INTERNATIONAL ATOMIC ENERGY AGENCY
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H4.SMR 346/30

SCHOOL ON
NON-ACCELERATOR PHYSICS
25 April - 6 May 1988

SOLAR NEUTRINOS, NEUTRINO OSCILLATIONS

by

G. Gelmini
S. I. S. S. A.
Trieste

DETECTION OF HEAVY ($m \gtrsim O(\text{GeV})$) GALACTIC DARK MATTER:

(Graciela Gelmini
TRIESTE - MAY 1988)

1. Elementary particle candidates (why $m \gtrsim O(\text{GeV})$)
   ν', L.S.P., "solar cosmions"
2. Could we detect the D.M. of our galactic halo?

   FOR HEAVY CANDIDATES : (I) INDIRECT DETECTION (brief)

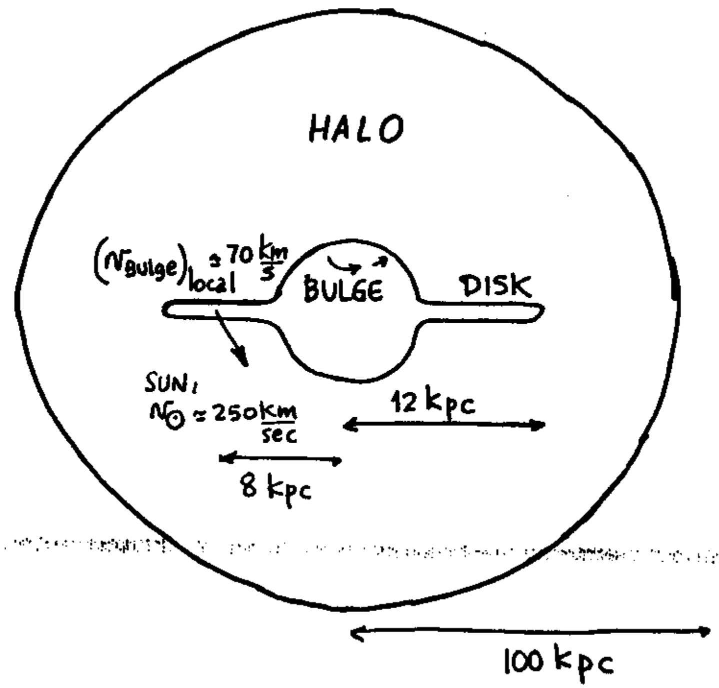
   (II) DIRECT DETECTION

3. 1st BOUNDS FROM (II) : using the Ge-detector of the USC/PNL collab.

   (the LBL/USB collab. has now the same results)

4. brief parenthesis : BOUNDS ON SOLAR AXIONS (and other Nambu Goldstone Bosons) FROM THE SAME DETECTOR (through the "axioelectric" effect)

OUR GALAXY :



$(\rho_{HALO})_{local} \simeq 0.4\,\frac{\text{GeV}}{\text{cm}^3}$ (factor of 2 uncertainty)

$(v_{halo})_{r.m.s} \simeq 250\,\frac{km}{sec}$, $(v_{halo})_{ESCAPE} \simeq v_{rms} \times 2$

WHAT IS IN THE DARK HALO?

- USUAL NUCLEONS ("JUPITERS", BLACK HOLES)?
  Possible but unlikely
- NEW D.M. PARTICLES? ν, axions, L.S.P($\tilde{\gamma}, \tilde{\nu}$...

"STANDARD" D.M. CANDIDATES PROVIDED BY ELEMENTARY PARTICLES:

(NON BARYONIC!)

HOT D.M. : light neutrinos : $m \simeq 30\,eV$

COSMOLOGICAL ABUNDANCE OF LIGHT PARTICLES: $\rho = nm < \rho_c \Rightarrow m < \otimes$

weak interactions $\Rightarrow$ $m_\nu \lesssim 30\,eV$

COLD D.M.

axions : very light but "cold" ($p=0$), $m_a \simeq 10^{-5}\,eV$

heavy particles : $m \simeq GeV$

COSMOLOGICAL ABUNDANCE OF HEAVY PARTICLES: $\rho \sim e^{-\frac{m}{T_F}} < \rho_c \Rightarrow m > \otimes$

weak interactions $\Rightarrow$ $m >$ few GeV

- Heavy Dirac or Majorana neutrinos
- The Lightest Supersymmetric Particle : $\tilde{\gamma}$ (photino), $\tilde{\nu}$ (sneutrino)

IF THEY ARE THE D.M. THEY ARE PASSING TROUGH US NOW! MAY WE DETECT THEM!

Cosmological abundance

- light particles : $\rho_x \simeq n_x m_x \lesssim \rho_c \Omega_x \Rightarrow m_x < \otimes$

weak int. $\Rightarrow$ $m_{light\,\nu} \lesssim 30\,eV$ for $\Omega_x \simeq 1$

- heavy particles : $\rho_x \simeq n_0 m_x e^{-\frac{m_x}{T_0}} < \rho_c \Omega_x \Rightarrow m_x > \otimes$

weak int $\Rightarrow$ $m_{heavy\,\nu} \gtrsim$ few GeV

EXAMPLES:

	$\Omega \le 0.1$	$\Omega \le 1$
HEAVY DIRAC NEUTRINOS	$m \gtrsim 5-15\,GeV$	$m \gtrsim 2-4\,GeV$
" MAJORANA "	$m_\nu \gtrsim 15-150\,GeV$	$m \gtrsim 7-13\,GeV$
L.S.P:		
$\tilde{\gamma}$	$m_{\tilde{f}} \simeq 40\,GeV \to m > 3\,GeV$	$\to m \gtrsim 2\,GeV$
	$m_{\tilde{f}} \simeq 100\,GeV \to m > 15\,GeV$	$\to m \gtrsim 5\,GeV$
$\tilde{\nu}$	$m_{\tilde{\nu}} \simeq 3\,GeV$	$m_{\tilde{\nu}} \simeq 10\,GeV$

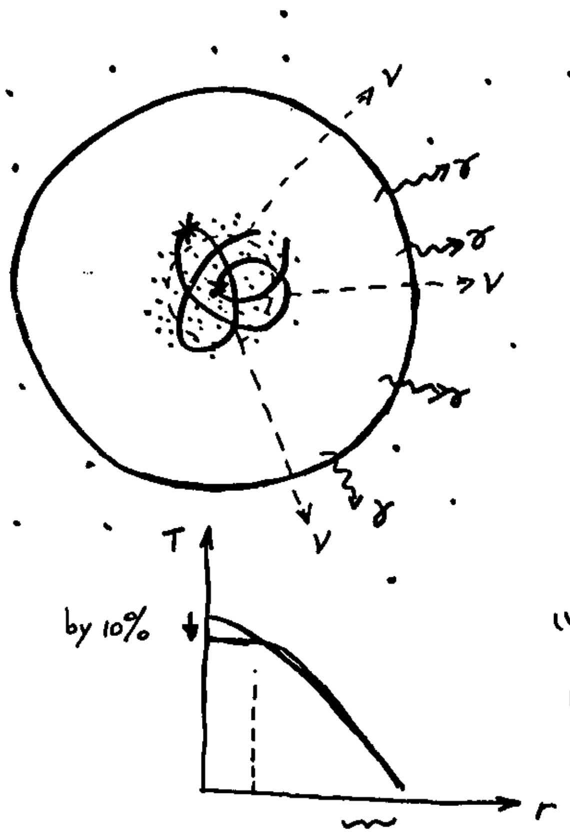
Particles with weak interactions must have $m \gtrsim GeV$ to account for $\Omega \simeq O(1)$!

SPECIAL CANDIDATES : "SOLAR" COSMIONS

Could the SOLAR ν PROBLEM be the first detected signature of DARK MATTER IN OUR GALAXY?

Bill Press: "The MISSING explains the INVISIBLE (or viceversa)"!

Faulkner, Guilliland (1977-1985) Press, Spergel (I and II) (1985)
all four, F-G-P-S (1985)



— Thermal population of "Solar Cosmions" in the ⊙

∴ transport ($kT_{central}$) per orbit ∴ to affect E-transport

$$\frac{N_{cosmions}}{N_{Baryons\ or\ \gamma's}} \simeq \frac{t_{orbit}}{t_{diffusion}} \simeq 10^{-11}$$

this is the number that the sun can capture from the halo!

"COSMIC COINCIDENCE" which allow this model to work

γ-producing region is not affected

T of $^8B\nu$ producing core decreases, Rate $\sim T^{19} \Rightarrow \frac{1}{3}$ that solves the ⊙ problem

flux (^{37}Cl exp.) (Davis et al) $\simeq \frac{1}{3\text{-}5}$ flux (standard sun) (Bahcall et al)

It is nontrivial that the picture may work,

SOLAR COSMIONS MUST HAVE

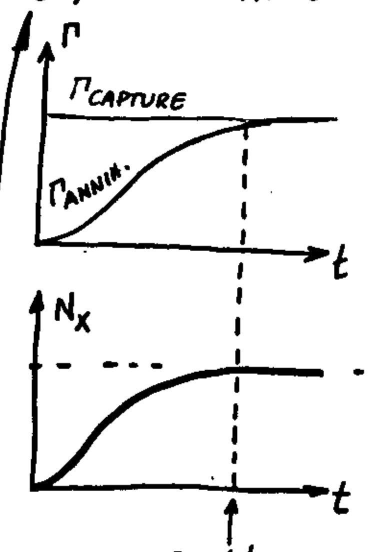
1) $m = 5$ to 10 GeV (may be 20 GeV)
↑ EVAPORATION ↖ THE CORE AFFECTED is too small

2) $\sigma_{SCATT} \simeq 4 \times 10^{-36}\ cm^2$ such that $\lambda_{\text{mean free path in the}\odot} = \frac{1}{n_\odot \sigma} \simeq R_\odot$

↑ OPTIMAL CAPTURE AND E-TRANSPORT

$\sigma \simeq 10\text{-}10^2\ \sigma_{weak}$

3) MUST AVOID ANNIHILATING FAST



$\Gamma_A \sim N_x N_{\bar{x}}$ ∴ increases

At equilibrium $\Gamma_A = \Gamma_C$

Freese Krauss Press Spergel

N_{eq} is too small unless

$$\langle \beta \sigma_{ANNIH} \rangle_\odot \lesssim 10^{-4} \sigma_{SCATT.}$$

usually $\sigma_A \gtrsim \sigma_{SCATT}$

4) MUST HAVE $\Omega_X \gtrsim 0.10$ TO ACCOUNT FOR HALOES

NON TRIVIAL PARTICLE PHYSICS, AT THE WEAK SCALE
NO "STANDARD" D.M. CANDIDATE WORKS ($\nu^{D,M}$, $\tilde{\gamma}$, $\tilde{\nu}$ ...)

 Freese Krauss Press Spergel

THERE ARE THREE PROPOSALS FOR "SOLAR COSMION" CANDIDATES:

1 G. Gelmini, L. Hall, J. Lin

χ = Dirac or Majorana fermion

$\sigma > \sigma_{weak}$ mediated by coloured Higgs field

2 S. Raby and G. West

χ = DIRAC HEAVY NEUTRINO WITH LARGE MAGNETIC MOMENT
"MAGNINO"

$\sigma > \sigma_{weak}$ mediated by photons (electromagnetic)

3 - S. Raby and G. West

χ = DIRAC HEAVY NEUTRINO
"EXON"

$\sigma > \sigma_{weak}$ mediated by the USUAL HIGGS FIELD (IF IT IS VERY LIGHT $m_{Higgs} \simeq 400$ MeV)

MAY WE DETECT D.M. PARTICLES FROM THE HALO OF OUR GALAXY?

$$\beta_{halo} \simeq 10^{-3} \quad , \quad flux \simeq \frac{1 \times 10^{7}}{\left(\frac{m}{GeV}\right)} \frac{particles}{cm^2 \, sec} \, !$$

No light ν's, $m_\nu = 30\,eV \Rightarrow E_\nu \simeq 10^{-5}\,eV$!
(mass measurement could tell!)

Yes axions ... $\gamma\gamma$ in cavities : Sikivie

Yes heavy D.M. (with $m \gtrsim$ GeV): such as heavy ν, or L.S.P ($\tilde{\gamma}, \tilde{\nu}, \dots$)

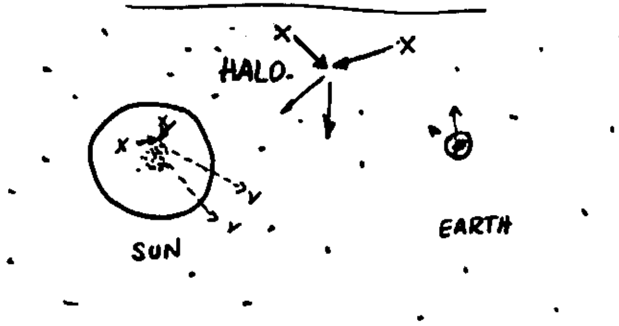
I) INDIRECT DETECTION : through annihilation products (annih in the halo, the sun, the earth)

II) DIRECT DETECTION : through the energy deposited T by the D.M. particle in a collision with a Nucleous

experimental threshold $\Rightarrow T \simeq$ keV $\therefore\ m\beta^2 \simeq 10^{-6} m >$ keV $\Rightarrow m >$ GeV

Goodman. Witten (84) based on Drukier-Stodolski (1982)

① INDIRECT DETECTION



DETECT ANNIHILATION PRODUCTS

ANNIHILATIONS IN THE HALO :

$\tilde{\gamma}\tilde{\gamma} \longrightarrow p\bar{p}$ ⇒ excess of $\bar{p}$ in cosmic rays (Silk - Srednicki) '86

$\nu\nu \longrightarrow p\bar{p}$ ⇒ account for the ENTIRE SPECTRUM of $\bar{p}$ in cosmic rays (Rudaz - Stecker) '87

$\tilde{\gamma}\tilde{\gamma} \longrightarrow (c\bar{c}) \longrightarrow$ charmonium + γ

(Silk - Srednicki - Theisen)

ANNIH. OF D.M. CAPTURED BY THE EARTH:

D.M. with coherent interaction with nuclei : $\nu^D, \tilde{\nu}$ with

$\nu^D \nu^{DIRAC} \longrightarrow \nu\nu$ $\quad m > 12\,GeV$

$\tilde{\nu}\tilde{\nu} \longrightarrow \nu\nu$

IMB data ⇒ excluded if $12\,GeV < m \lesssim 20\,GeV$

(Freese / Krauss - Srednicki - Wilczek

ANNIH. OF D.M. CAPTURED BY THE SUN:

example $\tilde{\nu}\ \nu^{maj}\ \nu^D\ \tilde{\gamma}$ with $m > 4\,GeV$

→ high Energy ν's from the sun.

(Olive-Silk / Gaisser-Steigman-Tilav / Srednicki-Olive-Silk)

best bounds from FREJUS, IMB, KAMIOKA

Table 1. Photinos

$m_{\tilde{\gamma}}$ (GeV)	r (Case 1)	r (Case 2)	r (Case 3)
4	0.11	0.014	0.097
6	0.032	0.015	0.077
10	0.0067	0.016	0.054
20	—	0.0066	0.013
40	—	0.0023	0.0023
limit	0.14	0.024	0.036

Table 2. Higgsinos

$m_{\tilde{H}}$ (GeV)	r (Case 1)	r (Case 2)	r (Case 3)
6	0.045	0.0091	0.052
10	0.0084	0.010	0.040
20	—	0.0057	0.012
40	—	0.0023	0.0025
limit	0.14	0.024	0.036

Table 3. Majorana neutrinos

m_{ν_M} (GeV)	r (Case 1)	r (Case 2)	r (Case 3)
6	0.055	0.011	0.064
10	0.023	0.028	0.11
20	0.0058	0.051	0.11
40	—	0.076	0.082
limit	0.14	0.024	0.036

BEST ANALYSIS : K. Olive and M. Srednicki

DATA : IMB + KAMIOKANDE + FREJUS

90% C.L. BOUNDS

Table 4. Dirac neutrinos

m_{ν_D} (GeV)	r (Case 1)	r (Case 2)	r (Case 3)
4	—	0.022	0.087
6	—	0.044	0.12
10	—	0.10	0.17
20	—	0.30	0.24
40	—	0.70	0.28
limit	0.14	0.024	0.036

Table 5. Scalar electron neutrinos

$m_{\tilde{\nu}_e}$ (GeV)	r (Case 1)	r (Case 2)	r (Case 3)
4	—	—	3.7
6	—	—	6.3
10	—	—	11.
20	—	—	20.
40	—	—	26.
limit	0.14	0.024	0.036

Table 6. Scalar muon neutrinos

$m_{\tilde{\nu}_\mu}$ (GeV)	r (Case 1)	r (Case 2)	r (Case 3)
4	—	0.50	1.4
6	—	1.3	2.3
10	—	3.8	4.1
20	—	13.	9.5
40	—	35.	18.
limit	0.14	0.024	0.036

CASE 1 : IMB, Contained events, $1\,GeV < E_\nu < 2\,GeV$

$\theta < 30°$ from the sun : 11/89

CASE 2 : IMB, through going μ, $E_\nu > 2\,GeV$

$\theta < 8°$ from the sun : 2/187

CASE 3 : IMB + KAMIOKA + FREJUS, contained events $E > 2\,GeV$

(IMB) $\theta < 30°$: 13/10, (K) 0/23, (F) 0/31

- D.M. captured in the $\oplus$ may annihilate:

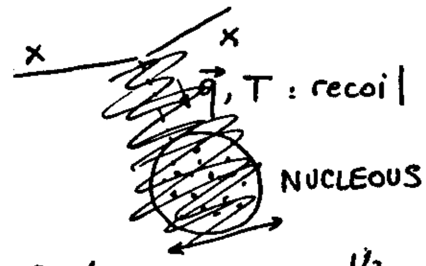
Freese PL B167, 295 ('86)

Krauss Srednicki Wilczek PR D33, 2079 ('86)

ONLY DIRAC ν and $\tilde{\nu}$ can be trapped in $\oplus$, $M > 10\,GeV$ (to avoid evaporation) and produce observable $\nu\bar{\nu}$

While σ_{SCATT} of $\tilde{\gamma}$, ν, $\tilde{\nu}$ in the $\odot$ are similar, in the earth are different

$$\sigma^{NR} = \frac{m_x^2 M^2}{\pi (m_x + M)^2} |\mathcal{A}|^2$$



If $\frac{1}{q} > R = \frac{1.2\, A^{1/3}}{200\,MeV}$

$\Rightarrow$ ν^{DIRAC}, $\tilde{\nu}$ have coherent interactions

weak int : $|\mathcal{A}|^2 = \frac{1}{2}\left(Z\,\underbrace{(1 - 4\sin^2\theta)}_{\approx 0} - N\right)^2$

but $\tilde{\gamma}$, $\nu^{MAJORANA}$ (MAJORANA FERMIONS)

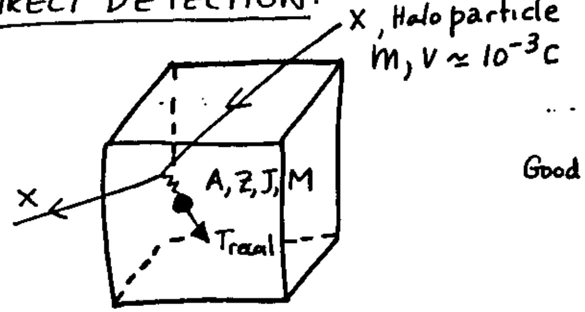
$$|\mathcal{A}|^2 \sim \lambda^2 J(J+1)$$

(J ↑ NUCLEAR SPIN)

This difference is very important for DIRECT DETECTION

σ^{NR} and $T^{MAX}_{RECOIL} = 2M\left(\frac{v}{c}\right)^2 \frac{m_x^2}{(m_x + M)^2}$ favour nuclei as targets

DIRECT DETECTION:



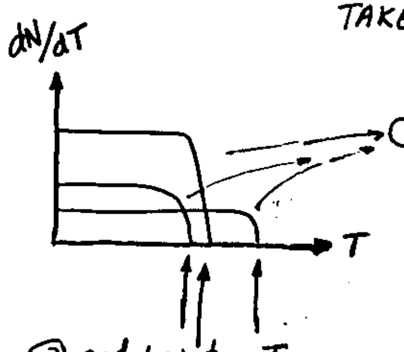
Good review

P. Smith, II ESO-CERN Conferen[ce]

SIGNATURES (IF DETECTION OCCURS):

TAKE VARIOUS MATERIALS

M, A, J



① Shape of spectra ⇒

⇒ **type of interaction**

$$\sigma^{NR} = \frac{m^2 M^2}{\pi (m+M)^2} |cA|^2$$

COHERENT INT ($\nu^{DIRAC}, \tilde{\nu}$) ⇒ $|cA|^2 \sim A^2$

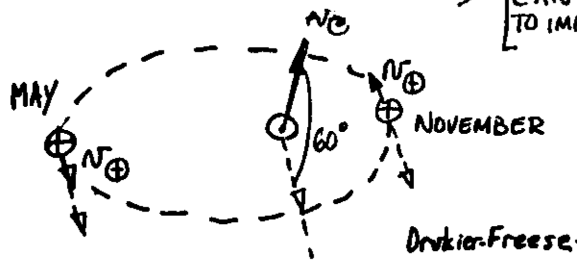
SPIN DEP. INT ($\nu^{MAJ}, \tilde{\gamma}$) ⇒ $|cA|^2 \sim J$

② end points ⇒ T_{max}

$$T_{max} = 2M \left(\frac{v}{c}\right)^2 \frac{m^2}{(m+M)^2} \Rightarrow \boxed{m, v}$$

③ How to know these are particles from the halo:

ANNUAL MODULATION OF THE SIGNAL (DUE TO THE MOVEMENT OF THE EARTH AROUND THE SUN) [CAN BE USED FOR $S/B < 1$ TO IMPROVE DETECTION FREESE, FRIEMAN, GOULD 1987]



Drukier-Freese-Spergel 1986

Solar cosmions $> 10 - 10^2 \times$ $\gtrsim 10^3 - 10^6 \frac{1}{kg\,day}$

Solar cosmion $\times\ 10 - 10^2 \times$ $\approx 1 - 10^3 \frac{1}{kg\,day}$

Expected Rates for some "standard" candidates

$\tilde{\nu}$, DIRAC ν : have coherent int with nuclei

$$10^2 - 10^4 \ \frac{1}{\text{kg day}}$$

$\tilde{\gamma}$, $\tilde{H}$, MAJORANA ν : have spin dependent int only (∴ non coherent)

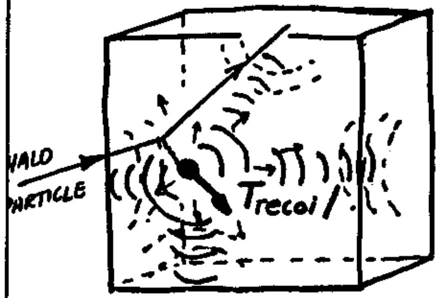
$$10^{-1} - 10 \ \frac{1}{\text{kg day}}$$

∴ typical C.D.M. detector : 1 - 10 Kg

Background expected now : $\frac{\text{few}}{\text{kg day}}$!

HOW T_{RECOIL} CAN BE DETECTED ?

NEED { low E - threshold (keV's) ; low background (some events / Kg day) }



Trecoil → THE LATTICE : Phonons

Ballistic Phonons : B. Cabrera.

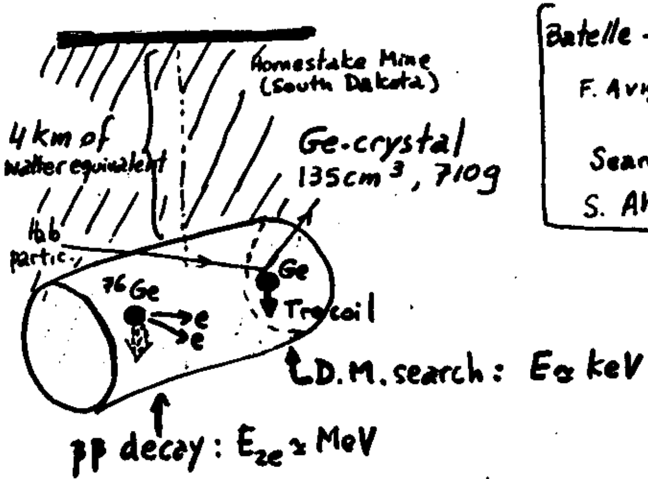
Thermalized ⇒ ΔTemp (A. Drukier, L. Stodolski, B. Sadoulet, P. Smith)

⇒ CRYOGENIC METHODS UNDER DEVELOPMENT

Trecoil → IONIZATION : Electrons (C.B / V.B)

Allowes the use of EXISTING (NON CRYOGENIC) Ge-DETECTORS

NEW TECHNOLOGY OF LOW BACKGROUND DEVELOPED TO SEARCH ββ DECAY

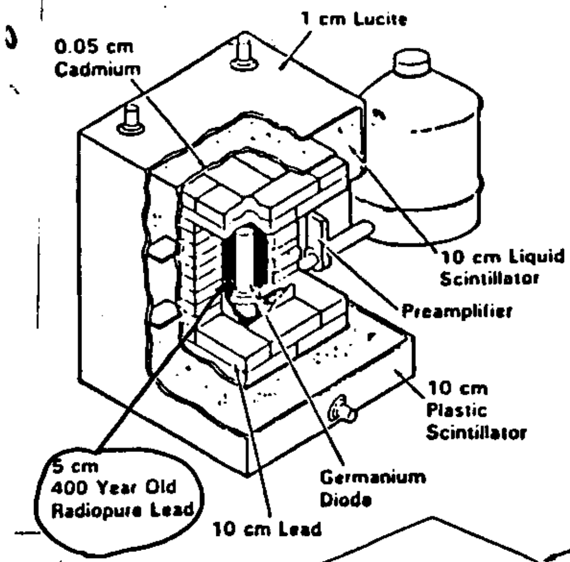


Batelle - Carolina (PNL/USC)
F. Avignone - R Brodzinski

Search for D.M. with S. Ahlen, A. Drukier, D. Spergel, G.G.

OBTAINED 1st BOUNDS FROM DIRECT SEARCH

NOW ALSO UCSB/LBL (Caldwell, Witherell, Sadoulet ....)



4000 m of water equivalent

The superpure copper had still cosmogenic radiactive contamination.

Now REPLACED BY 448 y old LEAD (from a sunken Spanish galleon)

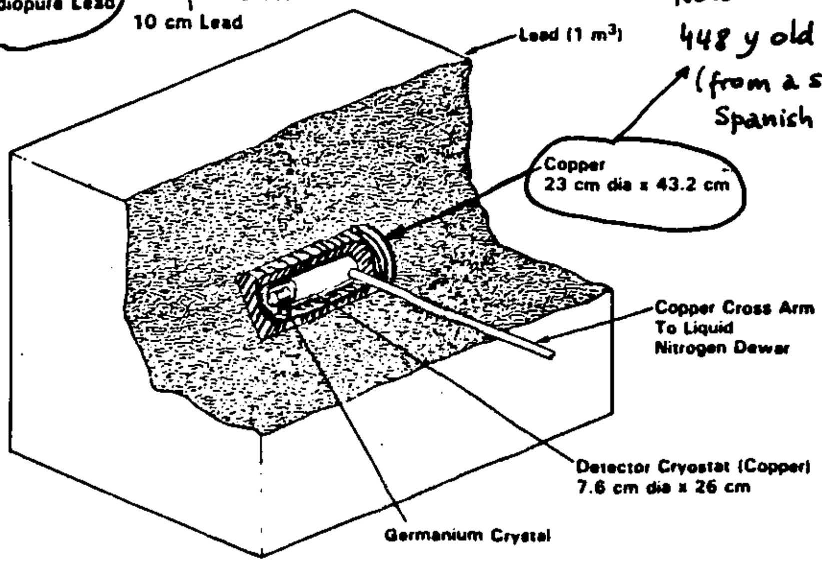
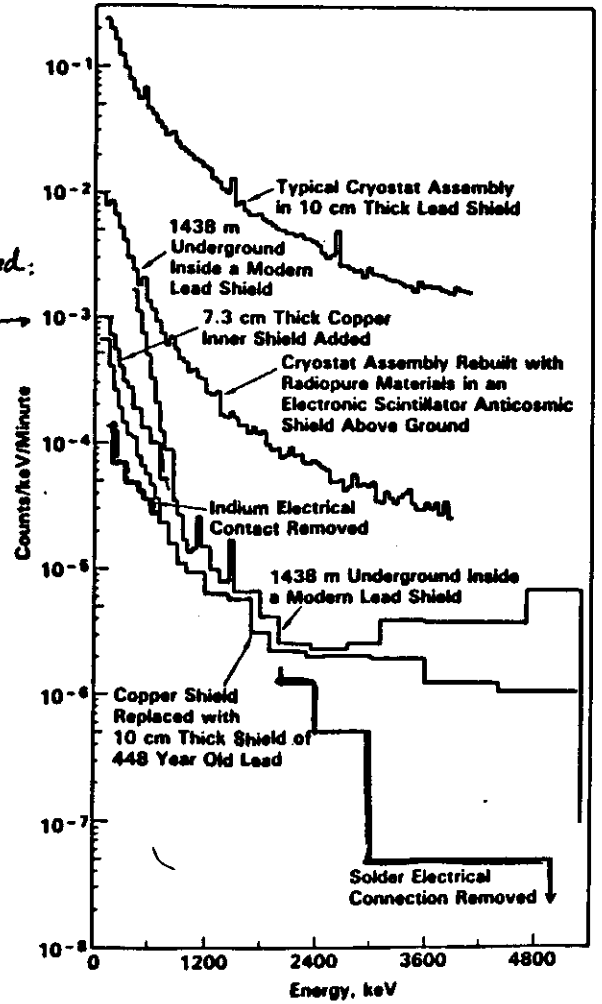


FIG. 1. Ultra-low-background, 135 cm³ prototype Ge detector with copper inner shield.

Background Spectra of a 31.5% Germanium Diode Gamma-Ray Spectrometer in Different Cryostats and Shielding Configurations

data we used:

2 counts / keV kg day →



8.9805 keV

10.551 keV

Fit a quadratic function (.1% non linear) ⟹ ERROR IN CALIBRATION AT E_{th} IS .1 keV

25.2713 keV

46.503 keV

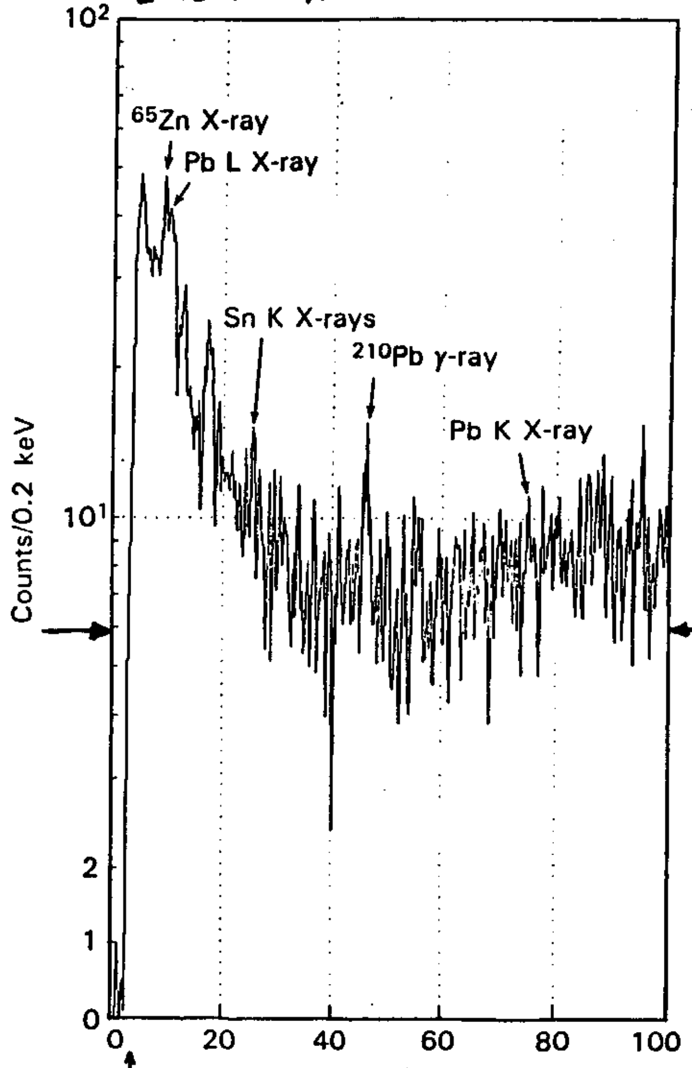
74.969 keV

PRELIMINARY NEW DATA

—— 54 days { december 23rd to feb 22nd

- 1000 hours of data - low E part of spectrum
- The identified peaks come from one solder point (now removed)
  - [^{115}In ($\tau_{1/2} \simeq 6\times10^{14}$ yr) β-decay (Q = 490 keV)
  - ^{210}Pb (β-decay) → ^{210}Bi (β-decay) ^{210}Po α-decays (5.3 MeV)]

.2 keV per channel

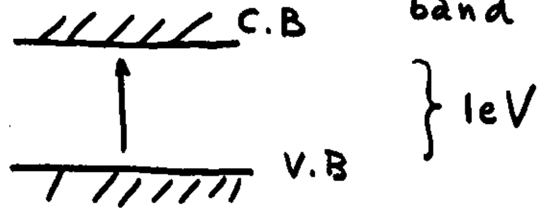


→ E^e (on e)

$\frac{1 \text{ count}}{\text{KeV}\cdot\text{Kg}\cdot\text{day}}$

sept 1985 E^e_{th} = 4 keV (= 15 keV on Ge Nucleous)
due to microphonic noise (mining operation)
NOW: ANTICOINCIDENCE FILTER, SOON E_{th} = 1 KeV !

Detector counts: Number of e^- which jump into the conduction band



R.E.F Relative efficiency factor	=	$\frac{N^{er} \text{ of e's if } e \rightarrow T_{recoil}}{N^{er} \text{ of e's if Ge} \rightarrow T_{recoil}}$	> 1

R.E.F. ≃ 3.75 for T_{recoil} ≃ O(10 keV)

calcul. by S. Ahlen, data from Chasman (1965) on Ge.
(agreement with calcul. of Linhadt, 1963 and data on Si from Sattler, 1965)

a given signal corresponds to { $e \rightarrow T^e_{recoil}$; Ge → (R.E.F) × $T^e_{rec.}$ }

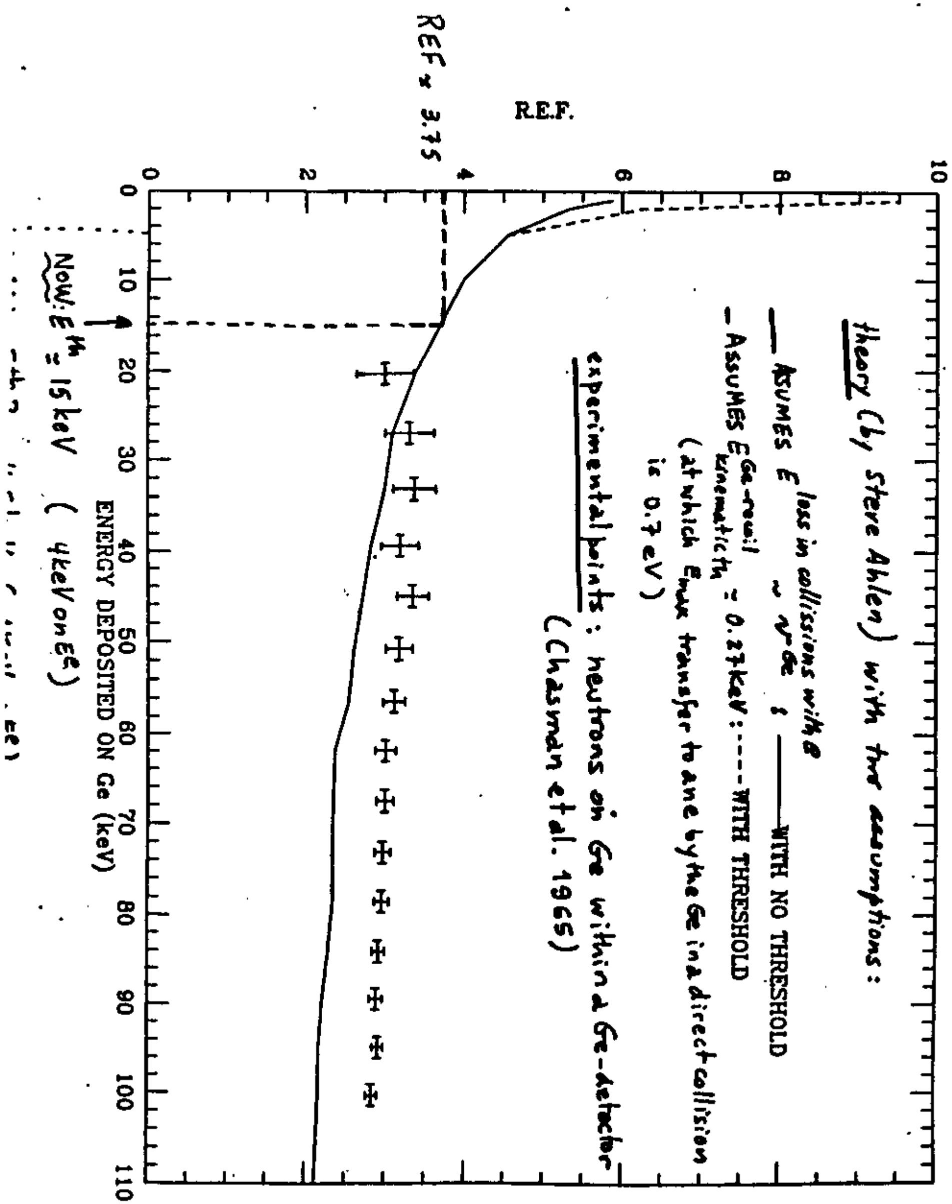
PNL/USC

$T^{\text{on } e}_{threshold}$ = 4 KeV , T^{Ge}_{th} = 15 KeV

soon: 1 KeV — reduce microphonic noise from blasting

Background = few / KeV Kg day

soon: × 10^{-1} — Cu → 500 y old Pb, remove solder, replace In



To get bounds

$$\text{Rate}_{\text{Predicted}} \sim \boxed{\frac{(\rho_x)_{local}\,\sigma}{m_x}}\,\langle v \rangle < \text{Rate observed}$$

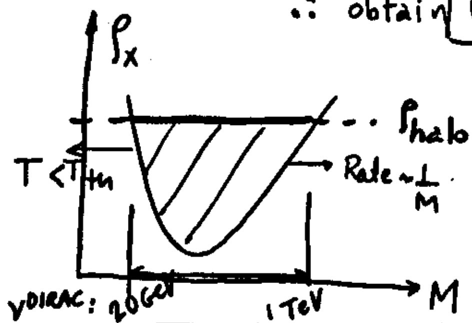
a few / keV·kg·day

↑ halo model:

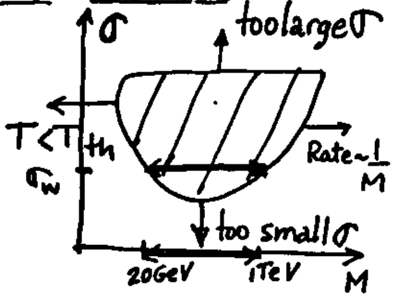
$f(\vec{v})$ Gaussian ; $(\rho_x)_{local} = 0.4\ \frac{GeV}{cm^3}$ (error: factor 2!)

Very conservative
$v_{r.m.s} = 250$ km/sec
$v_{max} = 550$ km/sec
$(v_{halo})_{local} = (v_{bulge})_{local} = 80$ km/sec

∴ obtain $\boxed{(\rho_x)_{local}\,\sigma < ⊗}$

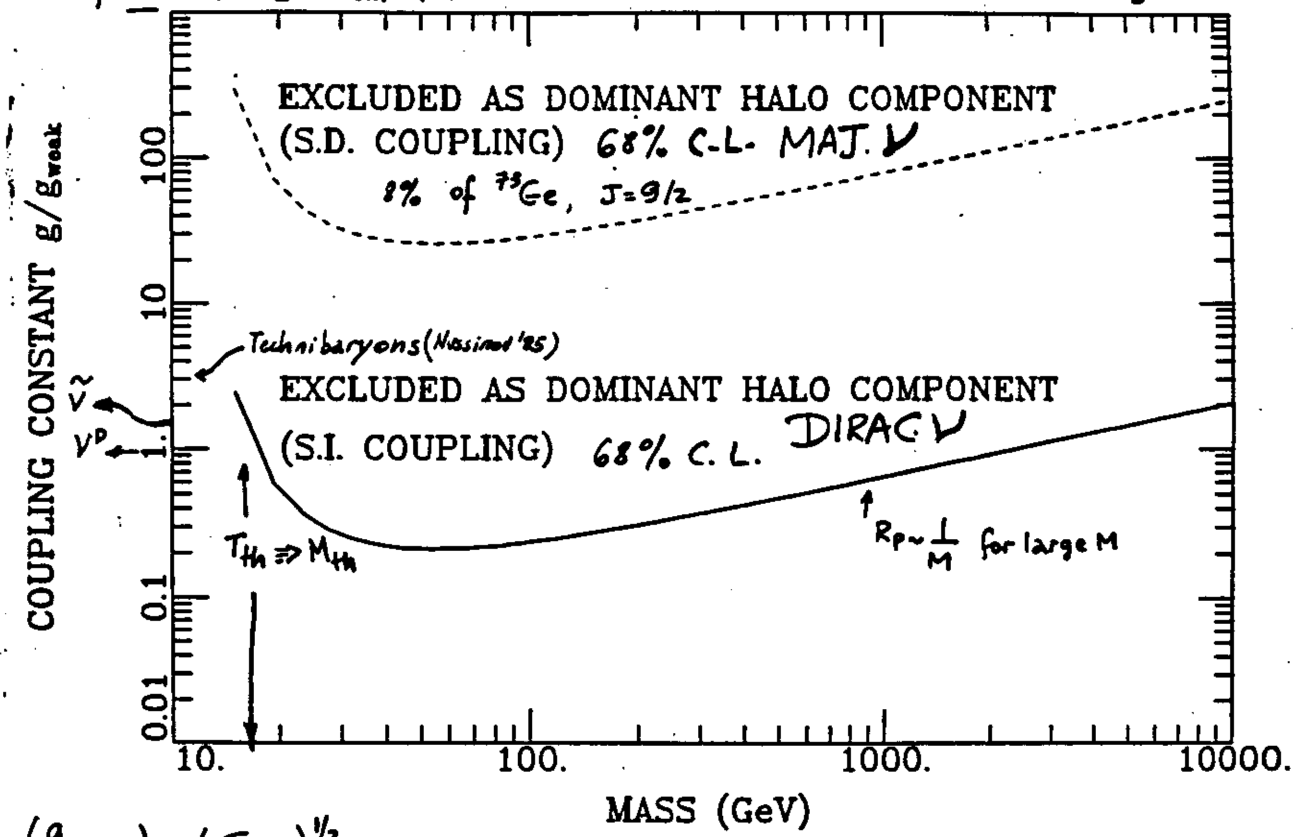


given σ (= σweak for ex.)
fix G (the c.c.)



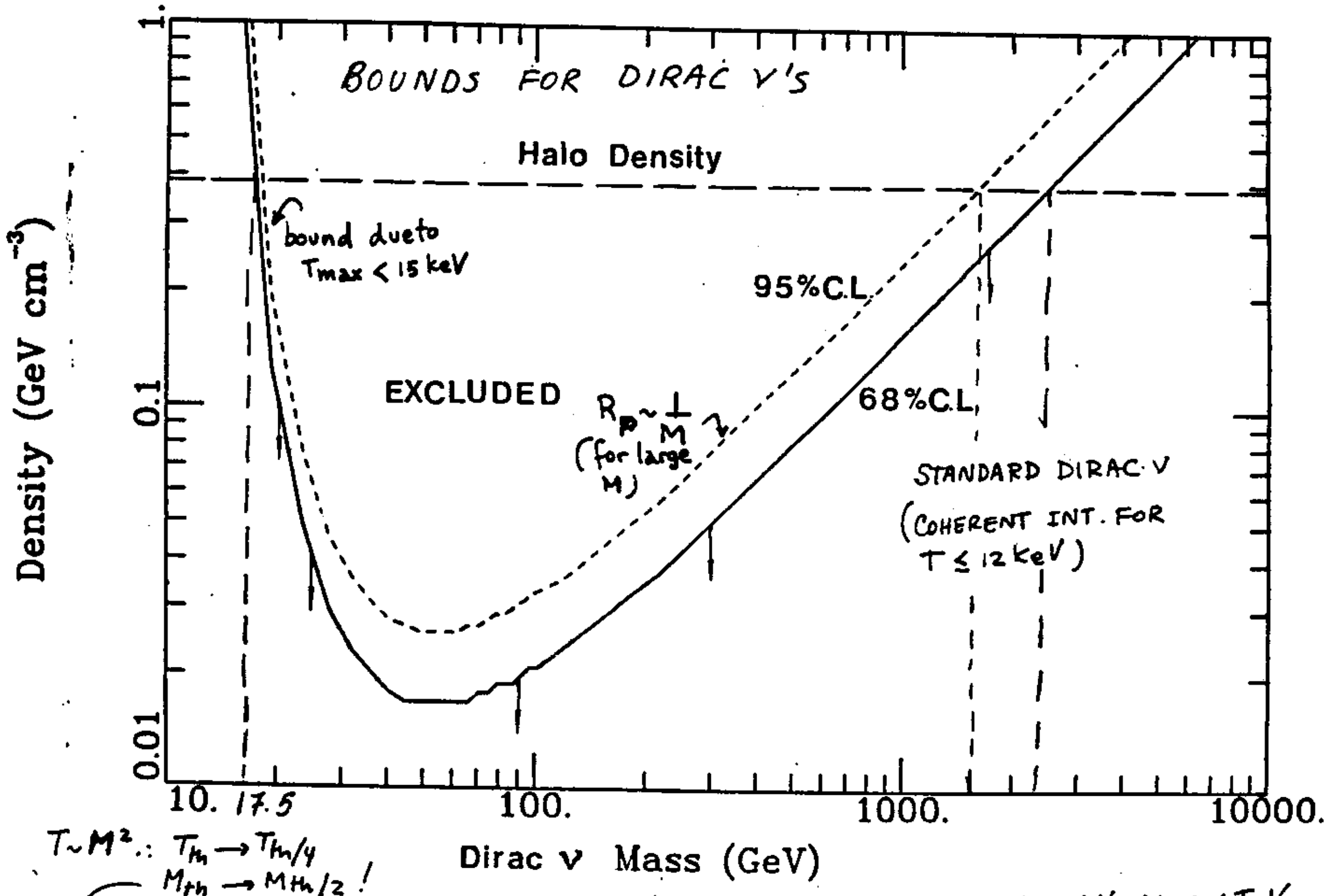
fix ρ = ρhalo

bounds finish at $\sigma \simeq 10^{-28}\,cm^2$: particles are stopped in the crust before reaching the Ge!



$$\left(\frac{g}{g_{weak}}\right) \equiv \left(\frac{\sigma}{\sigma_{weak}}\right)^{1/2}$$

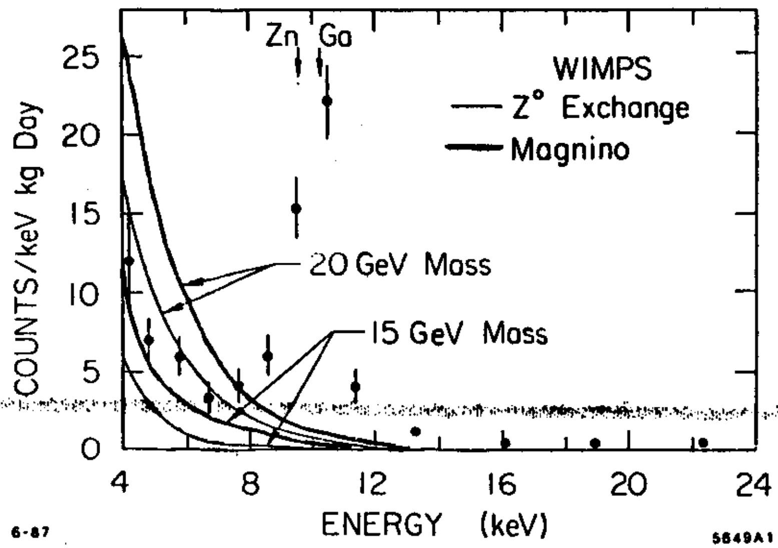
SOON BOUNDS BETTER by 10 !



$T \sim M^2$ ∴ $T_{th} \to T_{th}/4$, $M_{th} \to M_{th}/2$!

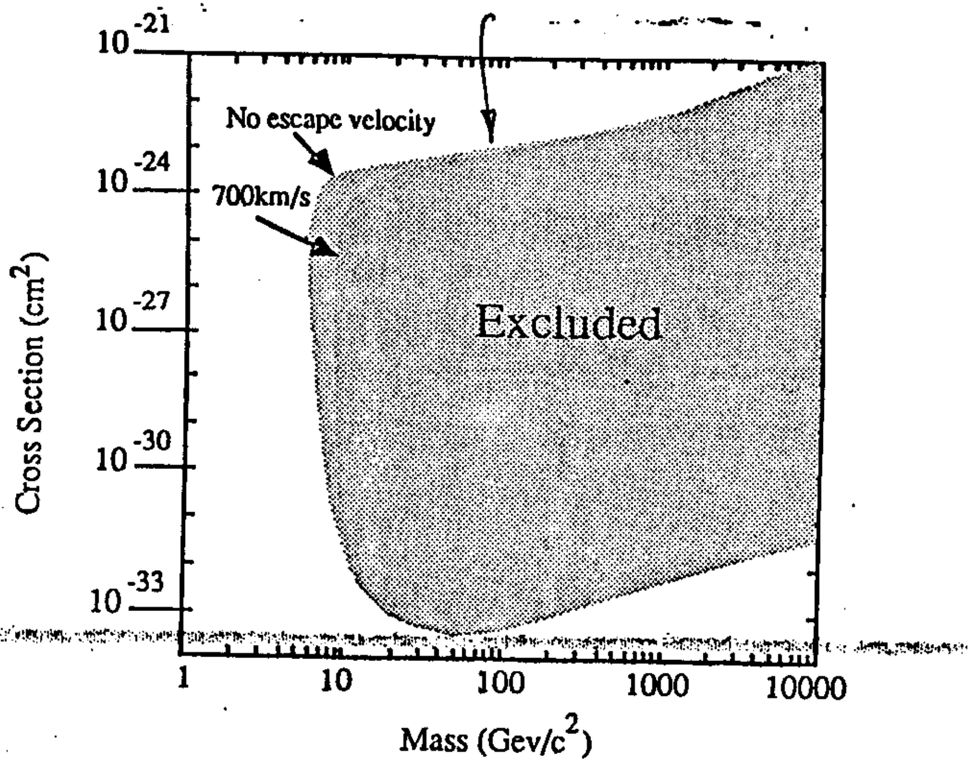
EXCLUDED AS MAIN COMPONENT OF THE HALO IF 20 GeV < M < 1 TeV

BEST POSSIBLE BOUND : M > 8 GeV!



LBL/UCSB (D. Caldwell et al) (1988)

The detector is at the <u>surface</u>



LBL/UCSB (D. Caldwell et al.) (1988)

[For "DIRAC NEUTRINO" LIKE PARTICLE WITH VARIABLE G INSTEAD OF G_F]

Axio-electric effect

S. Dimopoulos, B. Lynn, G. Starkman

Idem photo-electric effect : σ enhanced for $|k_\gamma| \simeq$ atomic bound states energies

- Free e : FORBIDDEN BY $\delta(E)\ \delta(\vec{p})$
- Atomic e

– $M \to \infty$ breaks translation invariance

$\therefore$ ~~$\delta(\vec{p})$~~ $\Rightarrow$ ALLOWED

(the Nucleous can absorbe any $\Delta\vec{p}$)

not $\Delta E \sim p^2/2M \sim 0$

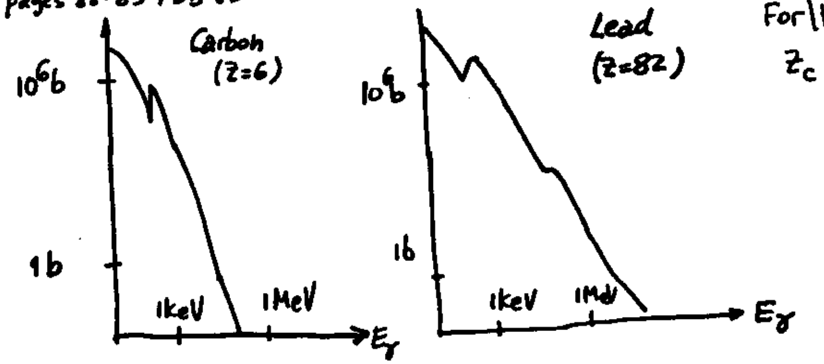
another point of view:

uncerteinty $\boxed{\Delta\vec{p} \gtrsim \hbar/\Delta r}$ $\therefore$ when $\boxed{|\vec{k}_\gamma| \le |\Delta\vec{p}| \Rightarrow \text{ALLOWED}}$

$\Delta|\vec{p}| \simeq \frac{1}{|\Delta r|} \simeq E_{binding} \simeq \frac{Z^2\alpha}{a_0} > |k_\gamma|$ for $\boxed{Z > Z_c}$ AND

- for $Z > Z_{CRITICAL}$: $\boxed{\frac{n^{er} \text{ of } e}{kg} \simeq \text{const}}$ $\left(\frac{n^{er} \text{ of } e}{at} \cdot \frac{n^{o} \text{ of } at}{kg} \simeq \frac{Z}{A} \simeq \text{const}\right)$

pages 88-89 PDB '86



For $|k_\gamma| \simeq 1$ keV
$Z_c \simeq 10$

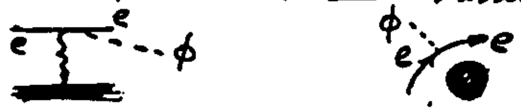
Bounds on light bosons from the sun

$L = g\, m_e\, \bar{e}\, i\gamma_5\, e\, \phi$,

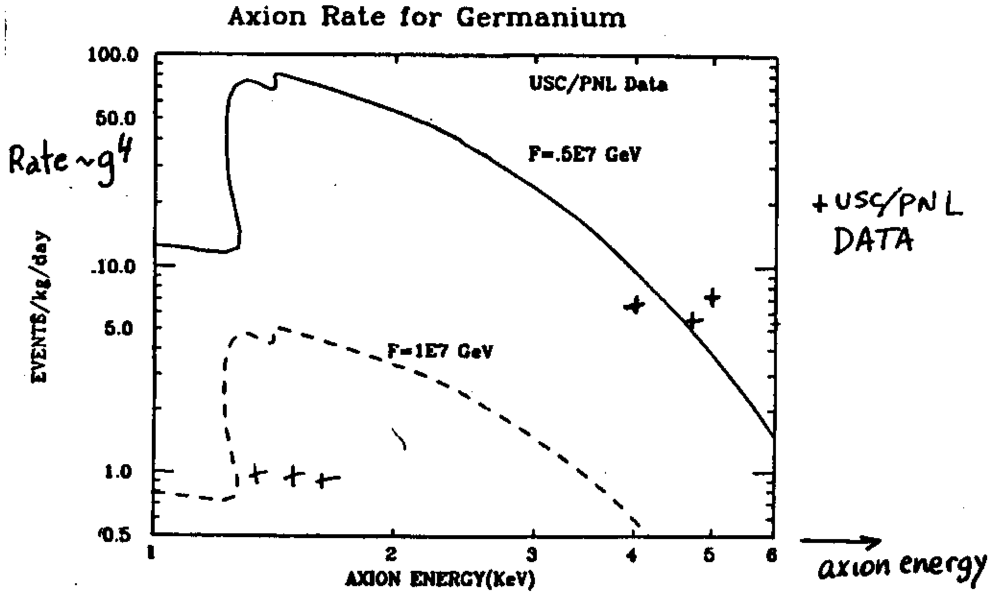
- ϕ = Nambu Goldstone boson $\Rightarrow$ $\boxed{m_\phi = 0}$ (Majorons, familons..)

or "almost": axion $\boxed{g = \frac{1}{F}}$ ← Peccei-Quinn breaking scale $\longrightarrow$ $\boxed{m_a \simeq 7\,eV \left(\frac{10^7\,GeV}{F}\right)}$

- ϕ emitted from the sun $\longrightarrow$ absorbed by an e in a Ge atom



"Axioelectric" effect
Dimopoulos Lynn Starkman
+ Avignone et al..



$\Rightarrow$ BOUND $F\ (= g^{-1}) > 0.5\ 10^7\,GeV$

AS GOOD AS THE ASTROPHYSICAL BOUND FROM THE SUN : $> 1.08\ 10^7\,GeV$

(from helium burning stars $F > O(10^9\,GeV)$!)

SOON : $E_{th} = 4. \longrightarrow 1\,keV$, background $\longrightarrow \times 10^{-1}$ } $\Rightarrow$ $F\ (= g^{-1}) \gtrsim 1.8\ 10^7\,GeV$

Conclusions:

- dark matter is the most abundant form of matter in the universe

- Experiments trying to detect D.M. particles are of the type in which a negative result is not meaningfull (since always we may find new candidates!) BUT A POSITIVE RESULT....

- The Ge-detectors for $\beta\beta$ decay represent a new thechnology: the frontiere of low background low E, small rate,

  and they exist now => results known in 1y from now!

If we find D.M.: YOU WILL CERTAINLY KNOW IT!

OTHERWISE, we just eliminated some candidates for the future cryogenic detectors

which are a new step towards the physics of low E low background, small rate.