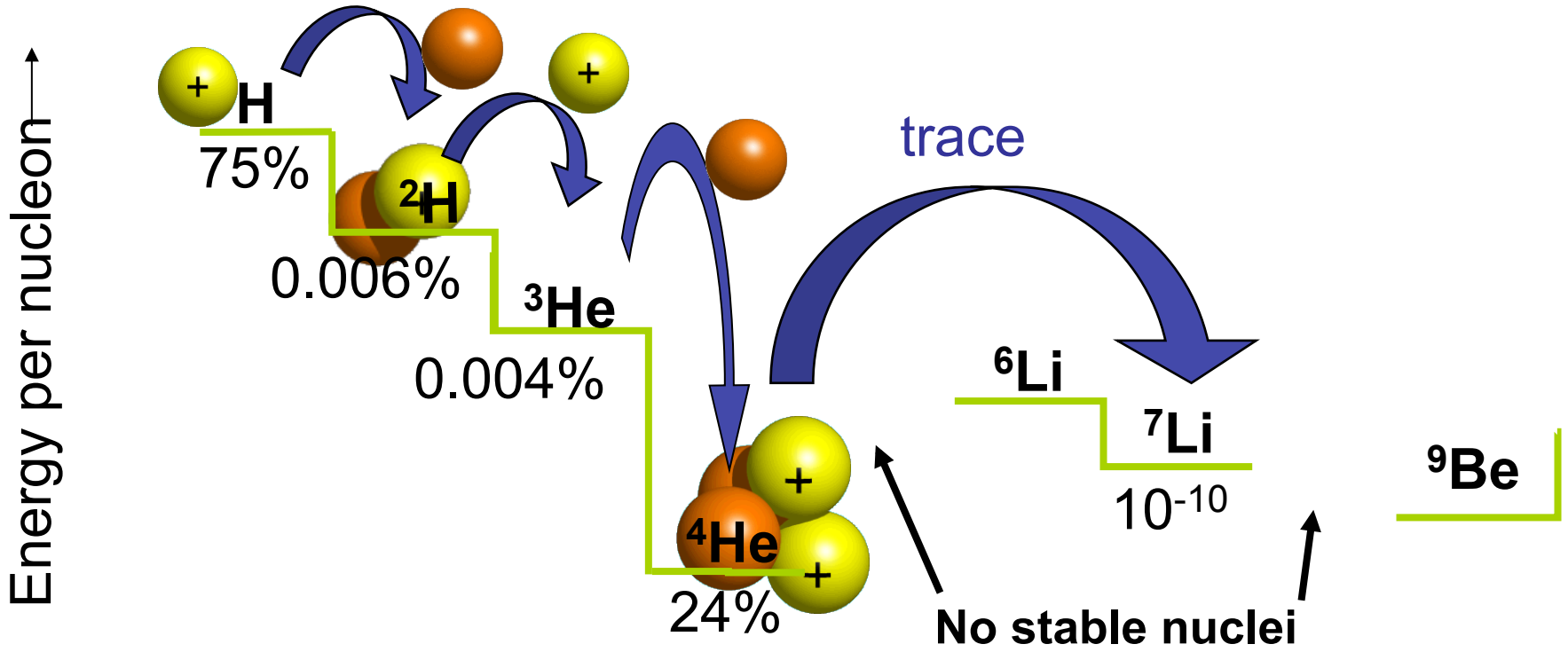
Dark Matter density $\rho_{DM} \geq 10\ \rho_{stars}$

* Galaxy image from DSS2 5" x 5"

§ Rotation curve for the galaxy NGC3198 from Begeman 1989

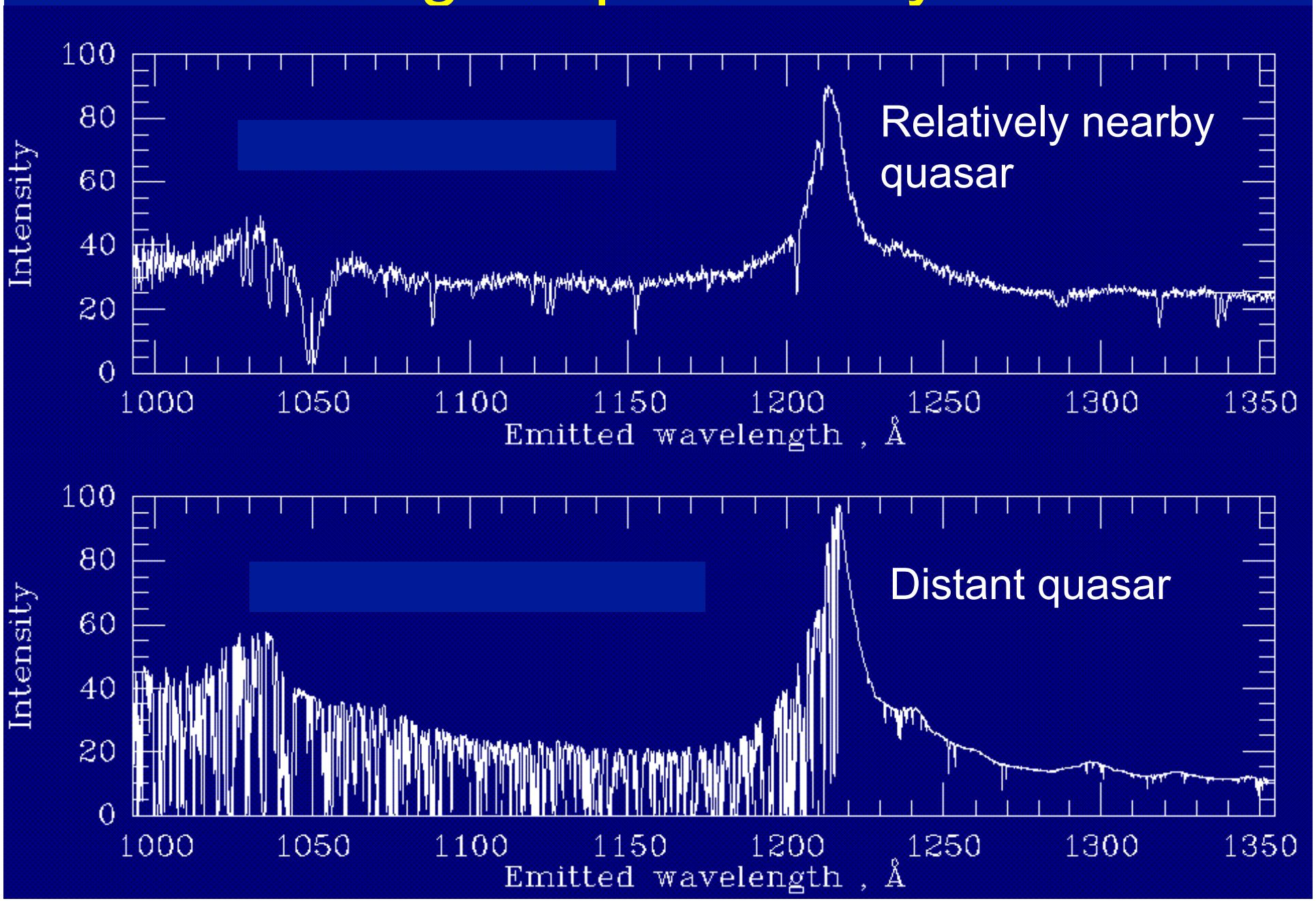
Could the Dark Matter be "Normal" Stuff?

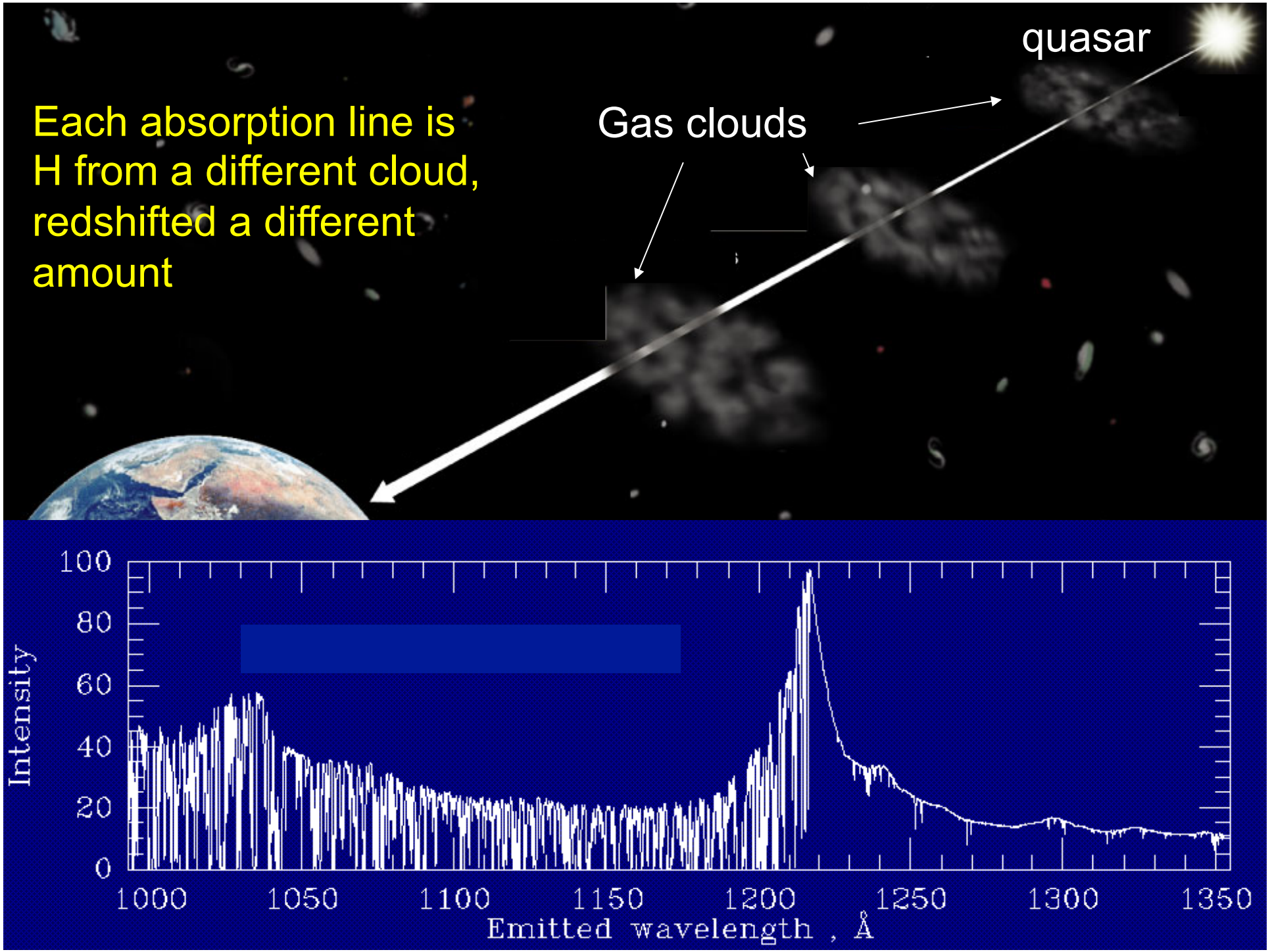
- Can determine total amount of protons and neutrons ("baryons") in the universe by how much deuterium formed in first 30 minutes of universe



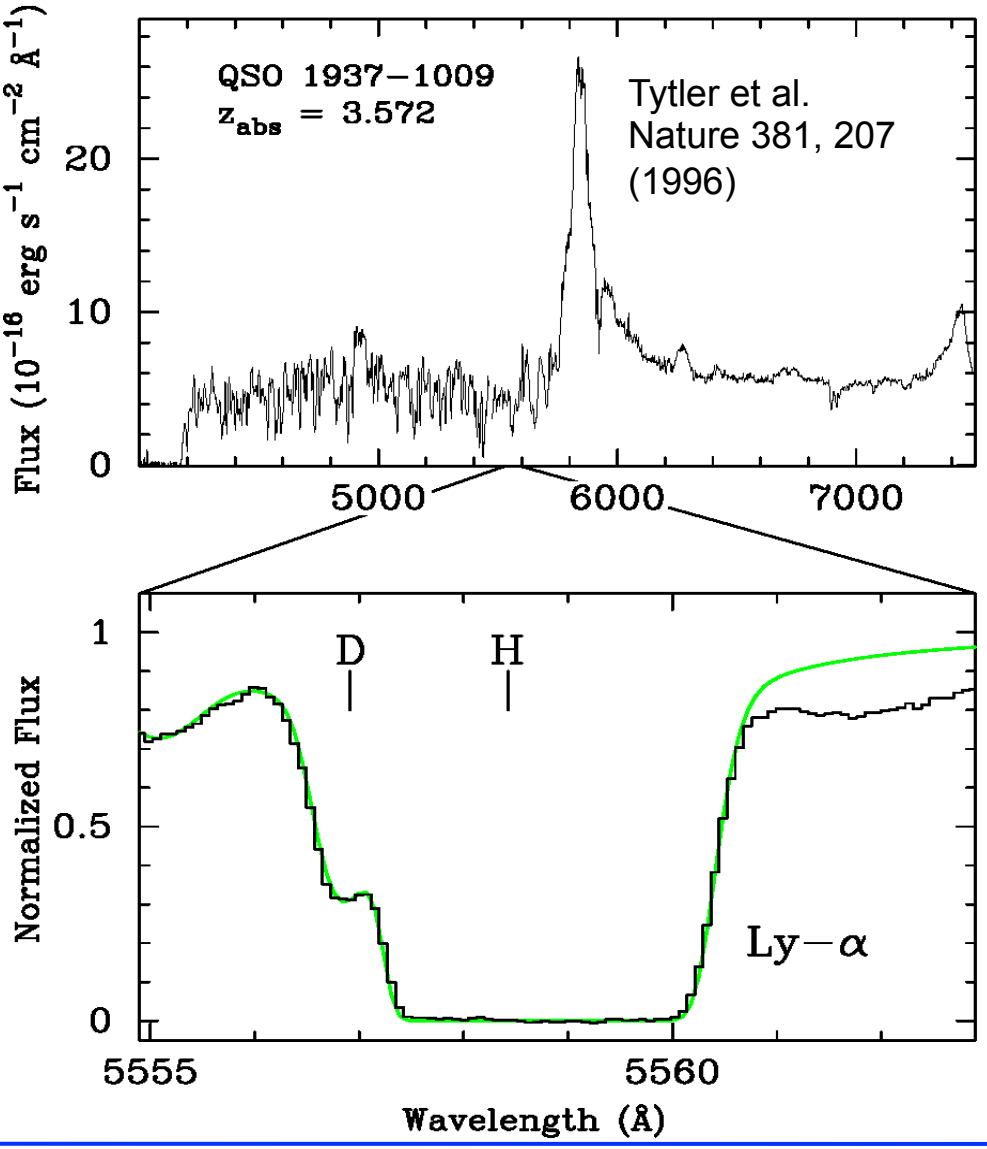
- More protons and neutrons would make reactions go faster, resulting in less "leftover" ^{2}H, ^{3}He

Quasars Light Up the Early Universe




quasar
Gas clouds
Each absorption line is H from a different cloud, redshifted a different amount
Intensity
100
80
60
40
20
0
1000
1050
1100
1150
1200
1250
1300
1350
Emitted wavelength , Å

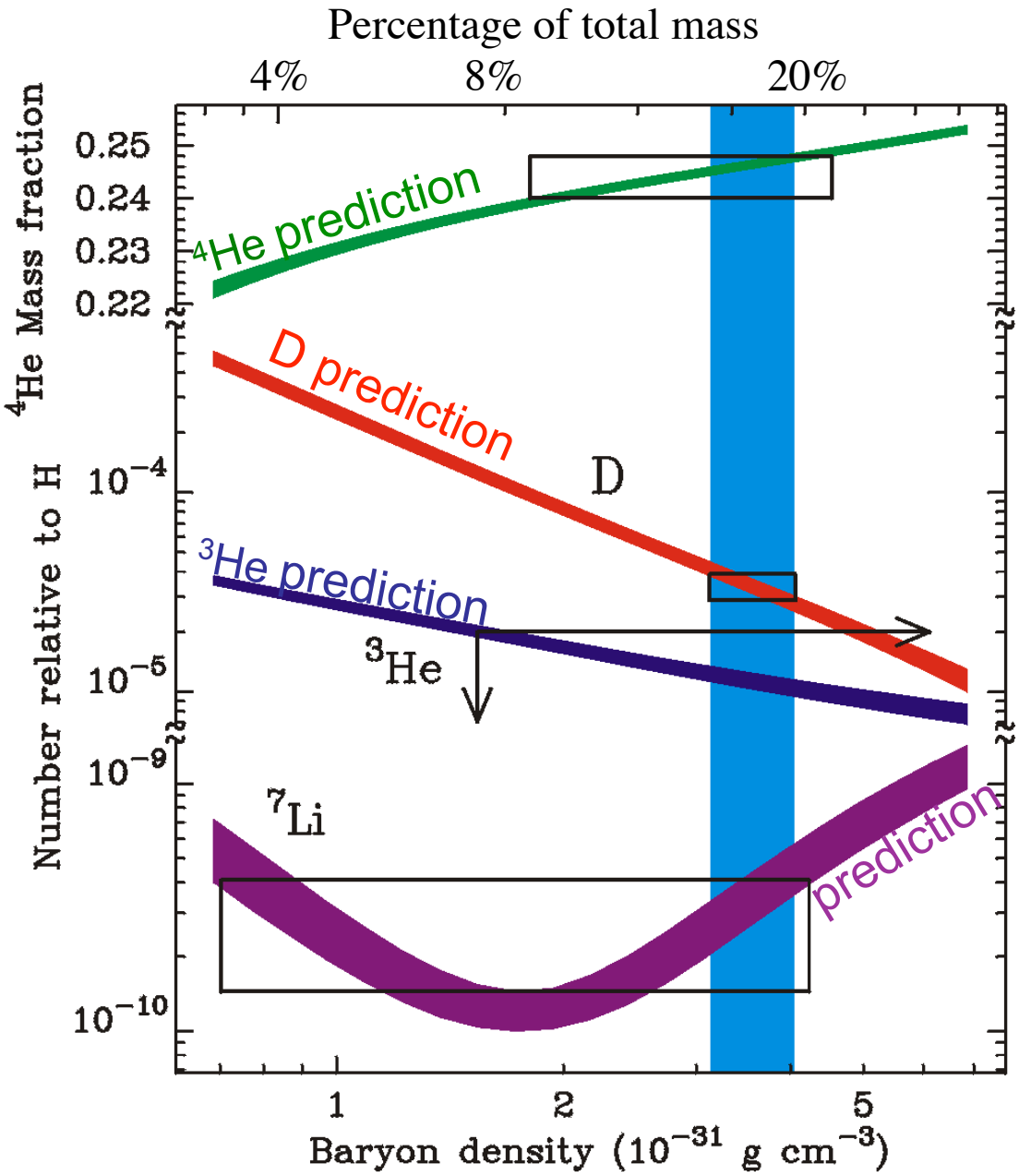
Deuterium Measurements



- Measure the amount of deuterium relative to hydrogen in some of these gas clouds
  - Compare number of photons absorbed by Hydrogen to number absorbed by Deuterium

Baryon Density

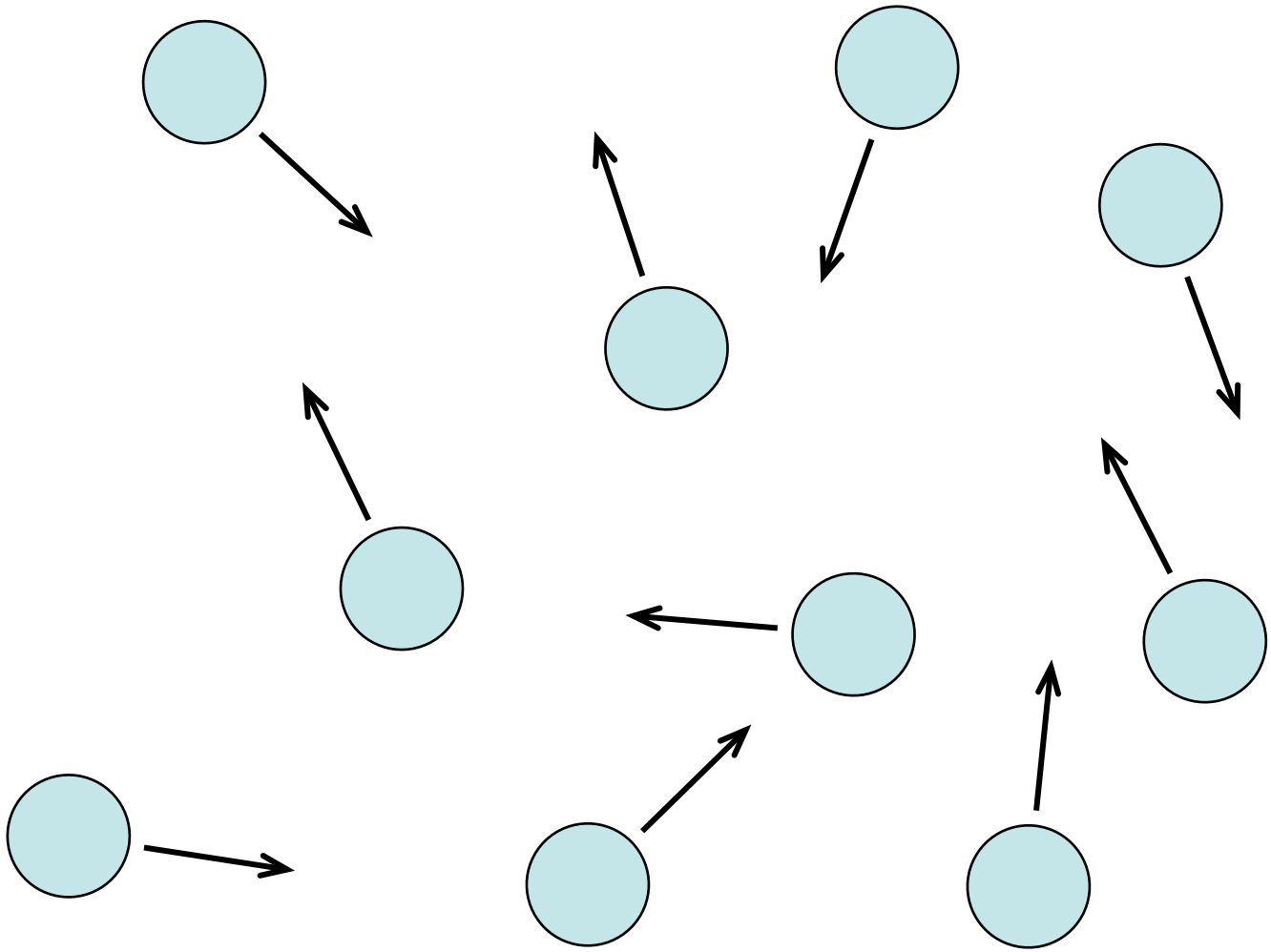
- Precisely measured deuterium abundance tells us the baryon density
  - Observations of other light element abundances consistent
  - Normal matter is only ~20% of the total mass in galaxies or clusters, as measured from gravitational effects



"Non-Baryonic" Dark Matter

- Unusual stuff… to us
  - Not made of atoms!
  - No such matter with the right properties has ever been observed!
    - Something new must exist!
- Particle physics would make a lot more sense if these additional particles exist… and these particles *may* be 80% of the mass density of the universe
  - Axions (searches I won't discuss are in progress)
  - WIMPs - Weakly Interacting Massive Particles
    - Massive: source of gravity
    - Weakly-interacting: not star-forming
    - Arise naturally under supersymmetry (and other favored extensions to the standard model of particle physics)

Definition: cross section ≡ probability of collision



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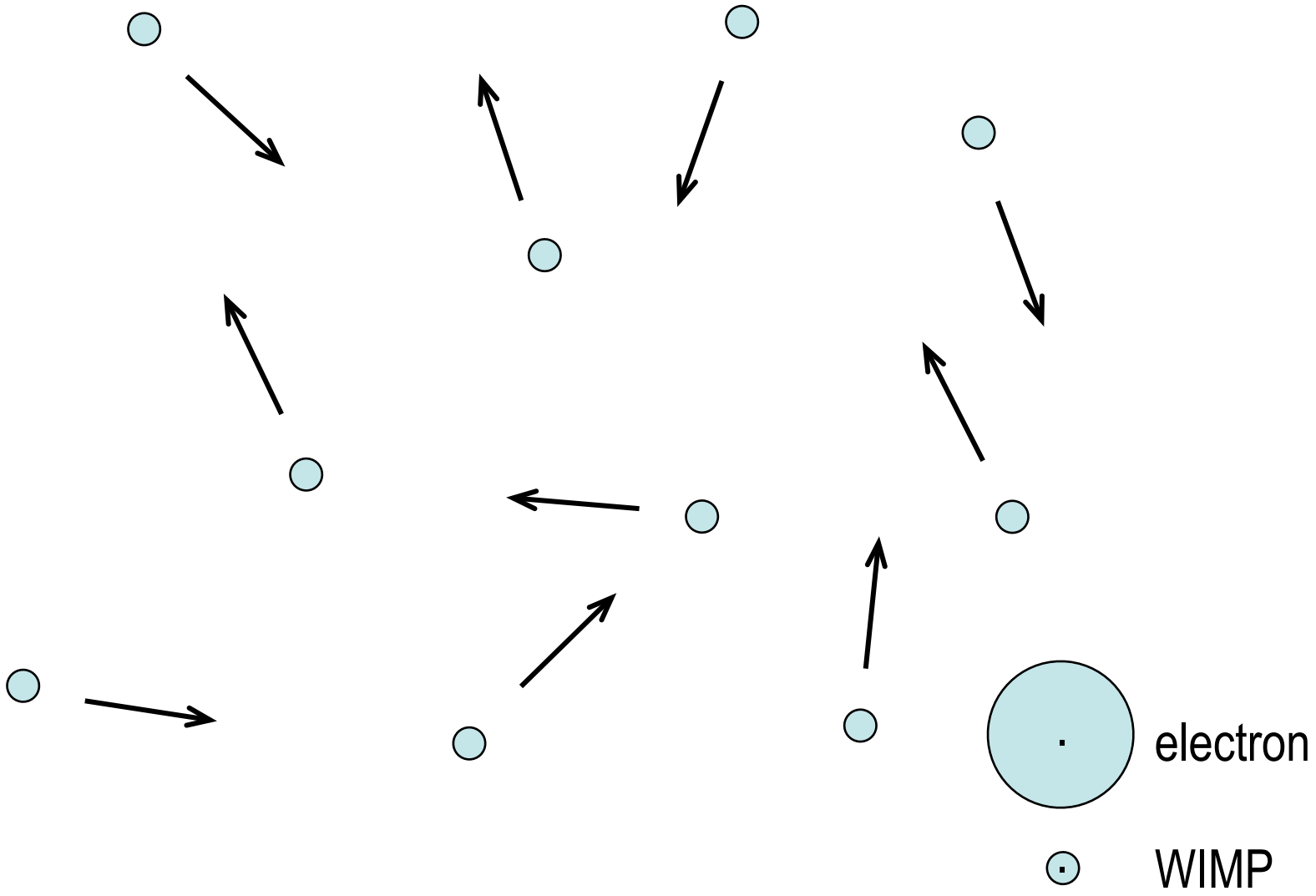
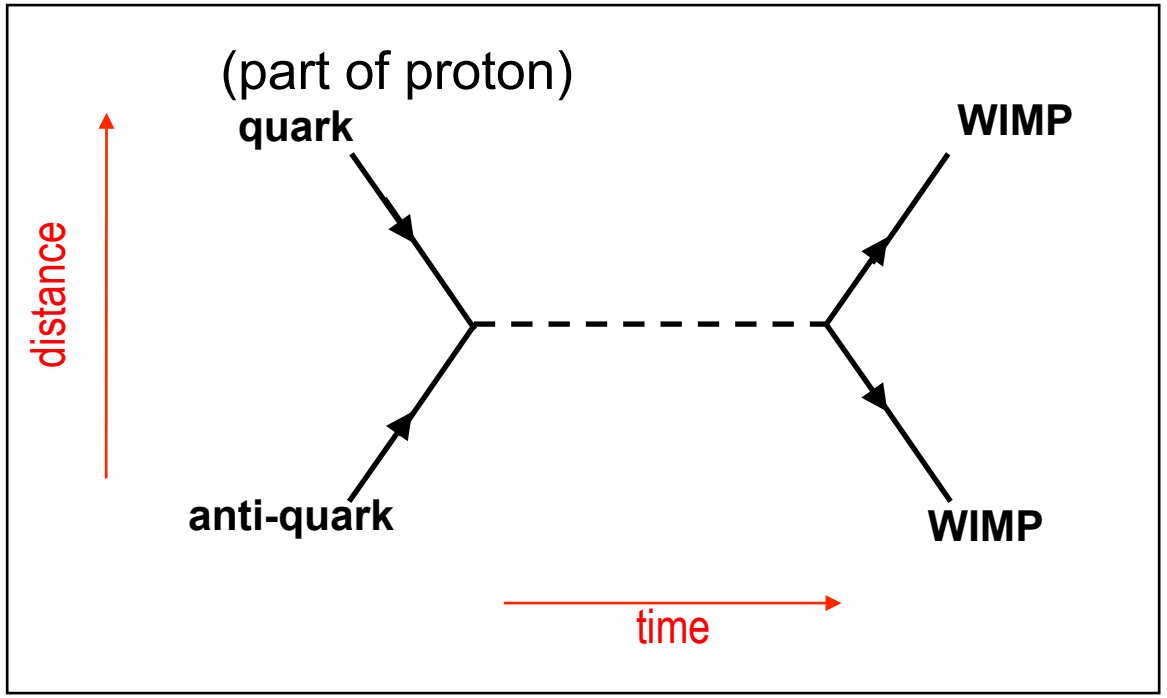


How are WIMPs Produced?

- Early Universe is a Particle Factory



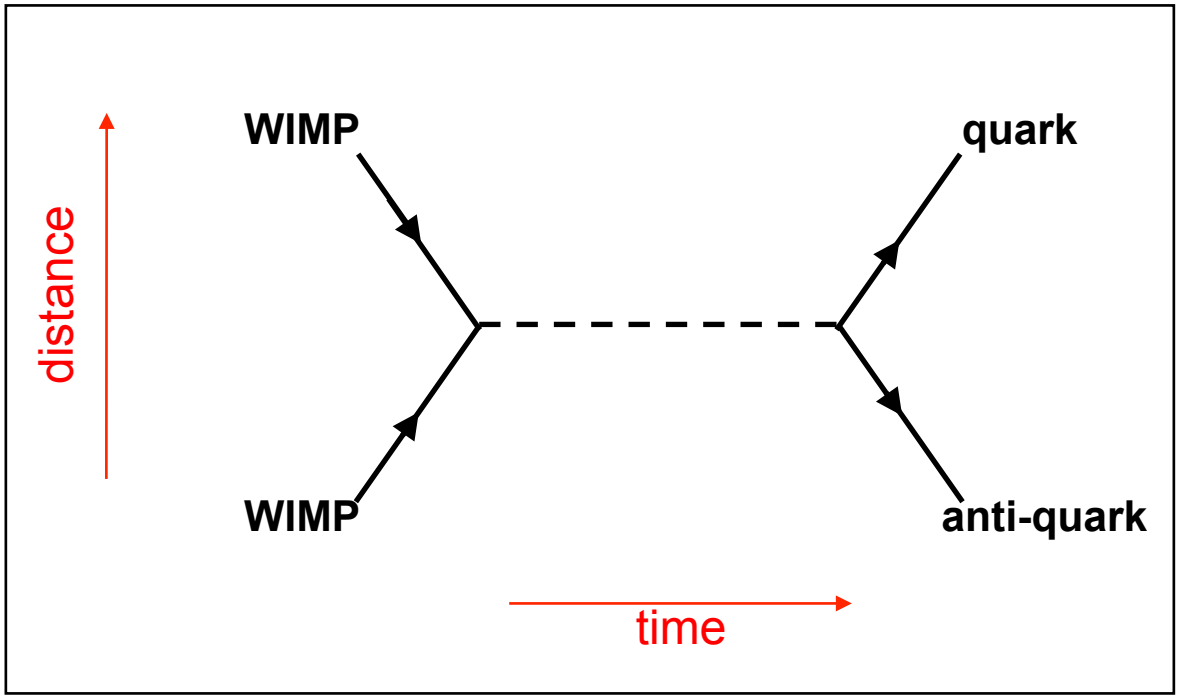
Convert energy to mass

$E=mc^2$

- When Universe expands/cools enough that particles have energy less than mc^2, WIMP production stops (to produce some today requires an expensive particle accelerator)

Still around?

Expanding Universe and Weak Interactions – annihilations stop if cross sections are small enough



There may be lots of WIMPs still around today.
Rough calculation suggests WIMPs would be ~80% of universe's mass!

Still around?

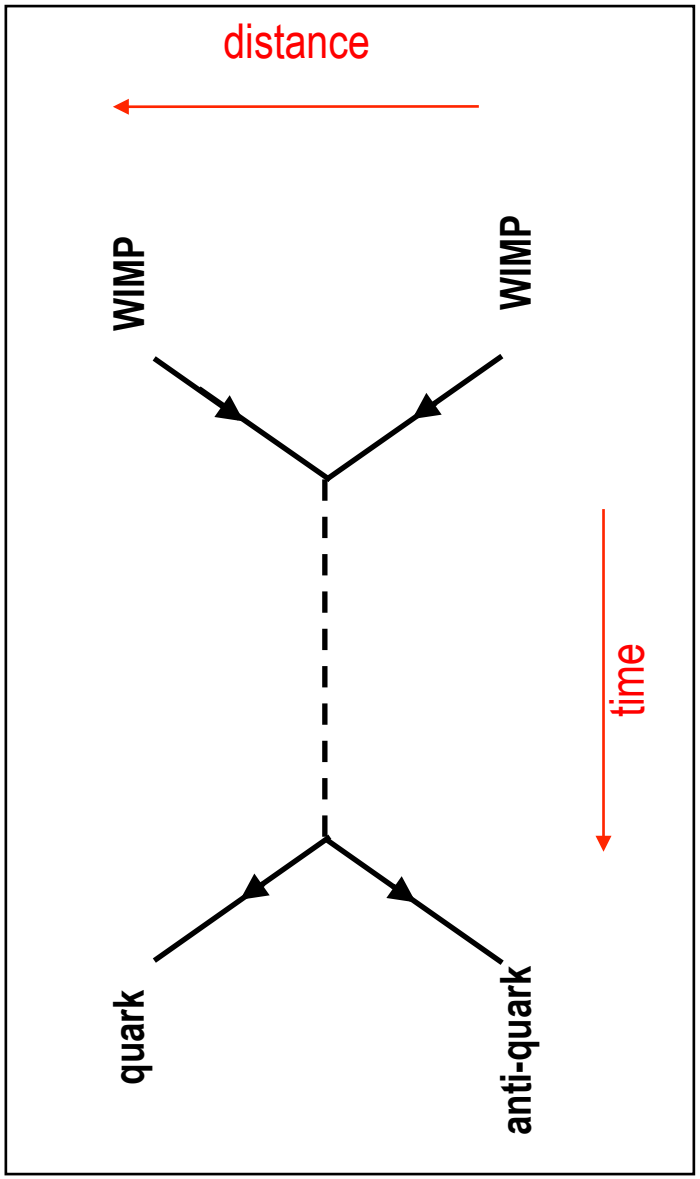
Expanding Universe and Weak Interactions – annihilations stop if cross sections are small enough

WIMPs would be most of the mass of our Galaxy

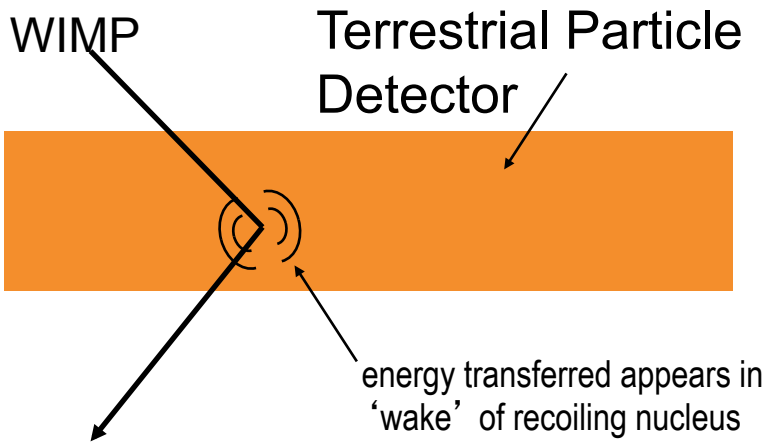
NUTRITIONAL WARNING: may contain ten 60-GeV WIMPs. 20 million WIMPs may pass through each second.

There may be lots of WIMPs still around today.
Rough calculation suggests WIMPs would be ~80% of universe's mass!

Annihilation implies Scattering

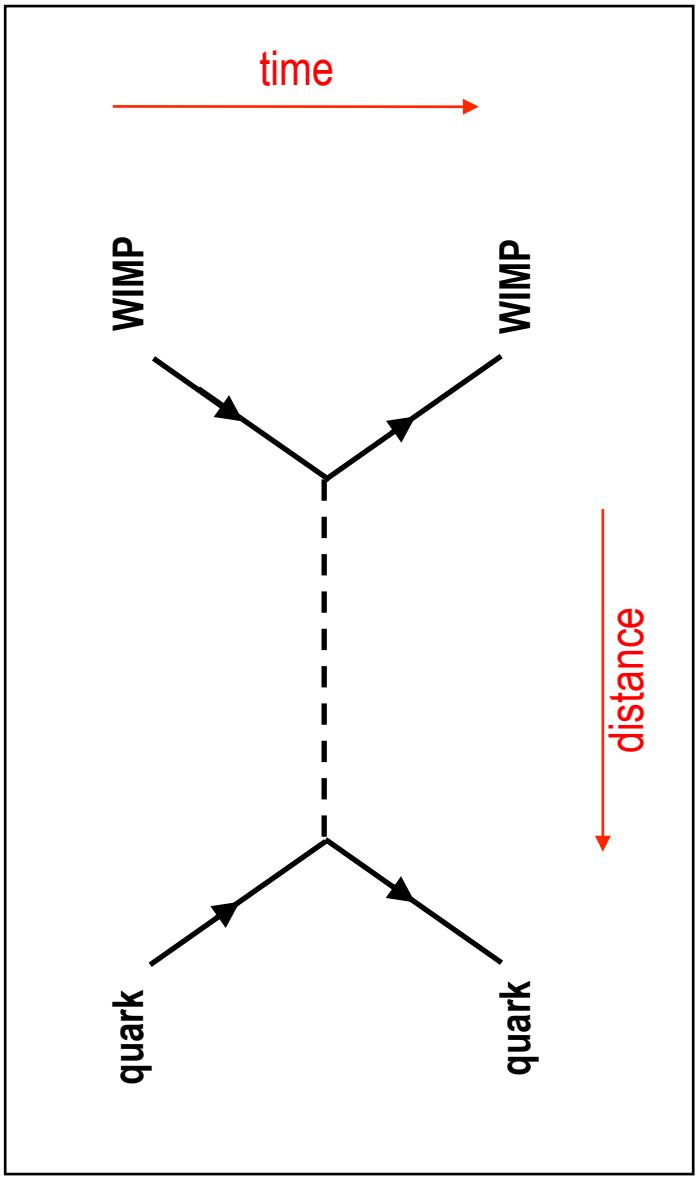


Occasionally, one of these billions of WIMPs might interact.



WIMP-Nucleus Scattering

Annihilation implies Scattering



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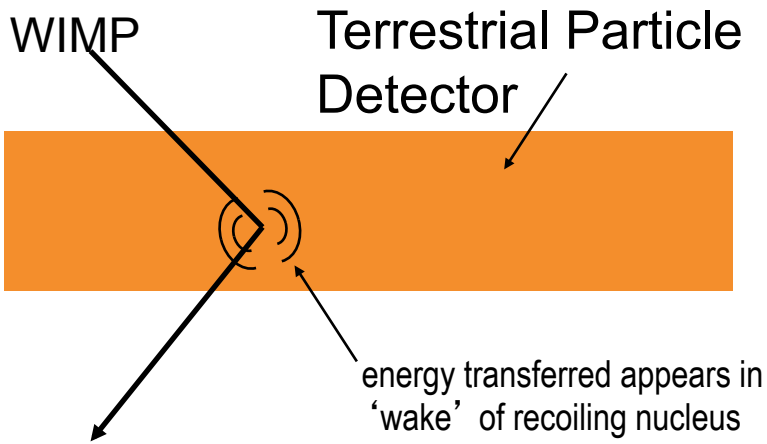


WIMP-Nucleus Scattering

Big Problem: weakly interacting. Expect less than one-a-year in a kilogram detector

Background Radioactivity: It's in the air

Collect dust particles on filter paper by vacuuming room air:

Background Radioactivity: It's in the air

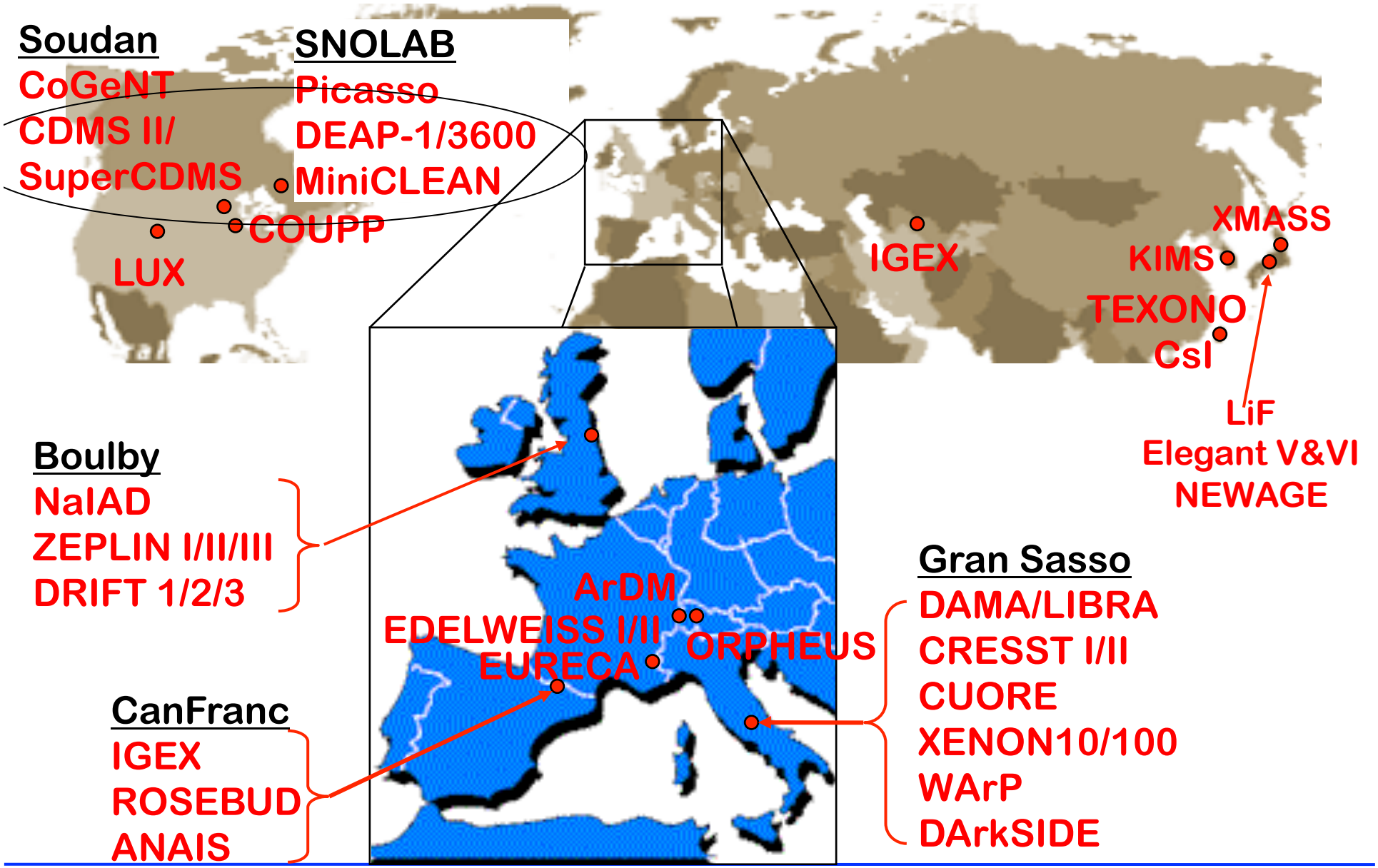
Then count the rate of radioactive decays with a Geiger counter:

What Nature has to Offer

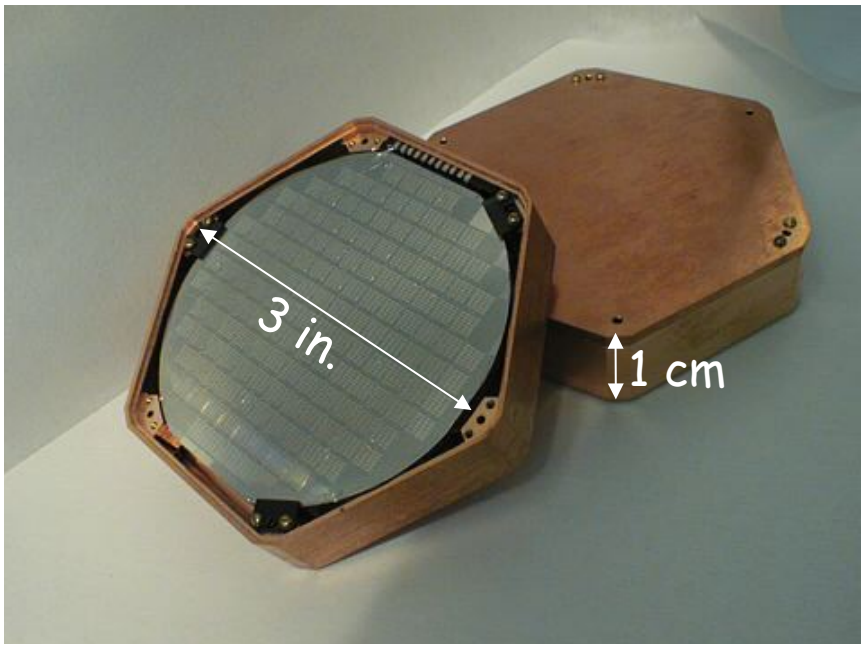
What we hope for!

D. S. Akerib

WIMP Detection Experiments Worldwide

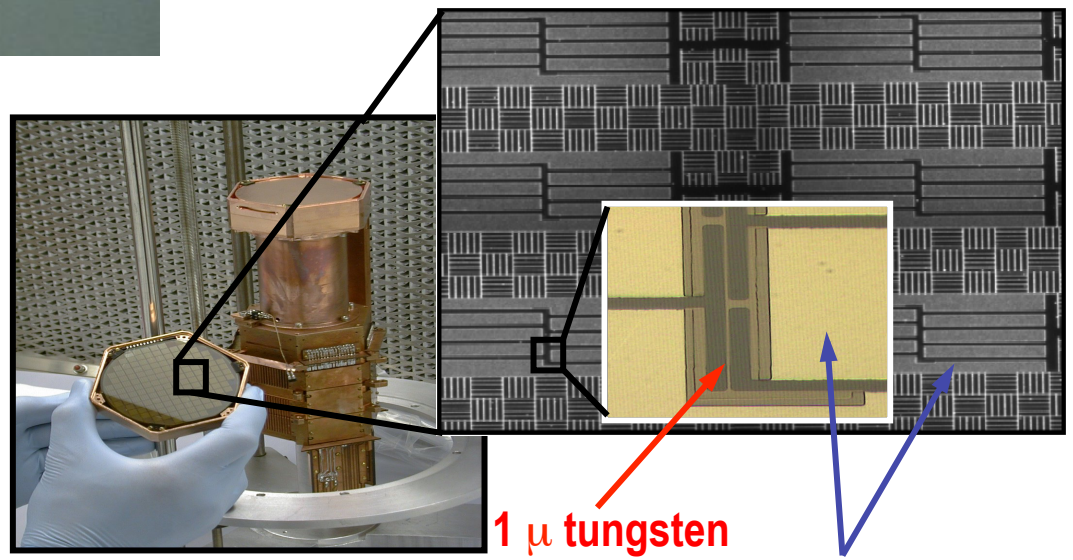


SuperCDMS:Really Cool Detectors



- Detectors sensitive to *individual particle interactions.*
- Cooled in ^{3}He-^{4}He dilution refrigerators using liquid nitrogen and liquid helium to 0.04° above absolute zero ("cryogenic")
- Tell WIMPs from non-WIMPs by measuring heating and ionization.

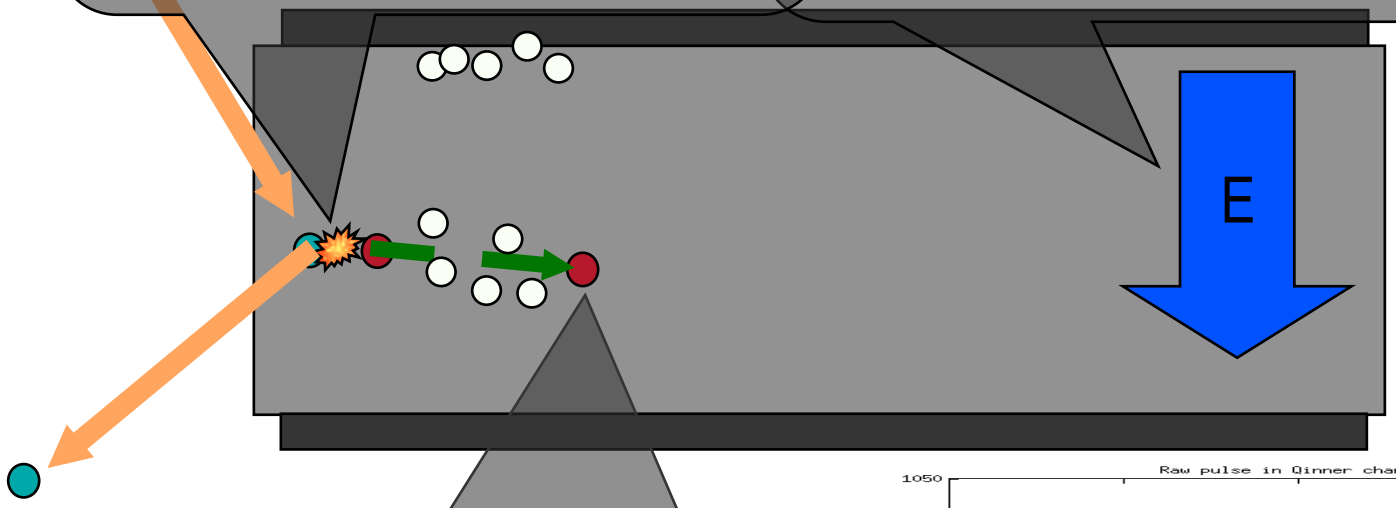
- Hockey puck of Ge with surface photolithography (like Si chips, but much larger)
- Our experiment is called the Cryogenic Dark Matter Search (CDMS/SuperCDMS)



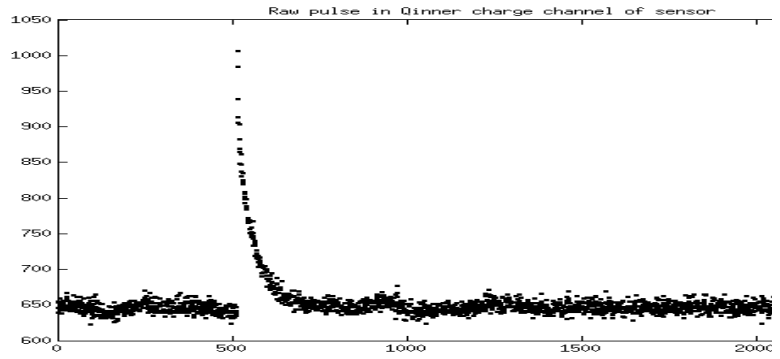
Measuring Ionization

An incoming particle scatters off of either an electron or a nucleus

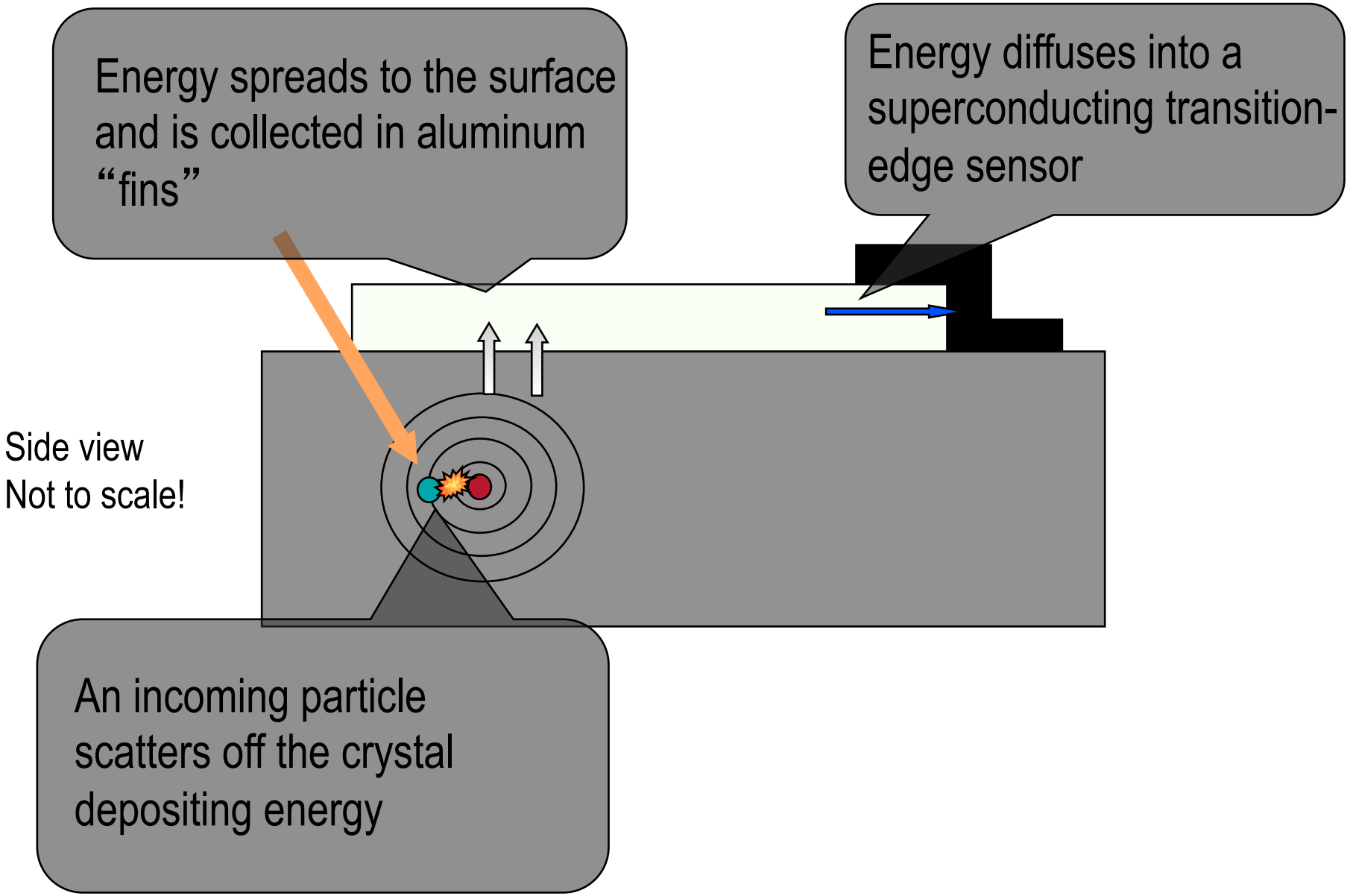
An applied Electric field drifts the charges to the surface, yielding a voltage signal



The recoiling electron or nucleus frees electrons as it travels through the semiconductor

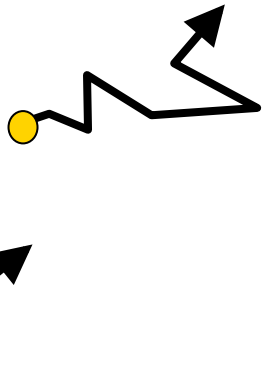


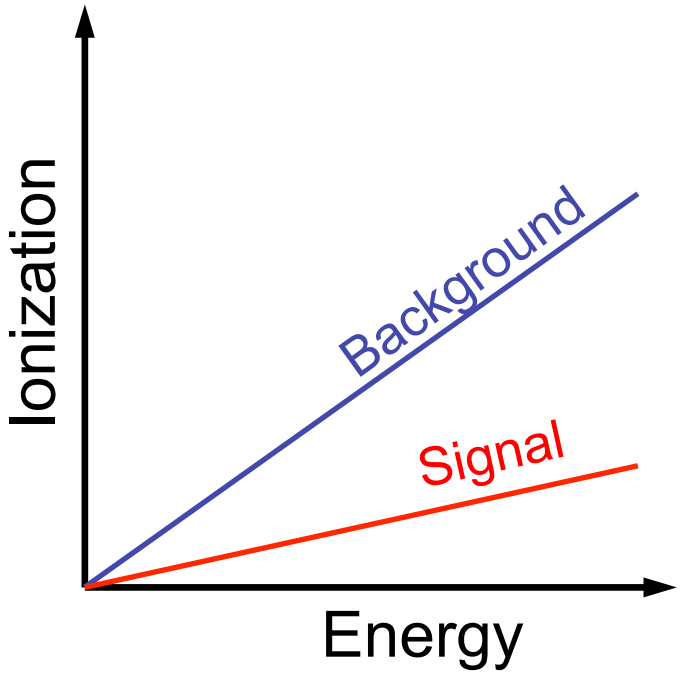
Measuring Deposited Energy

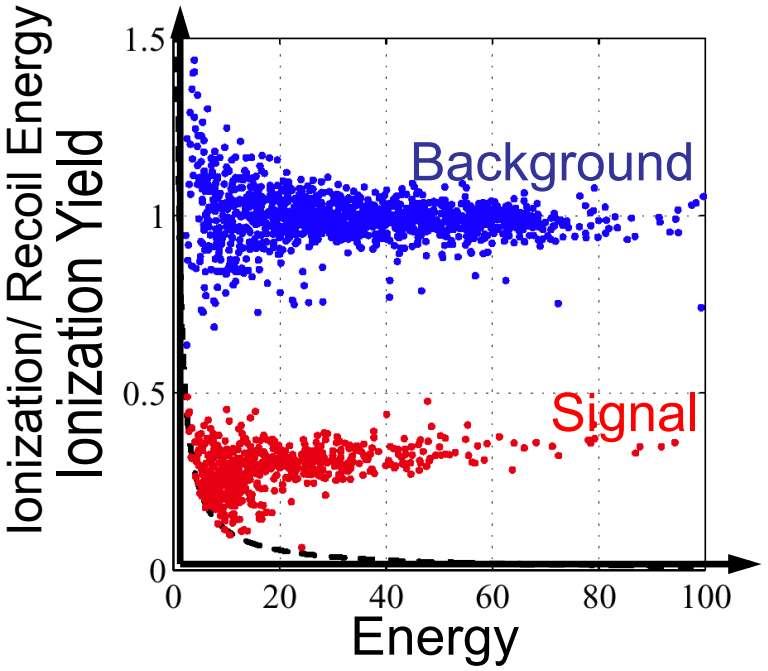


How CDMS Gets Rid of the Haystack

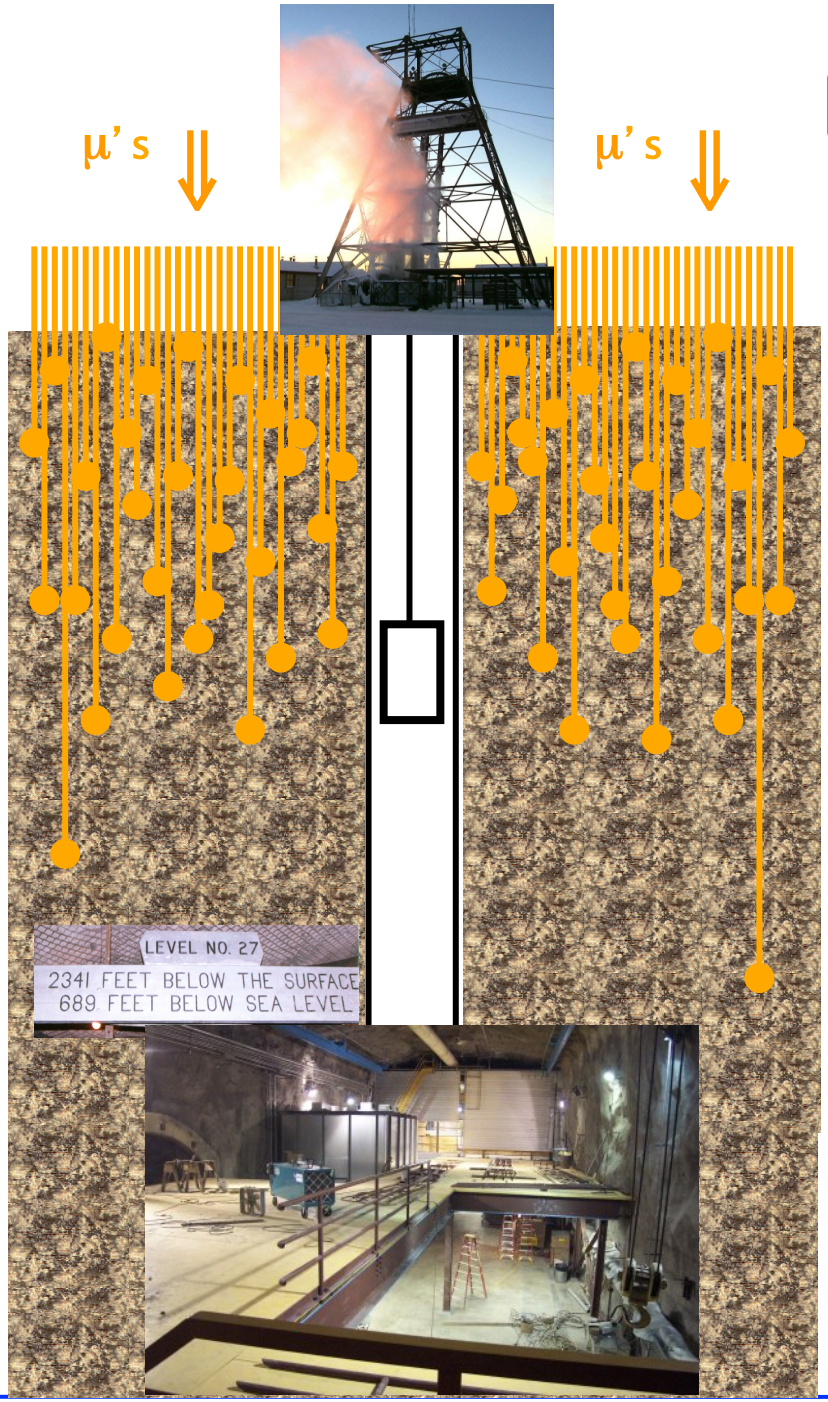
- WIMPs ‘look’ different
  - Photons and electrons collide with electrons
    - low mass so move quickly, ionize efficiently
    - produce more “fast” phonons
  - WIMPs (and neutrons) collide with nuclei
    - higher mass so move slowly, ionize much less





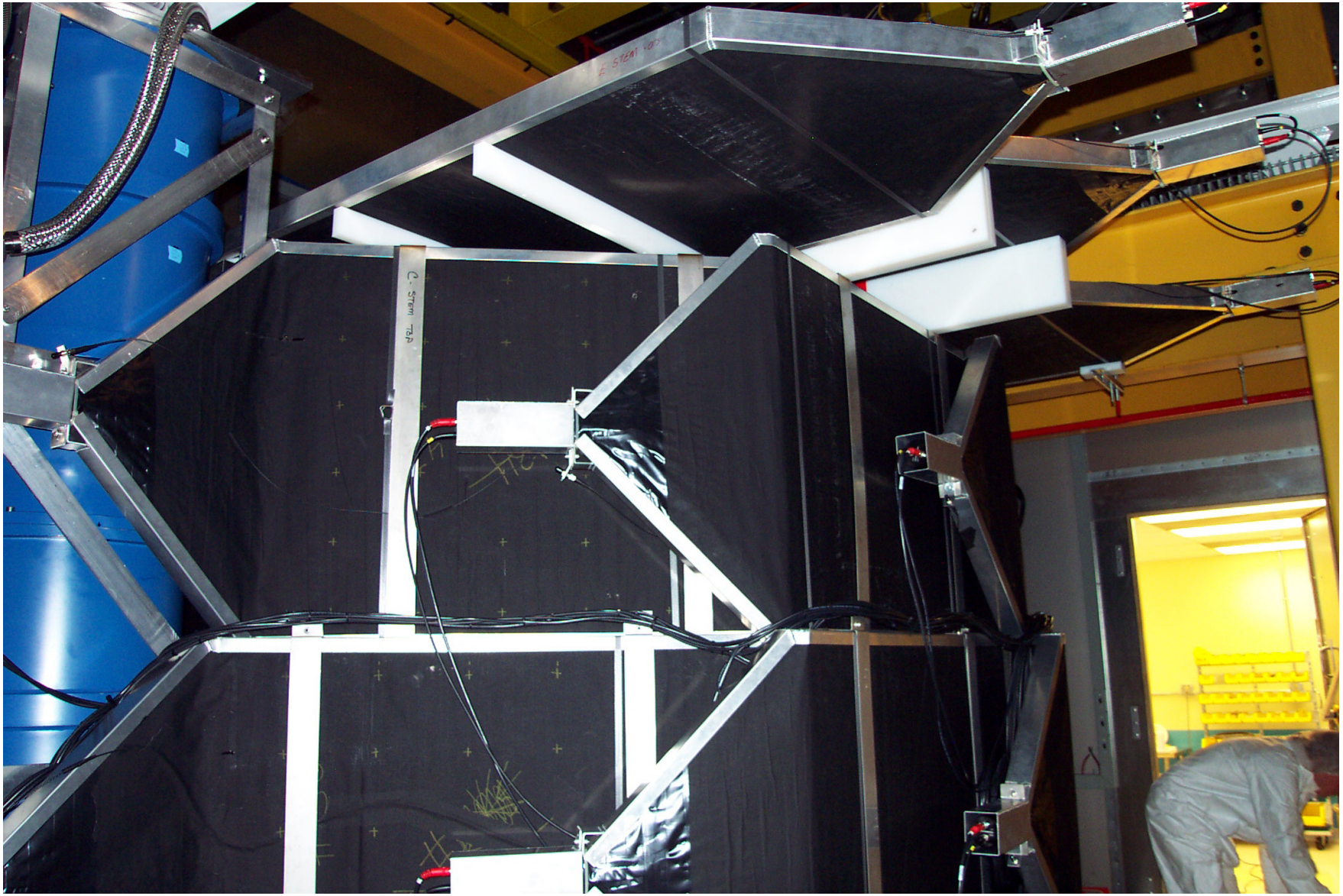


Reducing the "Hay"

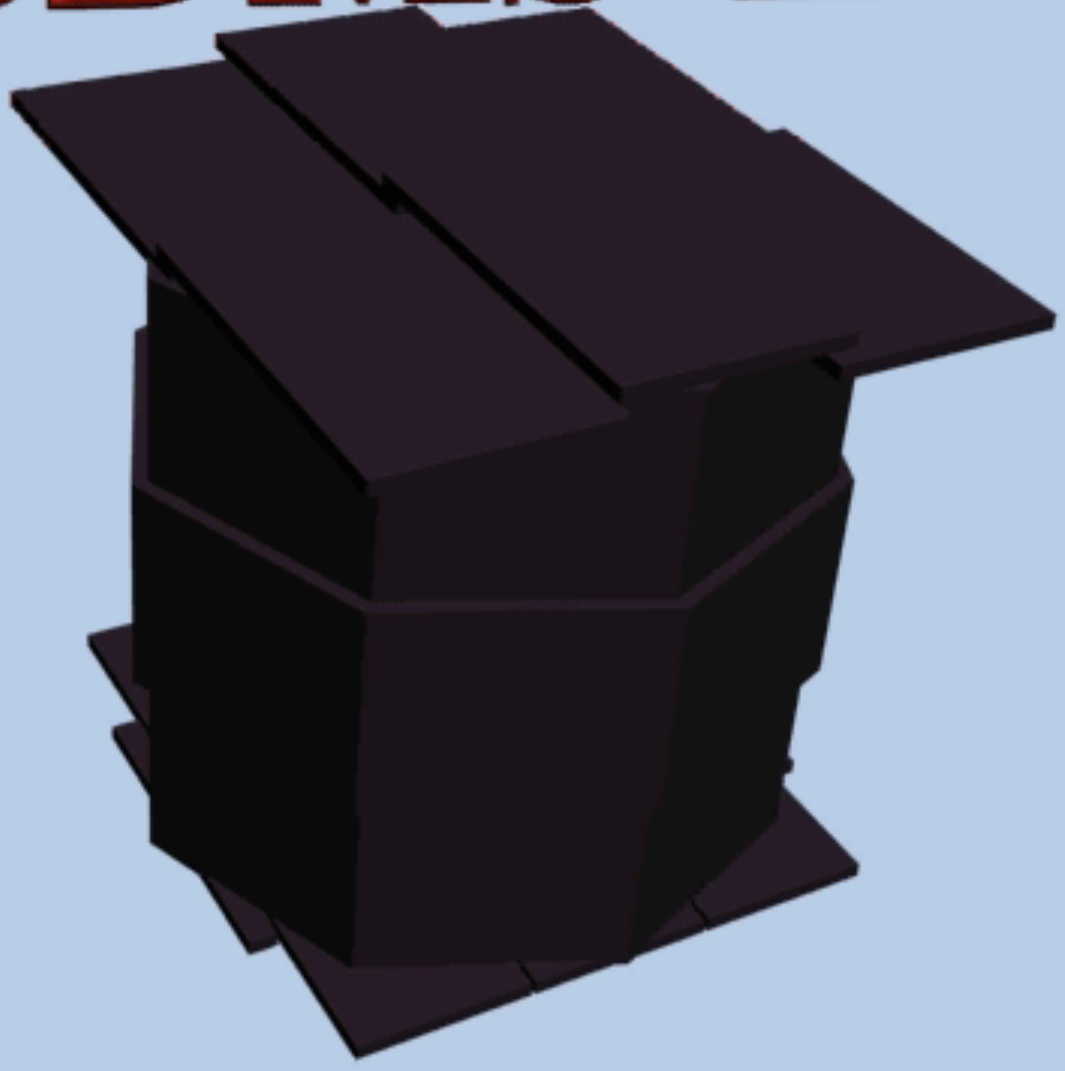


- Put experiment deep underground (Soudan Mine, Minnesota) so no cosmic rays, very few muons reach it
- Use clean, low-radioactivity (= screened) materials
- Surround detectors with clean shielding
- Especially important for getting rid of neutrons (since neutrons interact with the nucleus, just like WIMPs)

Outside the Shielding



CDMS III

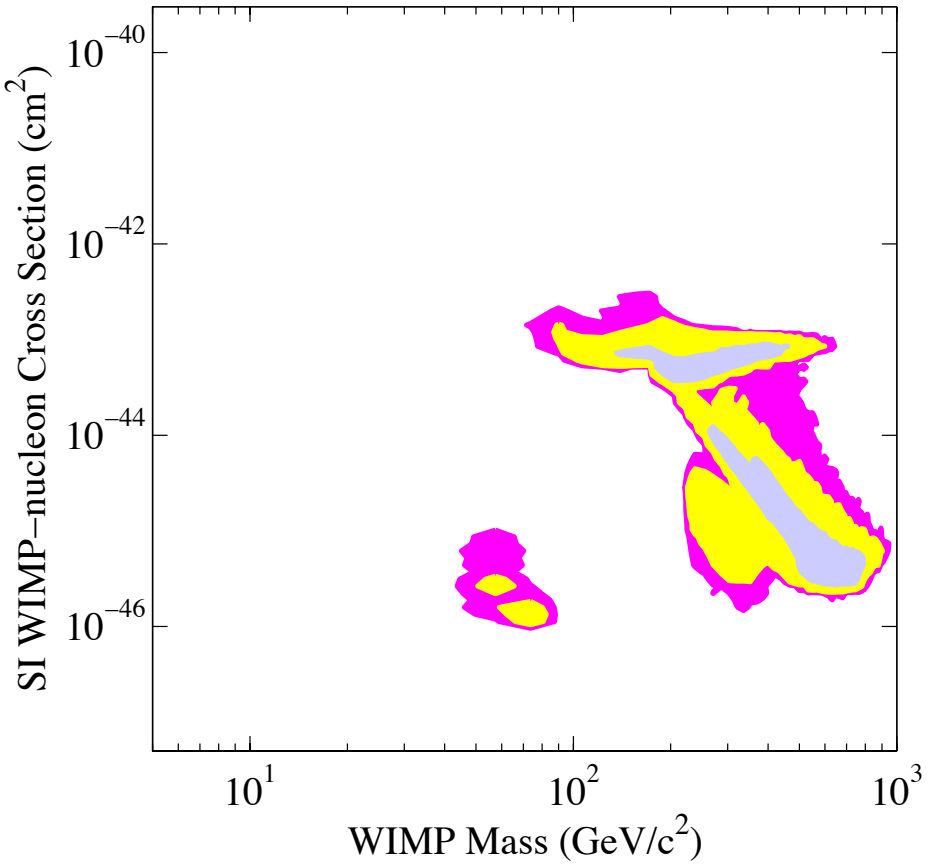


Mike Rousos

Inside the Shielding

Status and Projections of Dark Matter Detection

- Particle Physicists calculate what range of mass and cross section is possible for a given candidate particle
  - Big range of possibilities!



Status and Projections of Dark Matter Detection

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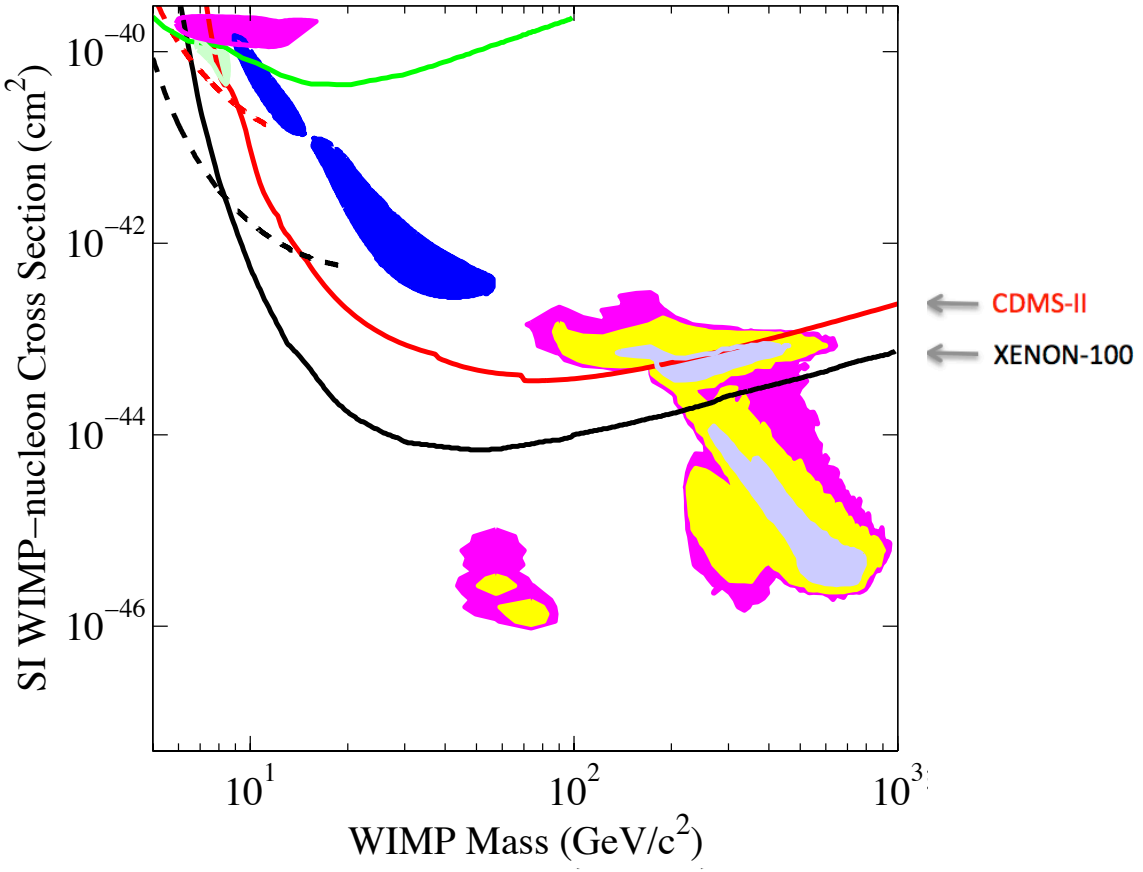
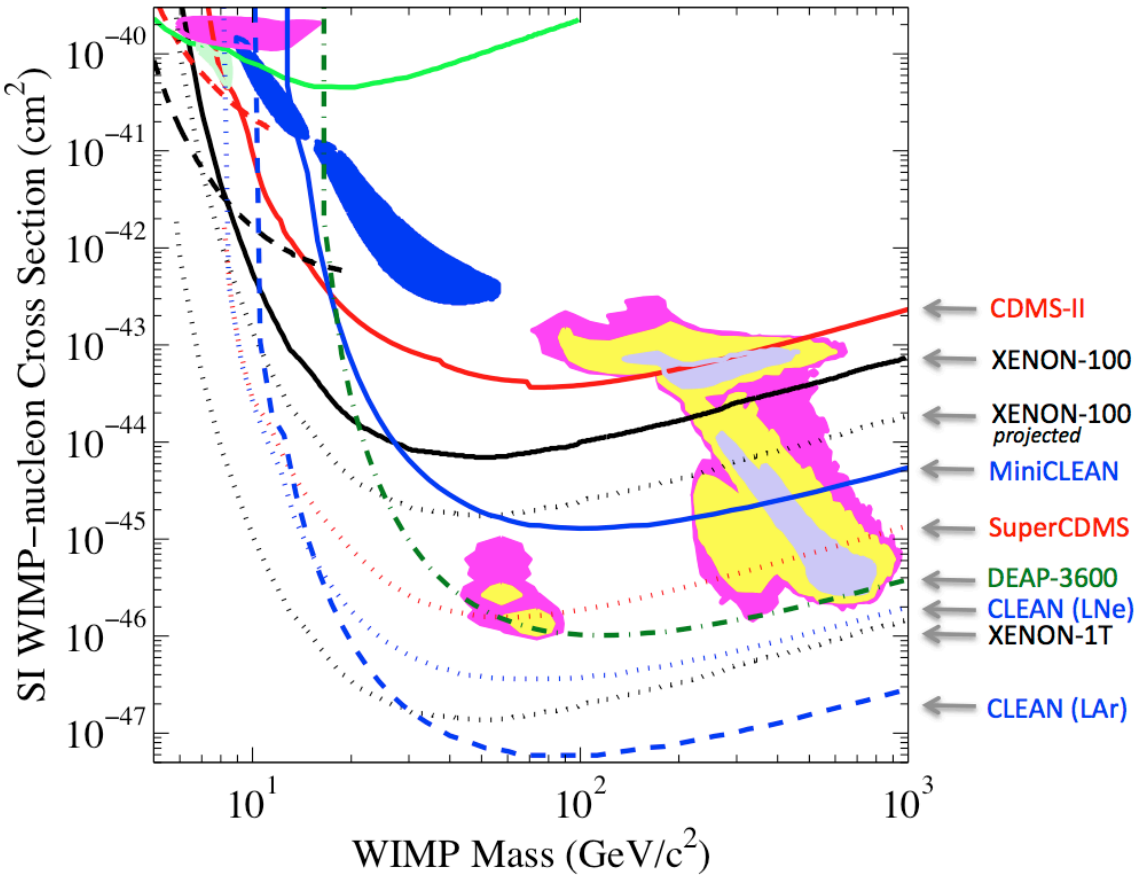
- No compelling evidence of WIMPs yet
  - Cross sections above curves are ruled out



Status and Projections of Dark Matter Detection

- Particle Physicists calculate what range of mass and cross section is possible for a given candidate particle
  - Big range of possibilities!
- No compelling evidence of WIMPs yet
  - Cross sections above curves are ruled out
- New technologies making steady progress
  - Improved rejection
  - Increase mass to ton-scale



Stay tuned for new results coming soon!

Thanks for listening!

Direct Dark Matter Detection

Home

People

CDMS at Syracuse

DEAP/CLEAN at Syracuse

Facilities

BetaCage

About Dark Matter

Main CDMS Page

Main DEAP/CLEAN Page

Internal Pages

Meet team Syracuse! These are the indivuals who are currently working on the CDMS and DEAP/CLEAN projects. E-mails, roles in the project, and offices are listed, if available. Feel free to contact any member.

Faculty:

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Principal Investigator

Post Doctorate:

Raymond Bunker
Beta Cage
Neutron Detection
SuperCDMS

Graduate Students:

Joseph Kiveni
SuperCDMS

Boqian Wang
Beta Cage
MiniCLEAN
Simulations

Yu Chen
MiniCLEAN
Neutron Vetos
SuperCDMS

Michael Bowles
Beta Cage

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