Cold Dark Matter Searches
Laboratori Nazionali di Frascati, November 24 2005

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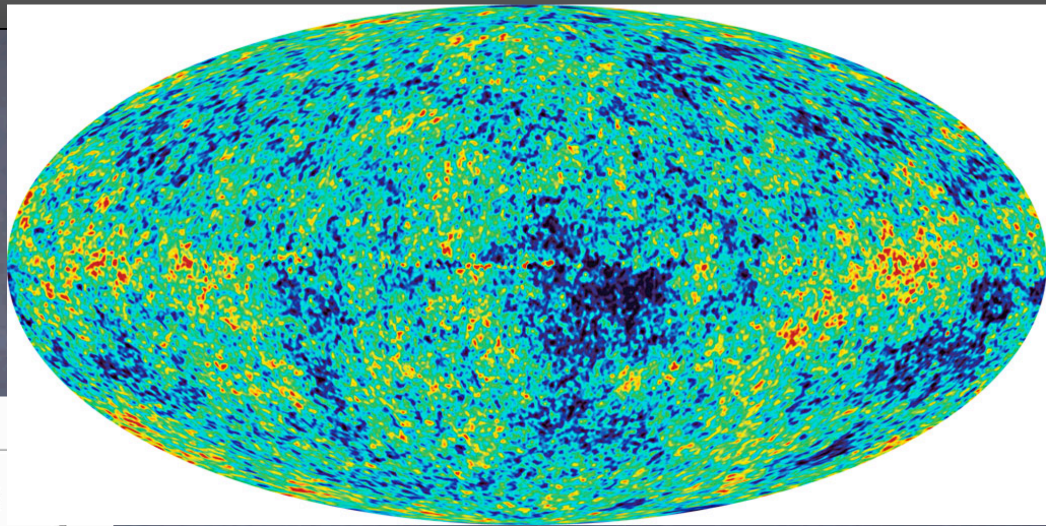
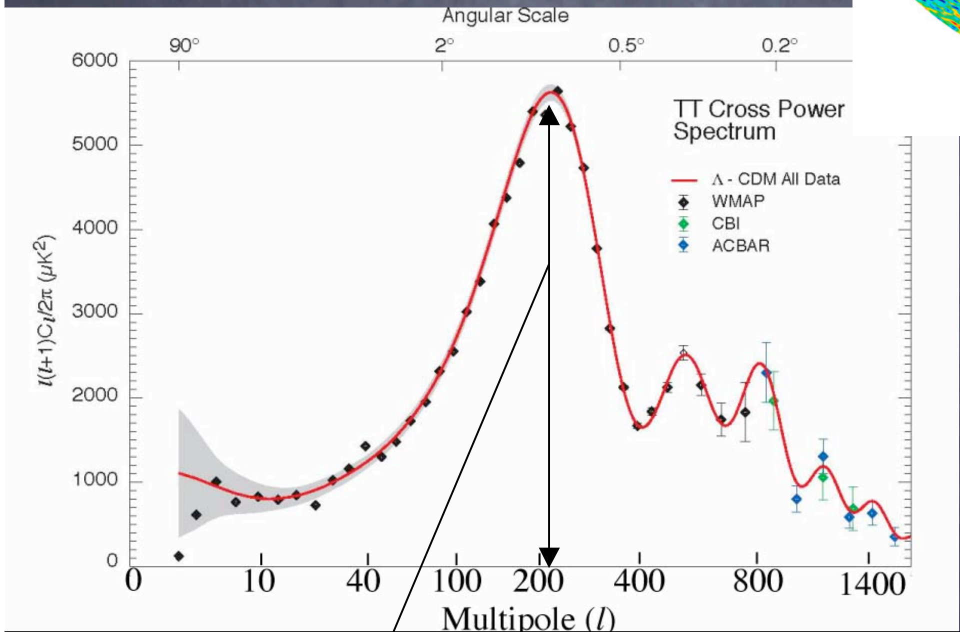
The Matter Density in the Universe

At *t*=372 000 yr dark matter shaped the density fluctuations through its gravitational potential





Matter is much more than what we see

From the position of the 1st peak $\Rightarrow \Omega_{tot}$ = 1.02±0.02
From its height $\Omega_m h^2$ = 0.0224±0.0009
And the rest?

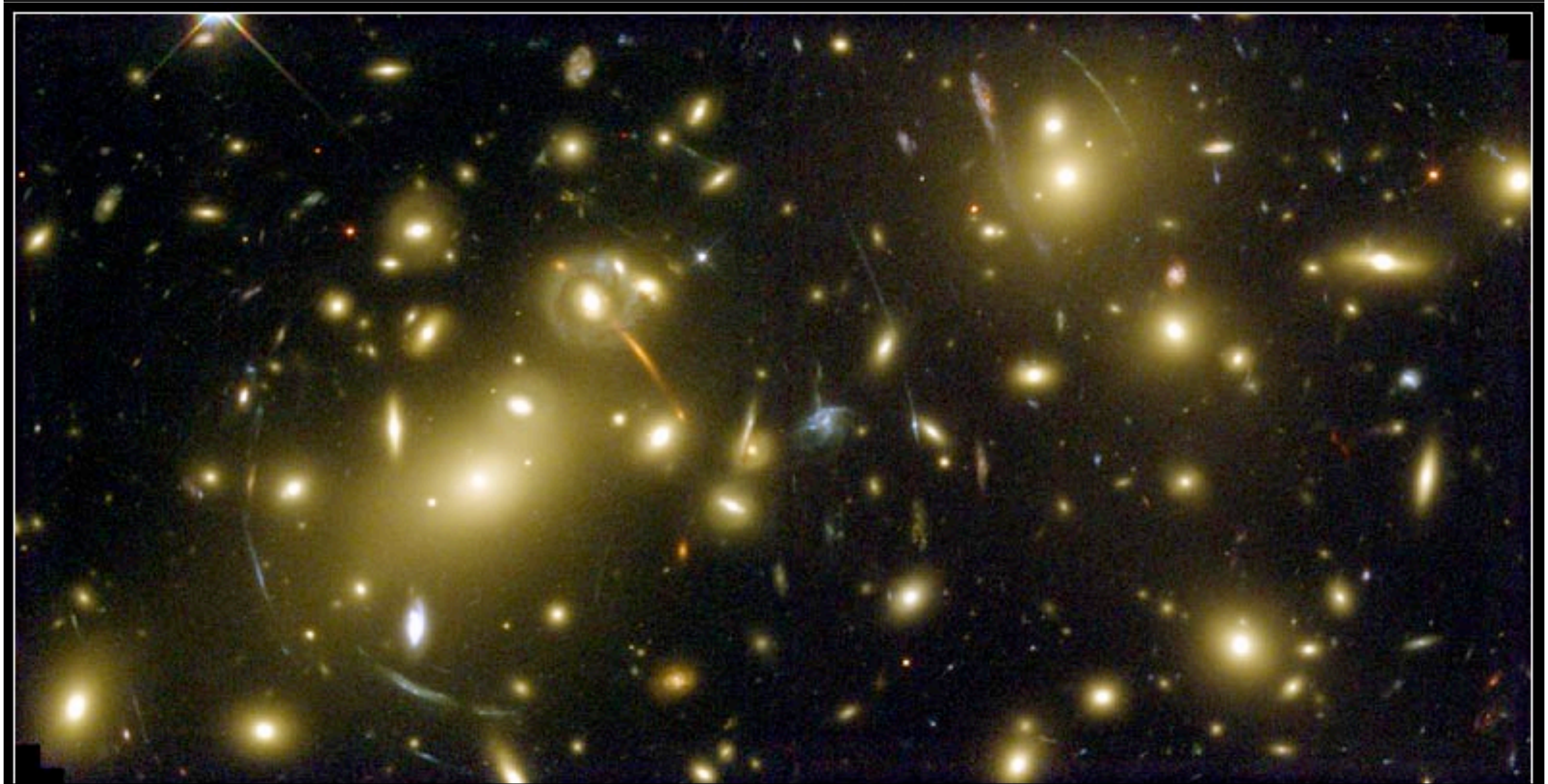
$\boxed{\Omega_m = 0.27 \pm 0.04 \quad h^2 \approx 0.5}$

Ω_m . *Kinematics in the Galaxy Clusters*

In the clusters Galaxies kinetic energies are much larger than the estimates from the visible mass (Zwicky 1933)

$\boxed{\Omega_m \sim 0.3}$

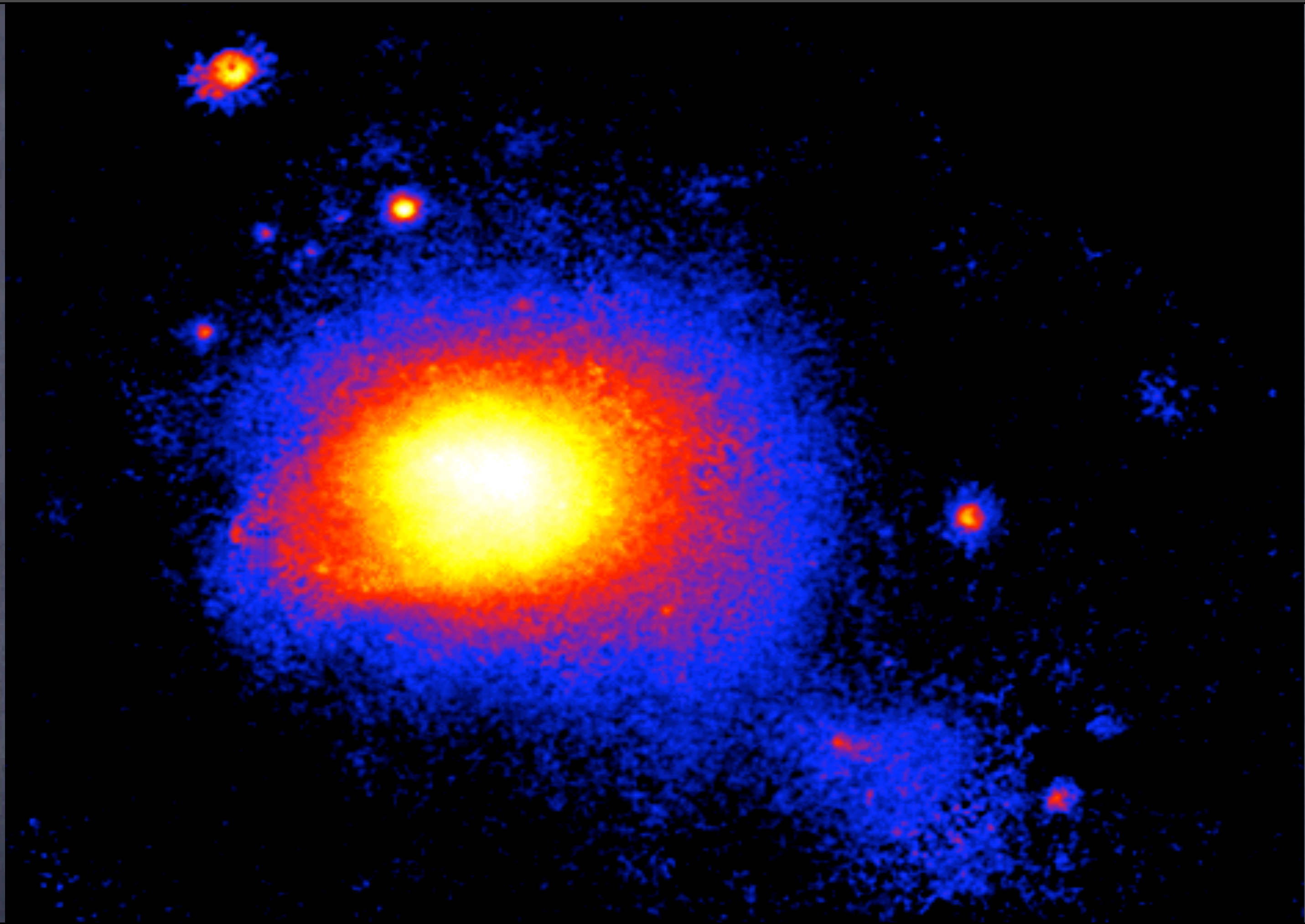
Ω_m . *Gravitational Lenses*



Massive bodies bent the light coming from farther sources, deforming their images
We infer their mass, even if dark

$\boxed{\Omega_m \sim 0.3}$

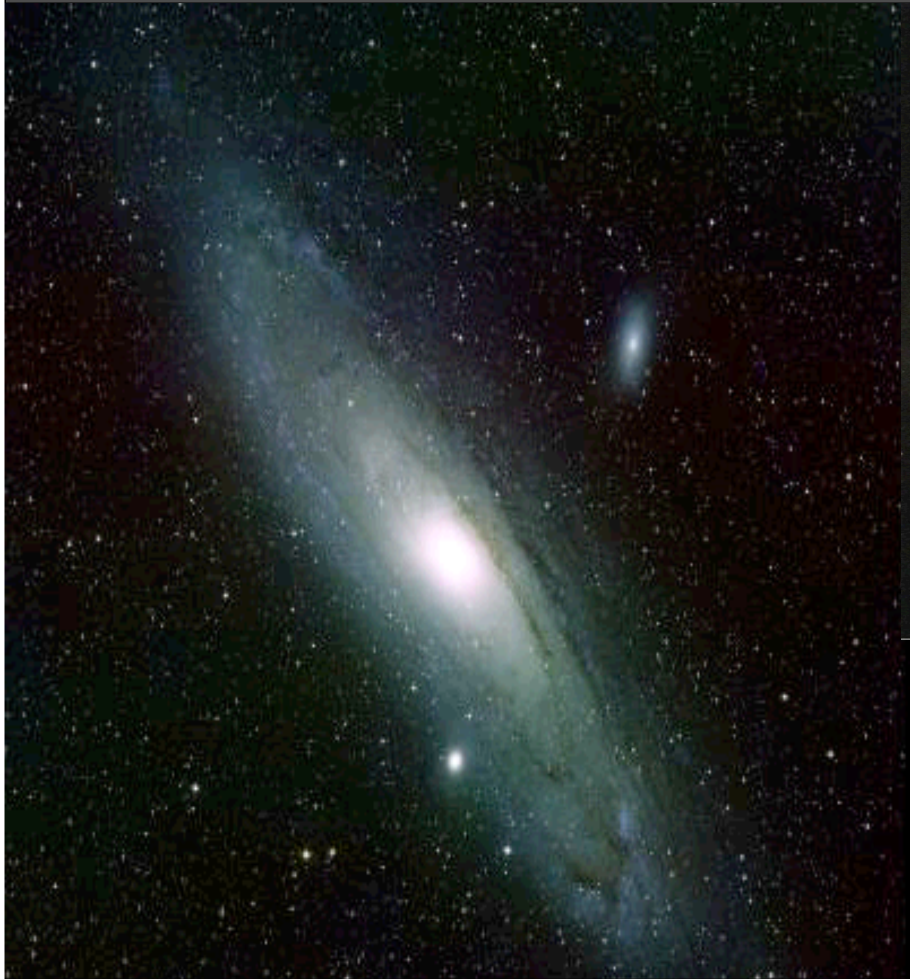
Ω_m . X Surface Luminosity in Galaxy Clusters

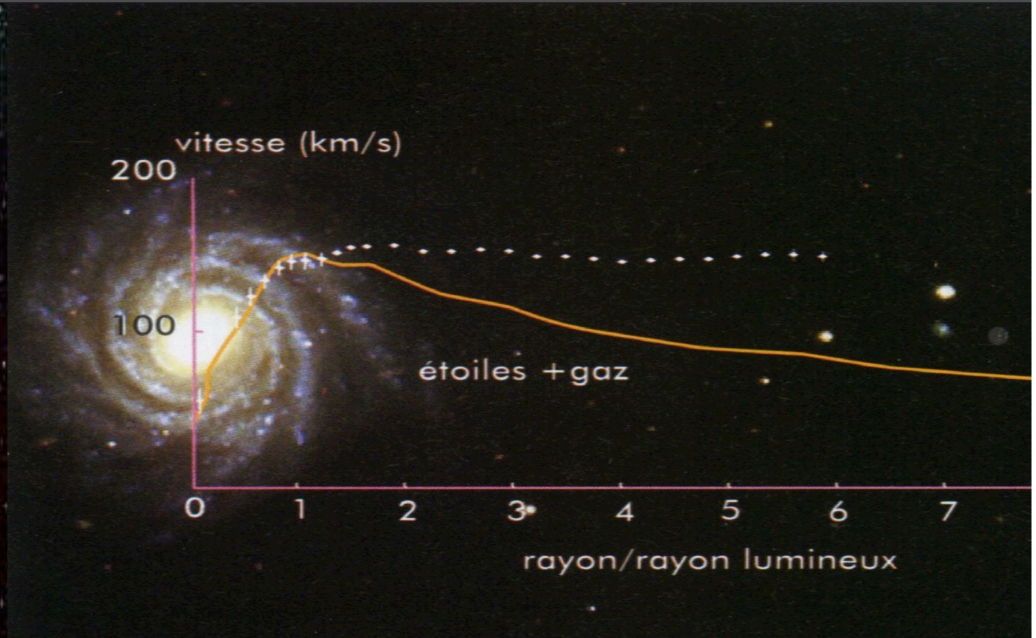


From the luminosity profile get the mass distribution

$\boxed{\Omega_m \sim 0.3}$

Ω_m.   *Galaxies Rotation Curves*



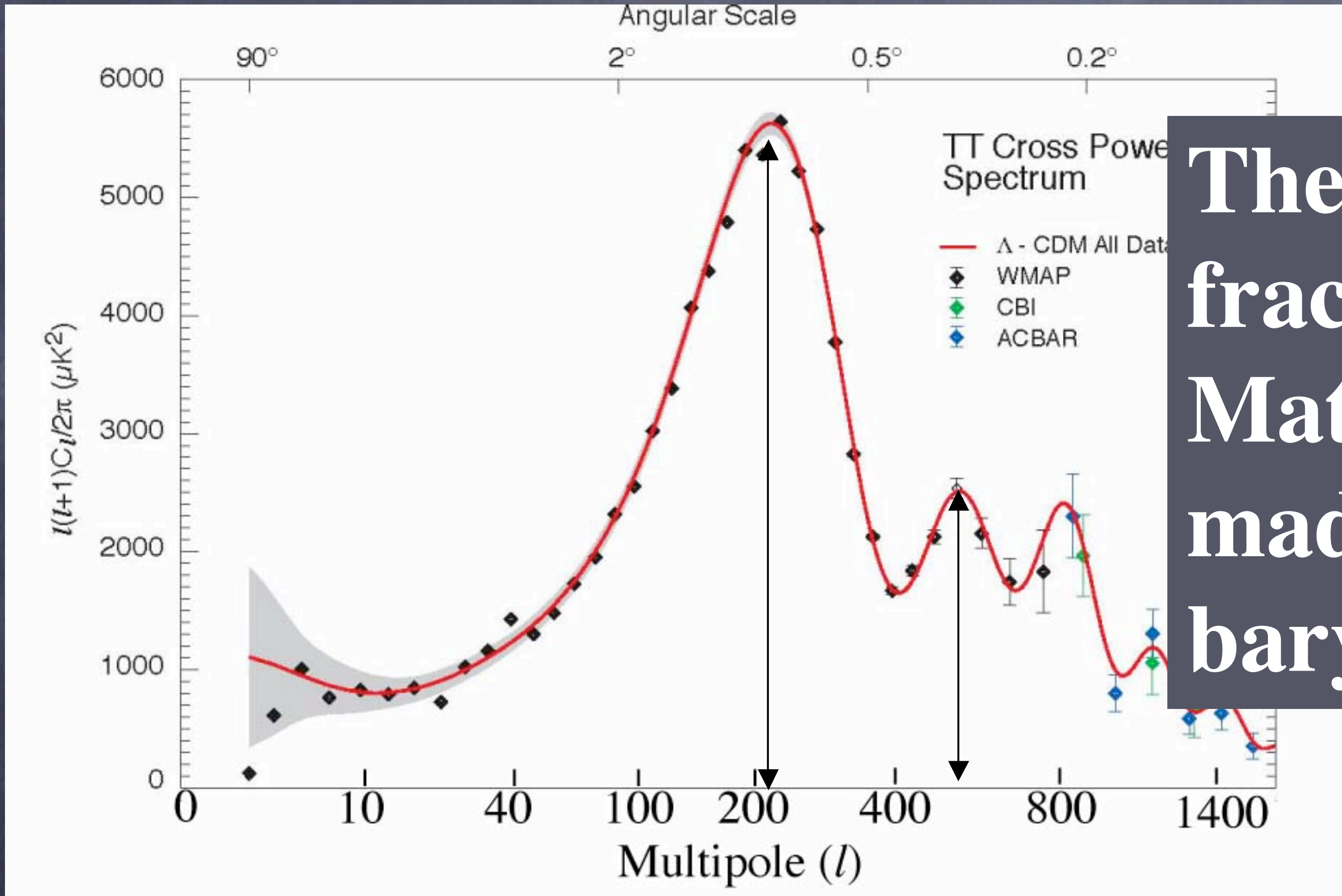


Dark matter is here, now

Stars and gases at the periphery of Galaxies rotate too fast comared to the Newton force due to the visible matter
Including our Galaxy

$\boxed{\Omega_m \sim 0.3}$

Matter Density in the Universe



The largest fraction of Dark Matter is not made out of baryons

The ratio of the heights of the two first peaks gives the normal ("baryonic") mass density

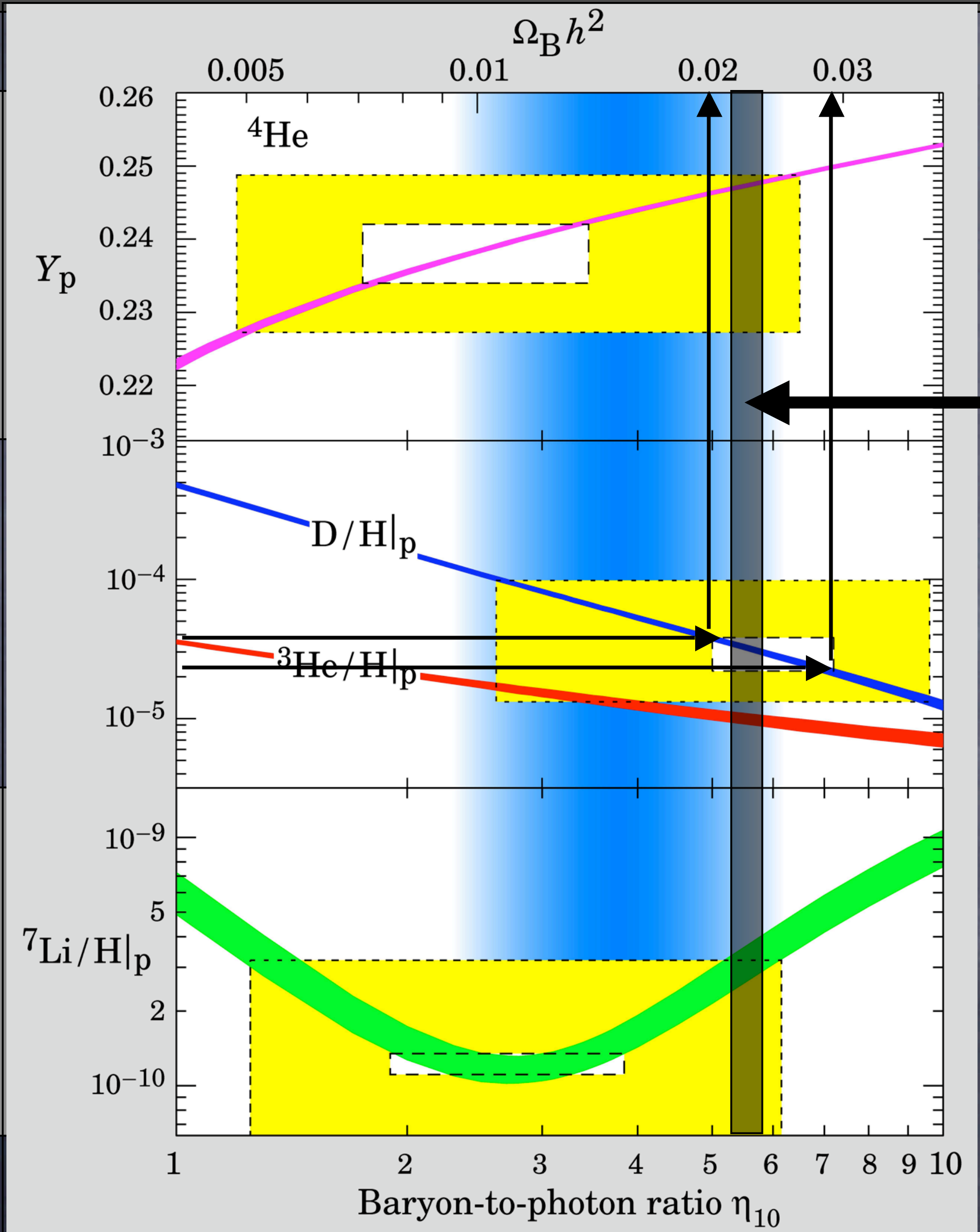
$$\boxed{\begin{array}{l} h^2\Omega_b = 0.020 \pm 0.002 \\ \Omega_b = 0.044 \pm 0.004 \end{array}}$$

Primordial Nucleosynthesis

Helium

Deuterium

Lithium



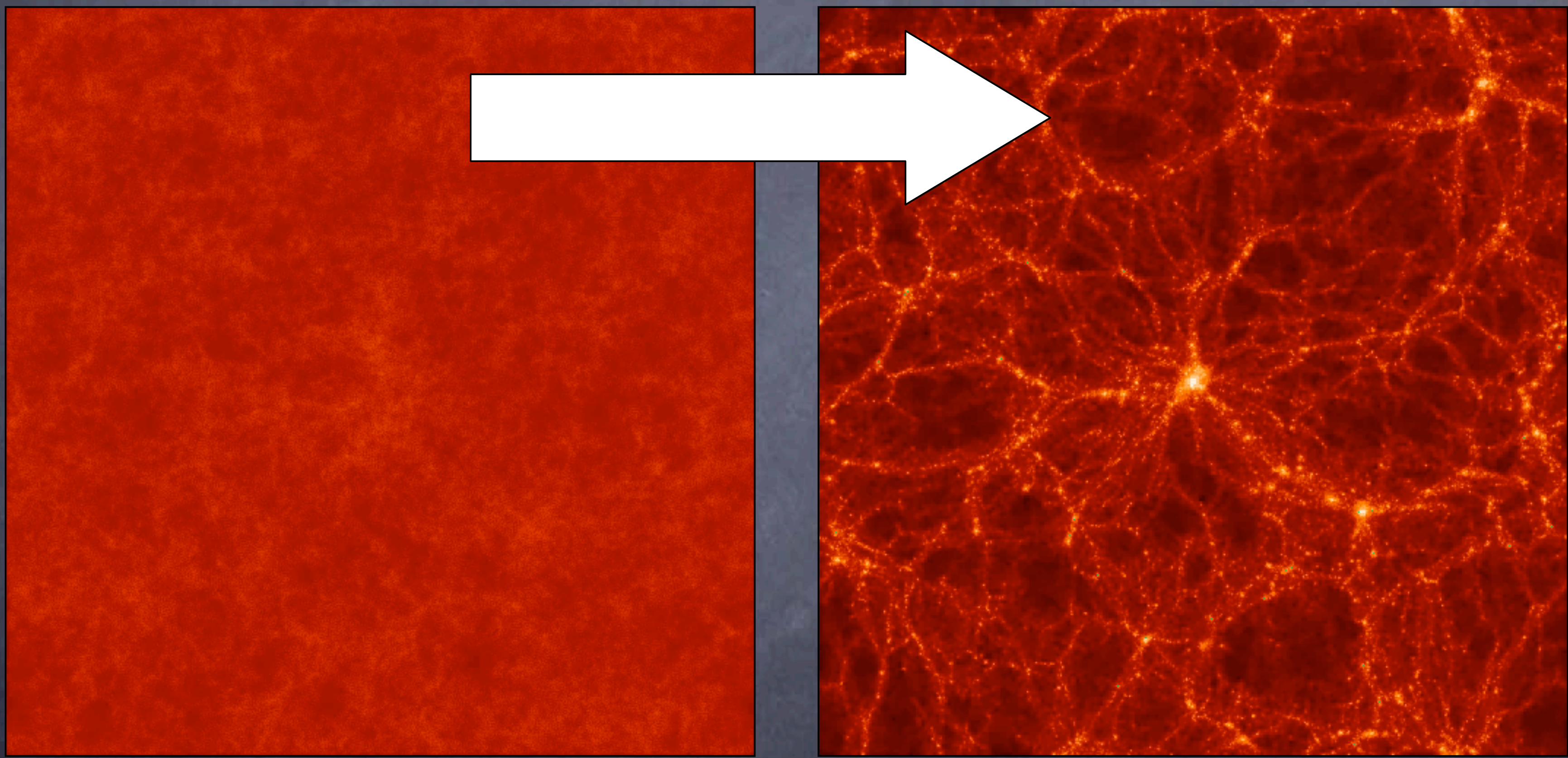
From CMB &LSS

The largest fraction of matter is not baryons

Review of Particle Properties

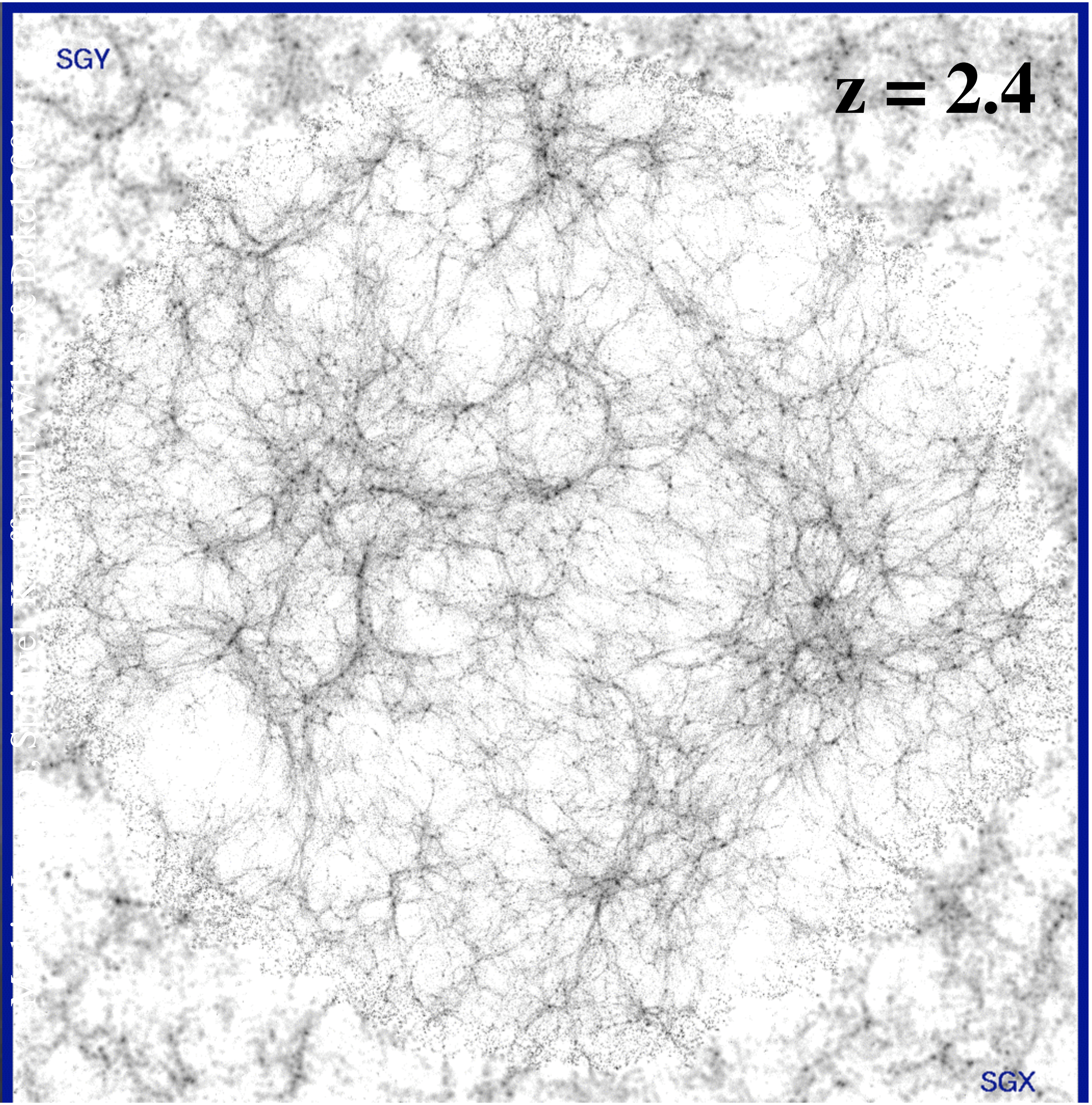
Large Scale Structures formation

The structures have been originated by the primordial density fluctuations, later amplified by the gravitational instability

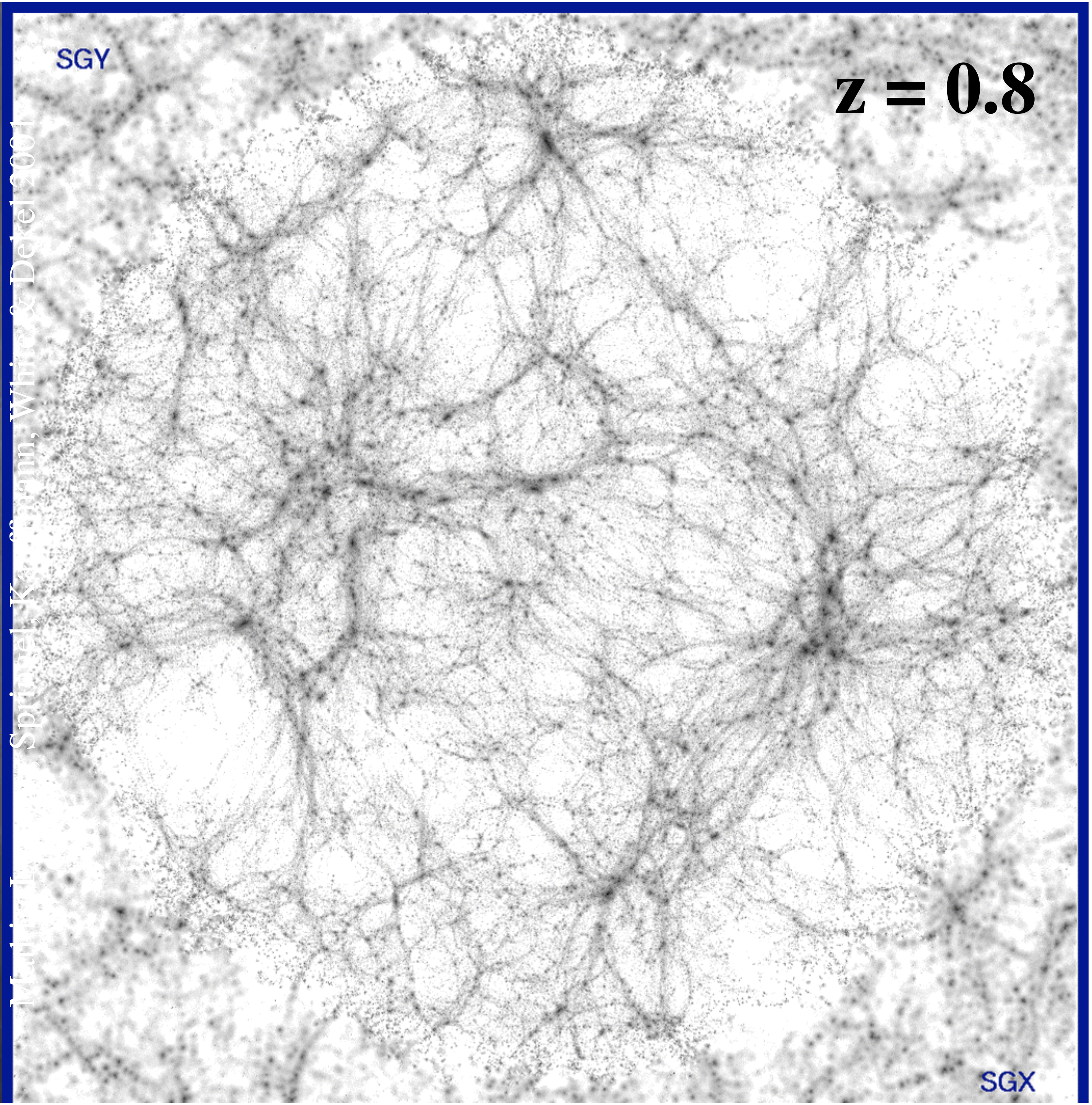


from Francis Halzen

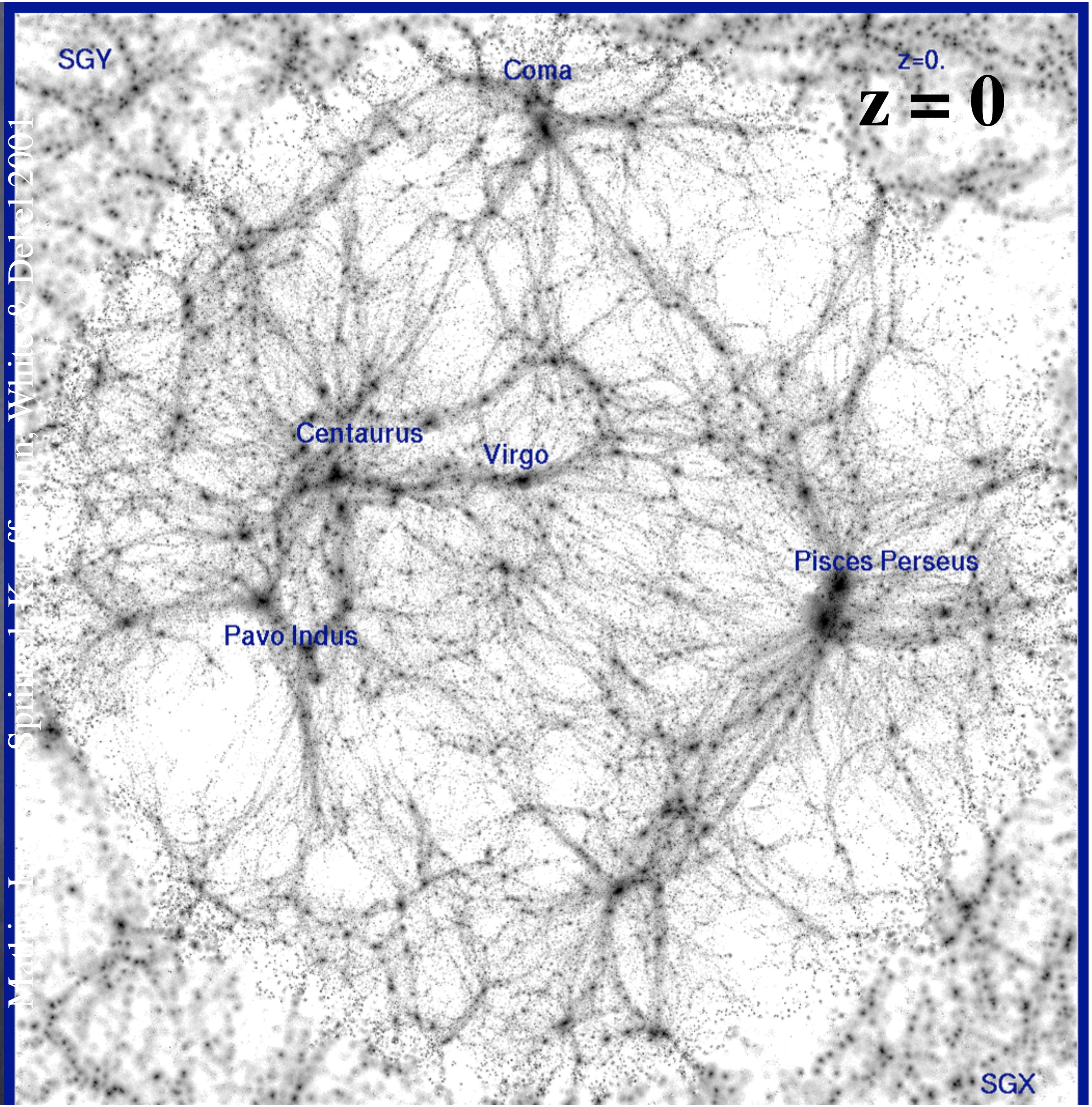
LSS movie



LSS movie

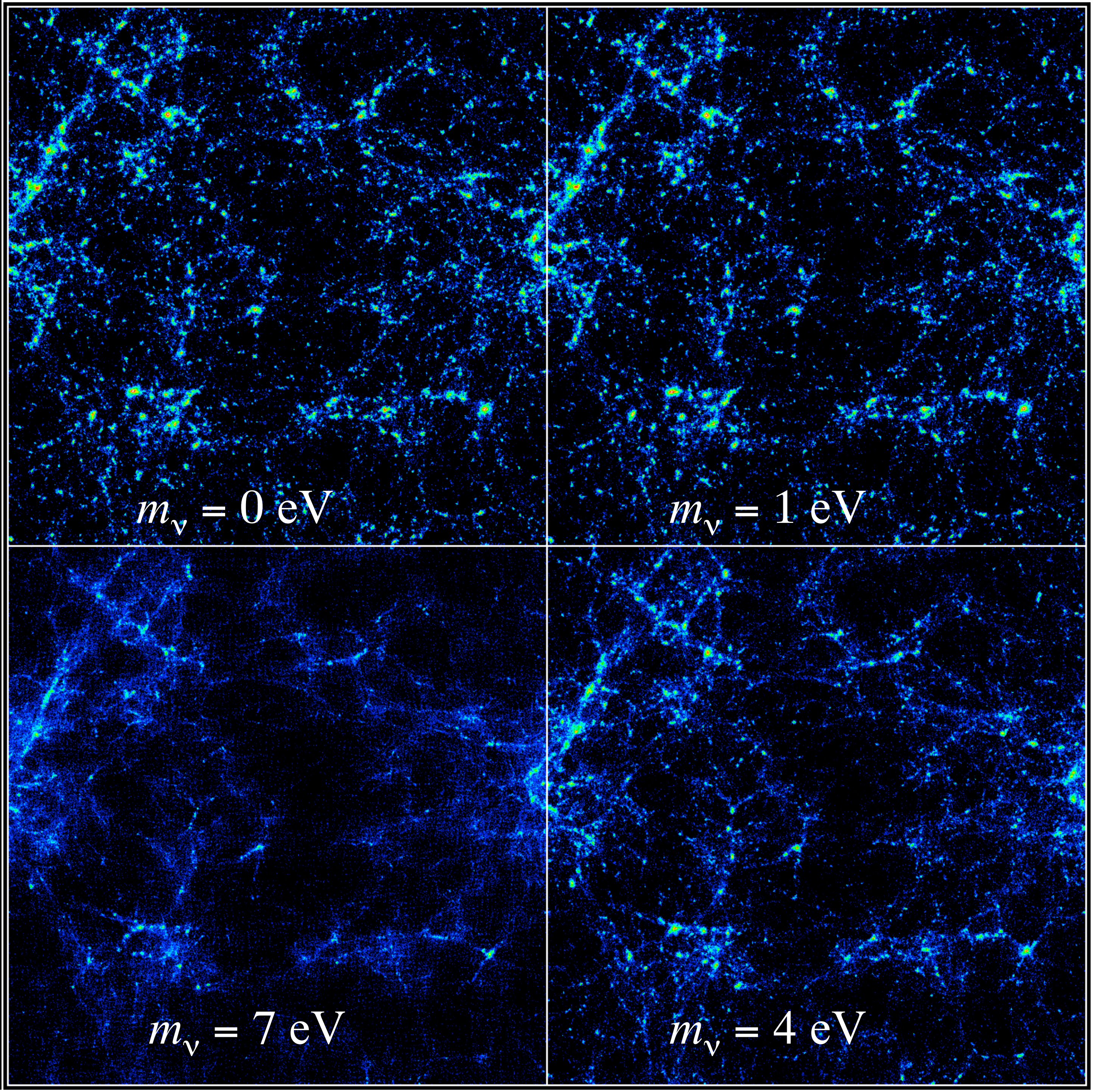


LSS movie


SGY
Coma
z=0.
z = 0
Centaurus
Virgo
Pisces Perseus
Pavo Indus
SGX
White & Dekel 2001

Neutrinos speeds are larger than the escape velocity from the smaller structures Moving from higher to lower density regions neutrinos suppress the formation of structures smaller than a scale *(D_F)*, inversely proportional to neutrino mass

$$D_F(\mathrm{Mpc}) \qquad \frac{1}{m_\nu(\mathrm{eV})}$$



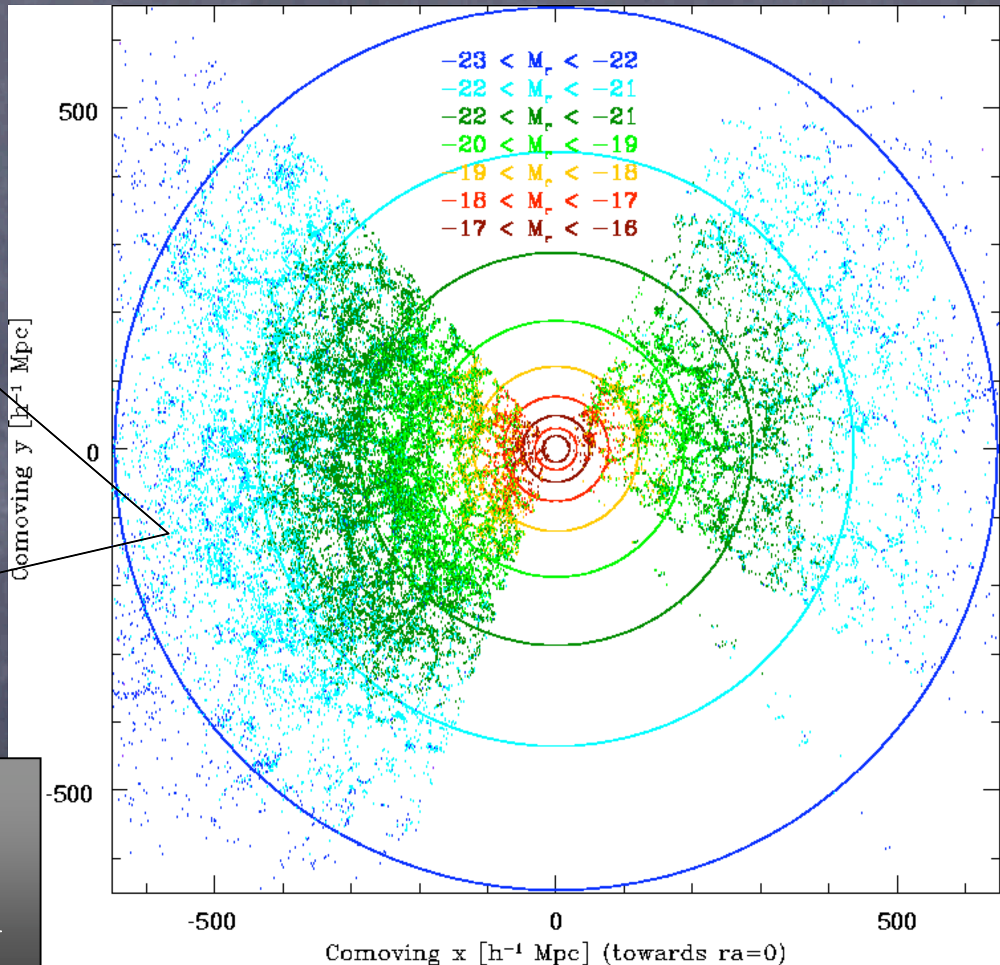
Dark Matter is not Neutrinos

Is non-baryonic dark matter made of neutrinos?

- ν's were cold @ last scattering epoch ⇒ little effect on CMB spectrum: z=1000
- at the epoch of LSS formation (z=0.1-0.2) ν's reduced the growth rate below ≈10 Mpc

SDSS will have ≈ 1 000 000
Similar data from 2dFGRS

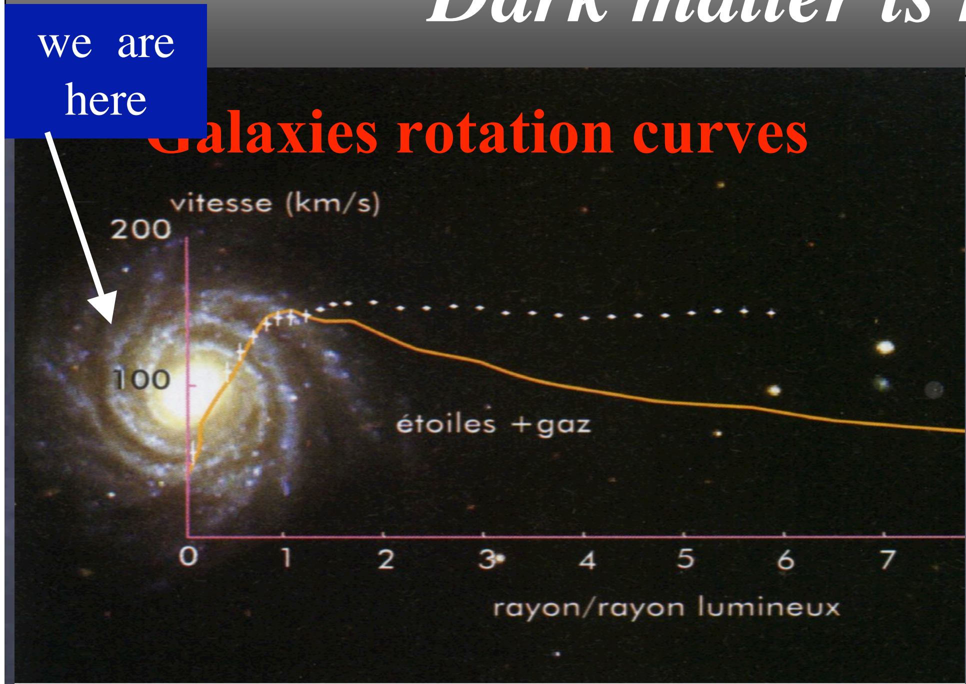
A dot = a galaxy



$$f_\nu = \Omega_\nu / \Omega_m < 0.015$$

Largest fraction of the dark matter is non-relativistic = cold

Dark matter is here and now



Cold dark matter is present at all scales including galactic halos (rotation curves), including ours (revolution speed of Magellanic Clouds, etc.)

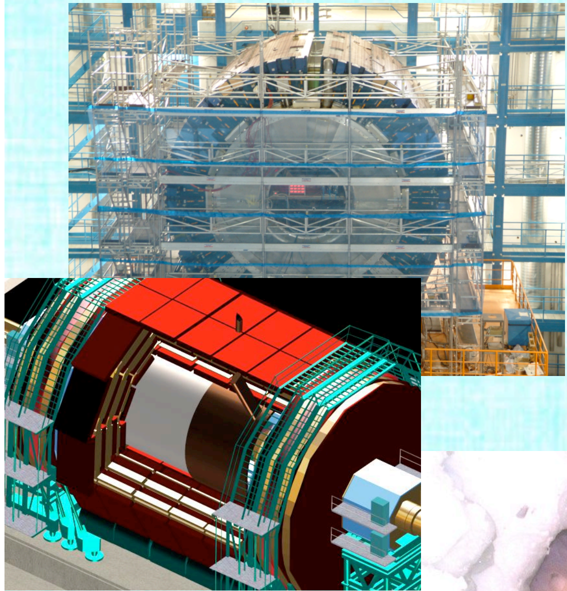
If dark matter particles do not have weak interaction, no hope to detect them, if they do are called **WIMPs**

Local WIMP density and velocity distribution are unknown
Assume an **isothermal halo model**
Velocity distribution in the Galaxy frame is presumably Maxwellian, truncated at the escape velocity $\upsilon_{esc}\approx$500-600 km/s

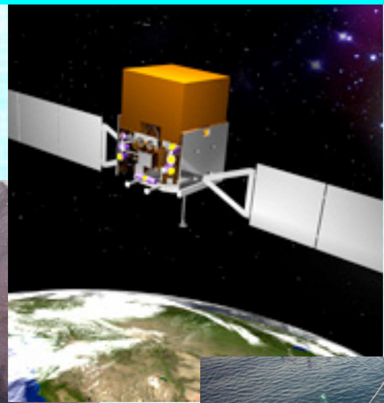
Speed in order of magnitude **$<\beta_W> \approx 10^{-3}$,** is the same as **stars (virial theorem)**
It is similar to **atomic electrons**
Expected density **$\rho_W \approx$ 300 TeV m^{-3}**
For **$M_W \approx$ 100 GeV** number density, **$n \approx$ 3000/m^3** flux **$\Phi_W \approx 10^9$ s^{-1} m^{-2}**
Typical kinetic energy E_{kin}=50 keV or less

Complementary search approaches

Being hunting for dark matter in the dark, we need to use different weapons, in an integrated way



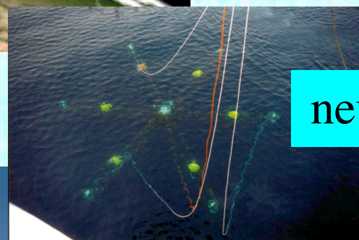
gamma-rays etc. on satellite



Direct searches in underground labs

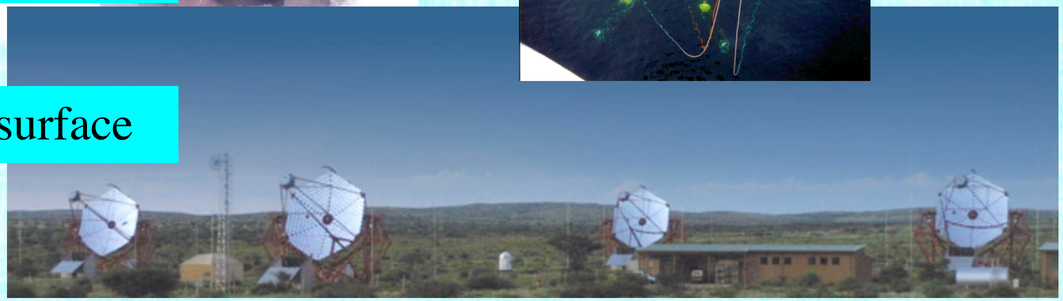
LHC experiments

neutrinos in ice



neutrinos deep underwater

gamma-rays on surface



Indirect searches

SUSY WIMPs

Standard model does not have any WIMP candidate

SUSY extensions of SM with *R*-parity conservation

the **LSP is a stable WIMP, the neutralino**

•**neutralino =** mixture of weak bosons and higgs superpartners,

•**Majorana particle ⇒≠χ=χ** annihilate each other

•This is only a possibility of many

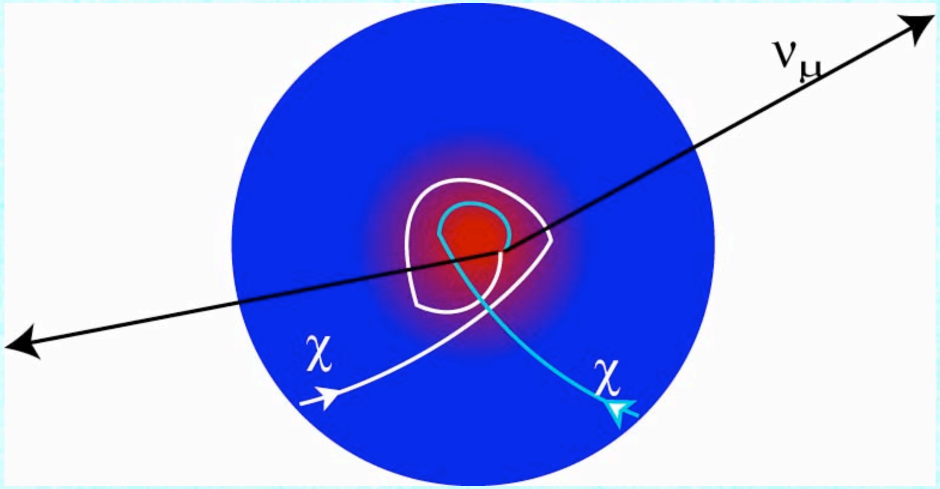
I'll forget many other candidates from theorists (axions, Kaluza-Klein, Wimpzillas, Kriptons,…)

Cosmology and SUSY give converging predictions

Two complementary searches are in order

- •search of the CDM constituents in the Universe, to understand the largest fraction of its mass
- •artificial production and detection in the LHC programme, for a precise study of their properties

Indirect searches



Basic assumption: Neutralinos accumulate in dense sites and annihilate each other

but no signal if no annihilation; e.g. $\chi \neq \neq \chi$ and asymmetry in their abundance

Annihilation rate $\propto \rho_\chi^2$

Annihilation $\chi\chi \Rightarrow$ large mass particles (τ leptons, b, c, t quarks; W and Z bosons)

Seek for excess flux of a (primary or secondary) particle kind above background

Signatures

•point to a source (need neutral messengers: ν, γ)

•lines in spectrum ($\chi\chi \rightarrow \gamma\gamma$, $\chi\chi \rightarrow Z\gamma$)

•distortions of spectrum,..

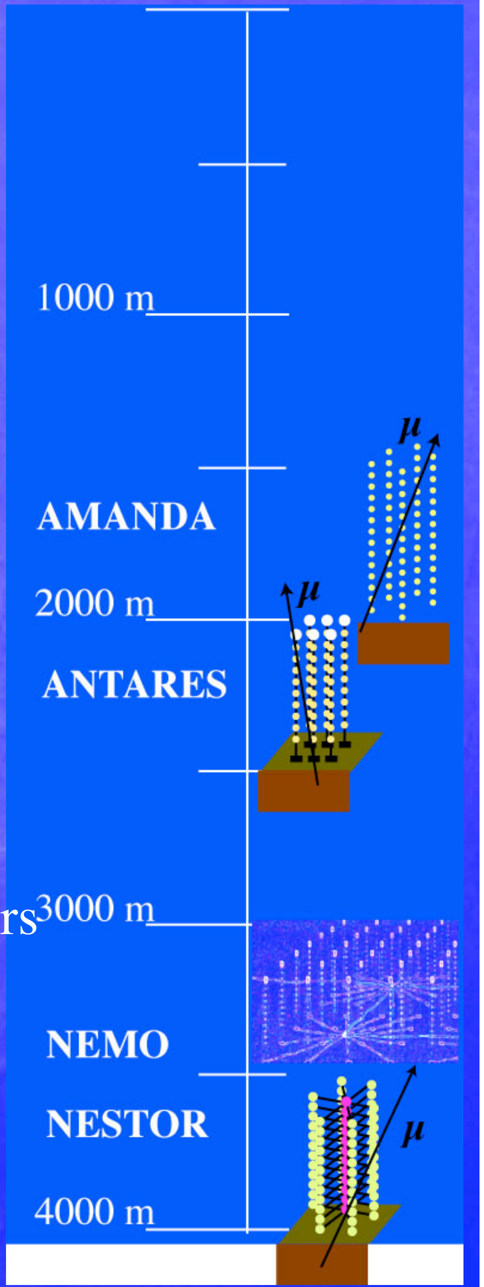
From measured (limited) flux calculate cross section and mass

Model dependence: ν, γ,.. energy spectra, physical structure of the source

Indirect Searches. ν_μ telescopes

High-energy muon-neutrinos from point sources

- **large scale detectors running for several years**
  - SK, Baikal, MACRO, AMANDA: interesting limits, but too small
- Background= atmospheric neutrinos, well known
- Very good perspectives for the future with
  - **deep ice/sea neutrino observatories**
    - ICECUBE, KM3 in Mediterranean sea



- **Sources**
  - **Sun. Structure (rather) well known**
    - WIMPs are trapped via interaction with protons
      - test of coupling type
    - ν_μ flux calc. depends on astrophysical and physical parameters
  - **Galactic Centre (GC)**, structure of the source (including black hole) poorly known; very interesting place to looked at
  - **Centre of Magellanic Clouds**
  - ……………

Indirect Searches-Gammas

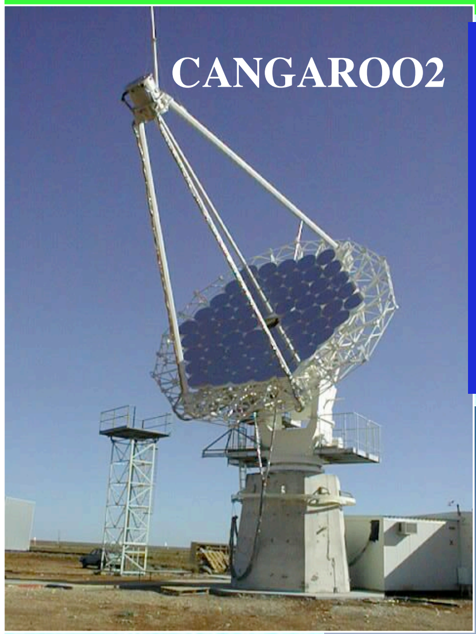
Three new-generation gamma ray (multi-)telescopes are taking data: CANGAROO2 in Australia, HESS in Namibia, MAGIC at La Palma. Construction of a fourth, VERITAS (in the US) is progressing

All detect excess of TeV γ 's from GC, but with different spectra

Is the excess due to multi-TeV mass WIMPs?

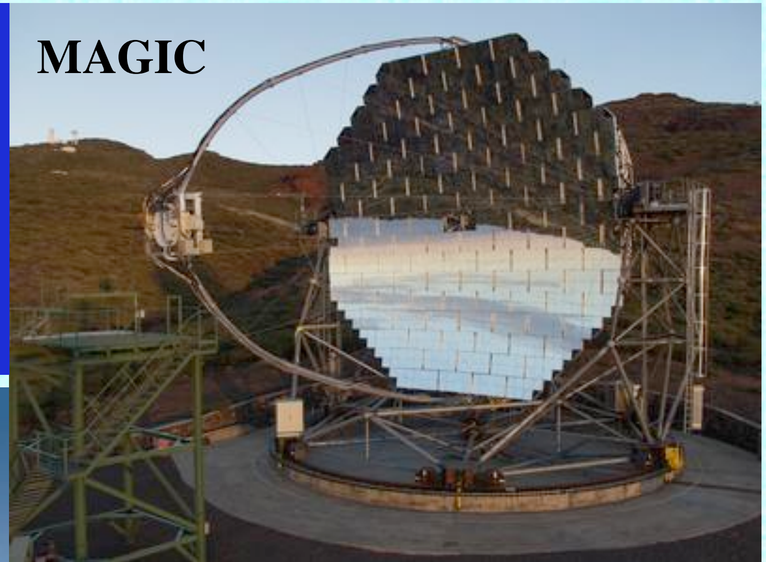
- fluxes >> (most) theoretical predictions as WIMP annihilation

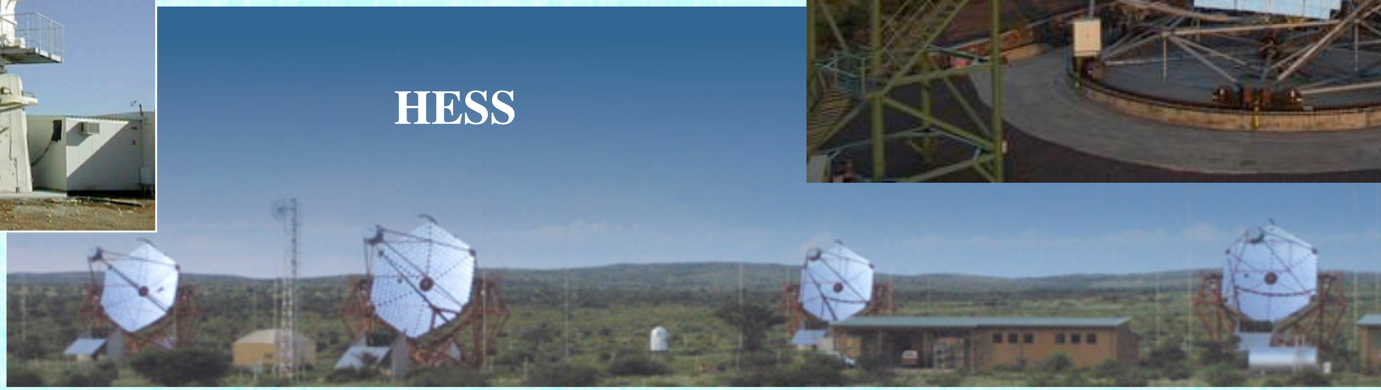
Alternative interpretations possible. Much better knowledge of GC needed



Clumps of dark matter may be present in GC and other high density regions

Complementary information from gamma and neutrino messengers





Spectrometers in Space

Past and present mainly γ's EGRET, INTEGRAL, AGILE

Thanks to P.G. Picozza, S. Gentile

•seek for lines or distorsions in the spectrum

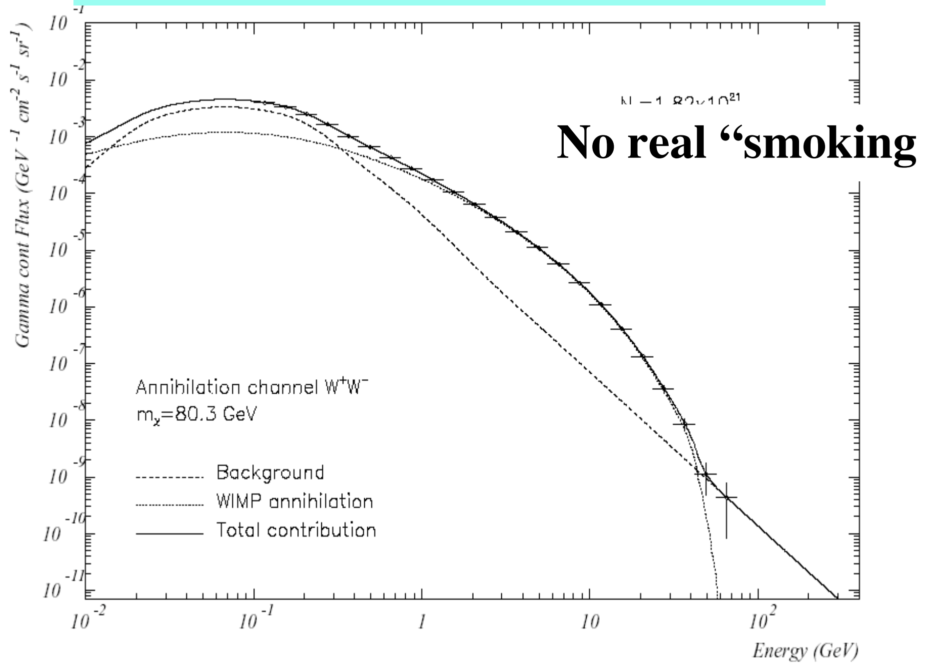
Brilliant future with the high acceptance spectrometers

Complementary observation of different possible WIMPs annihilation products: e^+,$\neq p$, γ

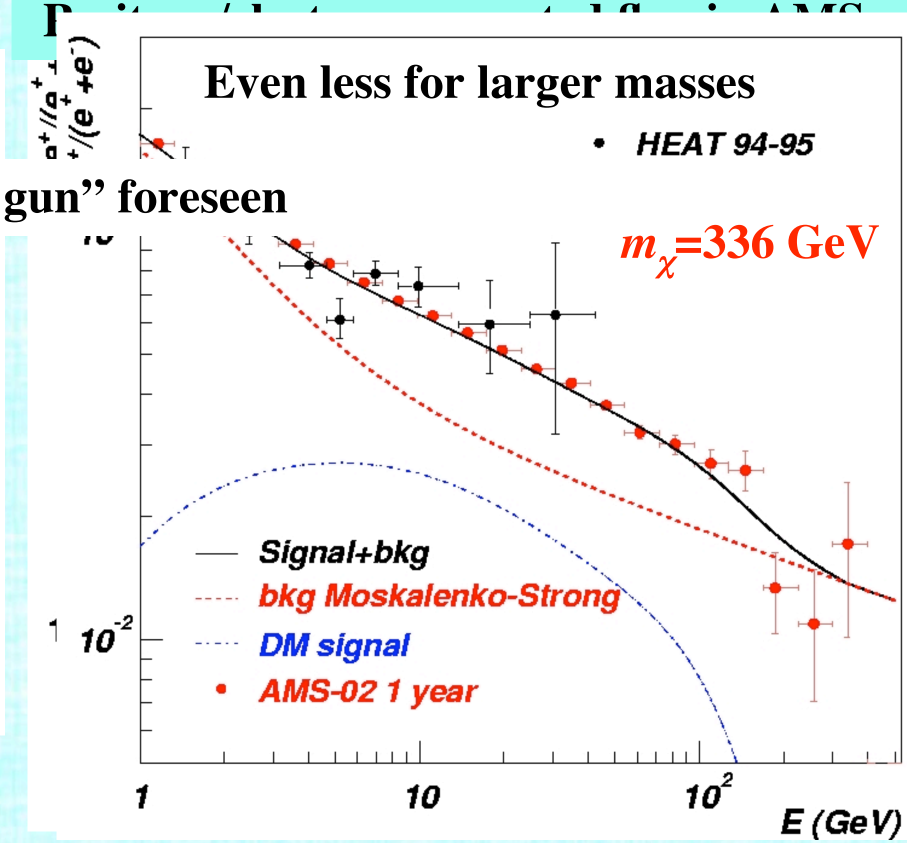
PAMELA, AMS, GLAST

Expectations dependent on SUSY model and astrophysical assumptions

Gamma expected flux in GLAST



No real "smoking gun" foreseen



A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, 2004 (June)

Direct Search of WIMPs

Look for WIMP-nucleus elastic scattering, detect energy deposited by recoiling nucleus

Two kinds of interactions of WIMPs with nuclei

•**SD** (spin dependent), axial vector coupling to nucleons spins; only unpaired nucleons couple to WIMPs ⇒ odd number of p or of n ($J \neq 0$), $\propto J(J+1)$

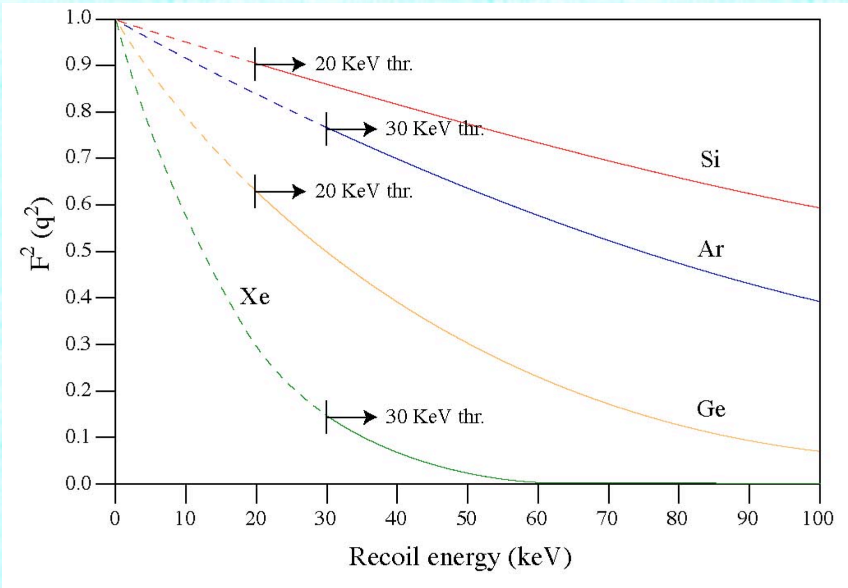
• **SI** (spin independent), scalar interaction with the mass of the nucleus

- •WIMP wavelength < nuclear radius ⇒ coherent process ⇒ cross-section $\propto A^2$
- •Coherence is lost at momentum transfer (Q) larger than the inverse nuclear radius (R) $Q > 1/R \propto A^{-1/3}$. Cross-section decreases
  - •Important for heavy targets
    - •Working at with high-Z (e.g. Xe) needs lower energy thresholds
  - •Important for heavy (several hundreds GeV) WIMPs

Loss of coherence is parametrised with a "form factor" $F(Q)$, which has roughly an exponential behaviour

Use of form factors is a source of uncertainty when comparing results on different nuclei

Search should be pursued with several different nuclei



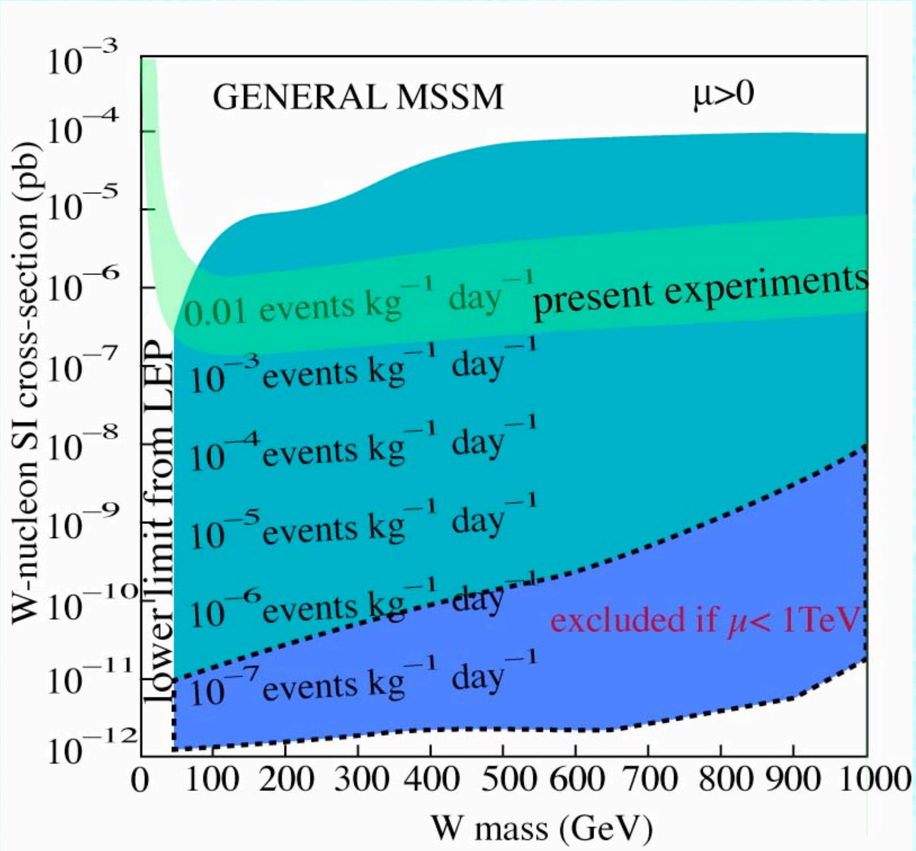
Neutralino SI cross sections

adapted from Y. G. Kim et al. hep-ph/0208069

•SUSY particles cross sections have orders of magnitude uncertainties

•Rates are proportional to the incoming WIMP flux = local density ρ_χ times velocity (velocity distribution) ⇒ halo-model dependent

Cross sections are given in terms of the computed σ on free proton ($\sigma_{\chi p}$)



Expectations on rates shown in the plot are indicative only, strongly dependent on target nucleus and on energy threshold

No firm theoretical upper limit on the χ mass (but reasonably < 1000 GeV)

DEFINITION: 1 dru = 1 ev/(kg keV d)

"Ultimate" detector ⇒ sensitive mass *O*(100 t) and background rate *b*< 10^{-8} dru (= one count in three years in a 10 keV energy window, in 10 t detector) !!!

Principles of WIMPs Detection

Target = Detector

Detection of the WIMPs = measure the energy deposited by the (elastically) hit **nucleus** in the target-detector medium

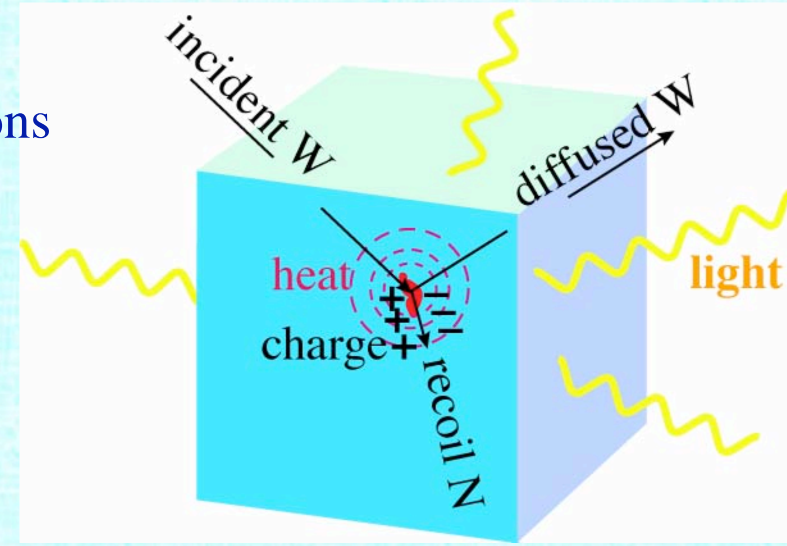
A fraction of this energy appears as **electrons, photons or phonons (heat)**

Main challenges

- Signal rate is small
- Energy deposit is tiny (few keV)
- Signal spectrum decreases exponentially

•3 basic backgrounds

- electromagnetic (β & γ); dominant ⇒ electrons
- neutrons (and WIMPs) ⇒ nuclear recoil
- surface contamination
  - only a fraction of energy is detected
  - may simulate signal



To fight the background

Work in an underground laboratory (as opposed to underground site)

Passive shielding. Works for external backgrounds only. Need very pure materials. In principle, large layers of extreme purity materials (e.g. BOREXINO-like techniques) may be useds

Active discrimination (against external and internal backgrnd) Exploit differences in the **physics** of the **energy transfer** to the detector molecules by electron-recoils and nuclear recoils

"Event by event" (after cuts) **rejection.** Most powerful and difficult, but necessary for "zero" background

Statistical rejection. In presence of residual background sensitivity proportional to square-root of exposure

The "Quenching Factors"

Speed of recoiling nucleus ≈ speed of atomic electrons. Only a small fraction of E_{rec} goes to ionisation. Different than relativistic particles

Furthermore, a large fraction (dependent on the applied E-field) of the ionisation disappears due to columnar recombination

Calibrate detector (e.g.) with γ rays of known energy E_{ee} (electron-equivalent energy): keV$_{ee}$

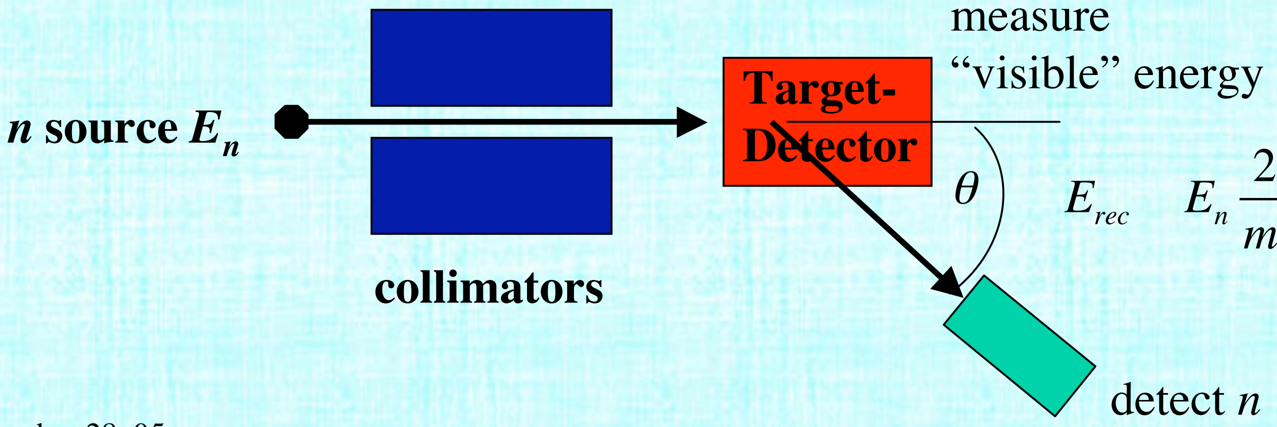
Measure the response to nuclear recoils of known energy E_{rec} (keV$_{rec}$)

Define the quenching factor $Q_F \equiv E_{rec} / E_{ee}$

Q_F depends on the detector material, on the detection technique and on the energy

Must be measured in the relevant energy range

Typical values: for Q_F(Ge) ≈ 0.25, Q_F(I) ≈ 0.10, Q_F(Xe) ≈ 0.30, Q_F(Na) ≈ 0.30



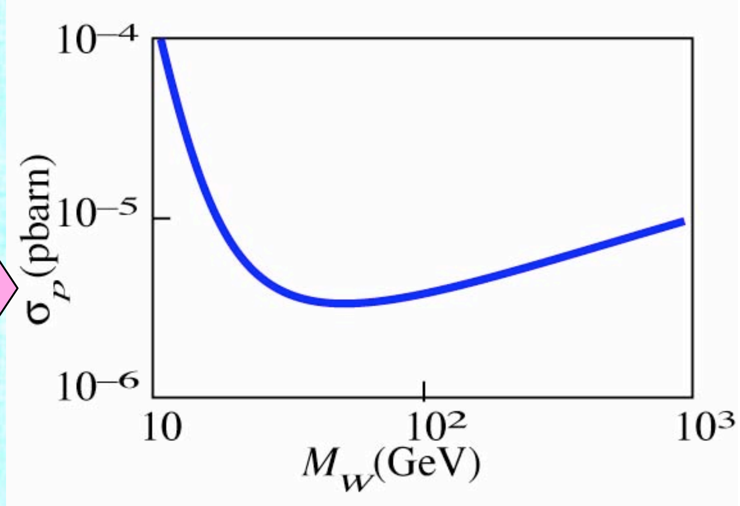
$$E_{rec} \qquad E_n \frac{2m_n M_T}{m_n + M_T}(1 - \cos\theta)$$

The Exclusion Plot and Signal Modulation

First ("classical") method

- Backgrounds cannot be accurately modelled and subtracted
  - develop selection criteria to define a "background-free" region in the experimental parameters space
- Assume a halo model (local WIMP density, velocity,..)
- Calculate for each WIMP mass m_χ the maximum possible signal rate allowed by the data

Result is model dependent



Second method: Signature for WIMPs interactions

Annual modulation of the rate. Earth velocity relative to halo is maximum in June (250 km/s), minimum in December (220 km/s). Counting rate expected to be in phase at high enough recoil energies (E_{rec}>E_X) (A. Drukier et al. '86; K. Freese et al. '88)

A positive effect is model independent

Above cross-over
***T*=1 year**
t_0 = June 2±1.3 days
$\upsilon_{orb}/\upsilon_{Sun}$ =0.07±0.01

DAMA. Annual modulation experiment

At INFN LNGS ⇒$\Phi_\mu / \Phi_\mu^0 = 10^{-6}$

1996-2002: **107731 kg d exposure**

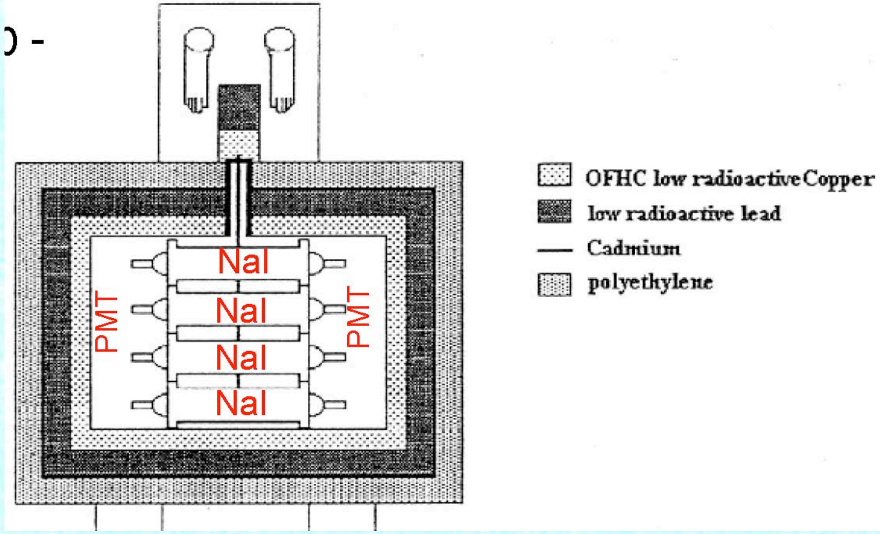
Ultra-low activity NaI scintillator: 9×9.7 kg crystals, each viewed by two low-background PMTs

Software energy threshold = 2 keV$_{ee}$

Passive neutron and photon shielding

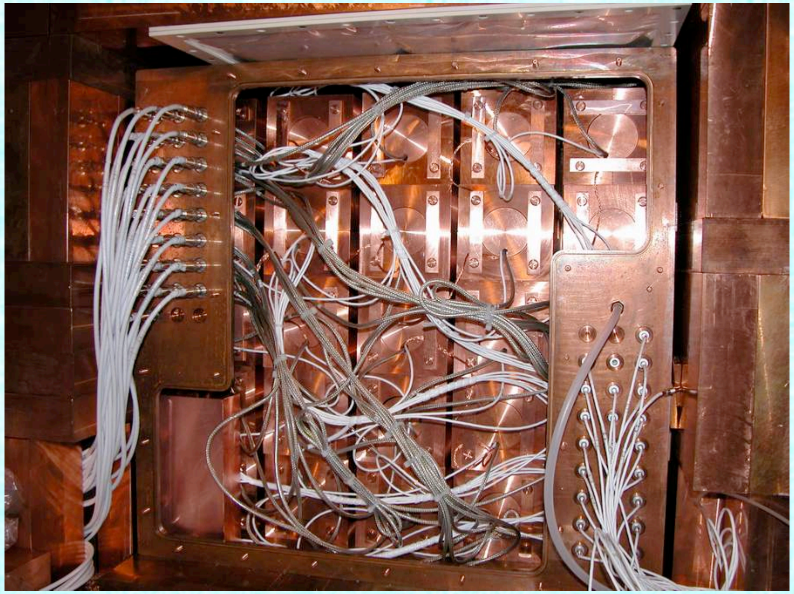
Background in the signal region ≈ 0.5-1 dru

Long term stability and monitoring of all relevant parameters (mandatory, requires good lab's infrastructures)

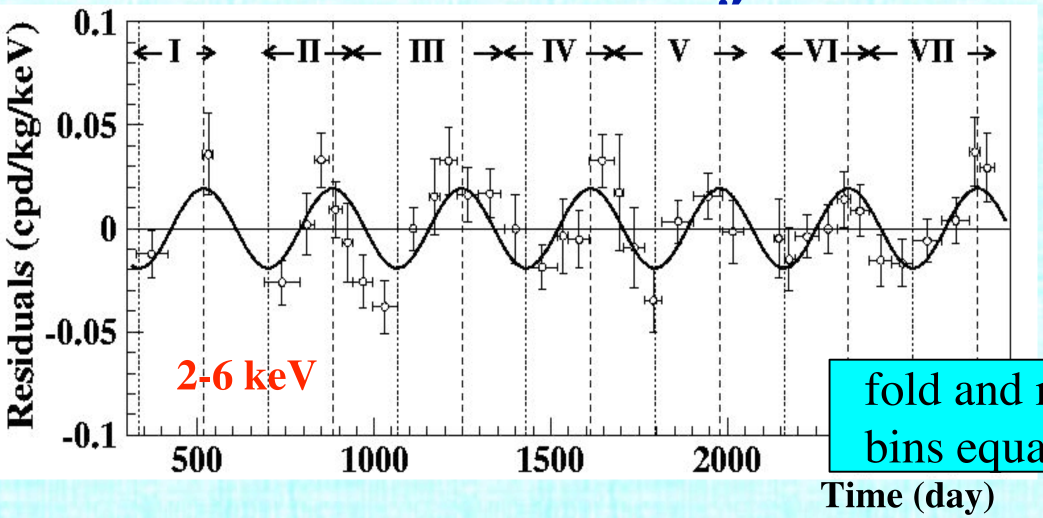


Characteristics of modulation signal

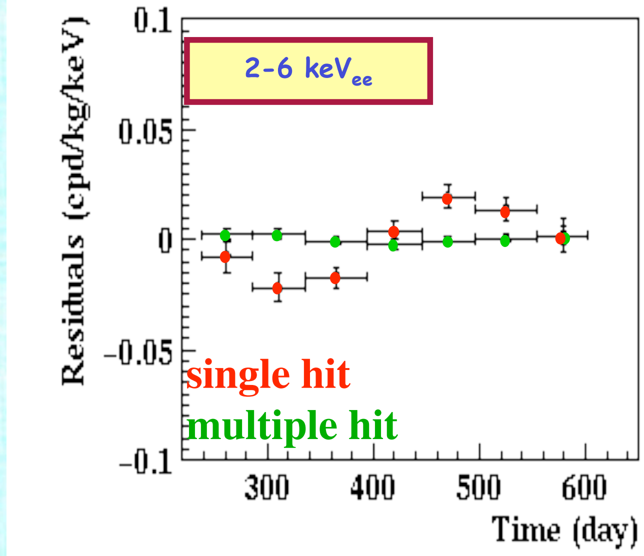
1. **Time dependence = cosine**
2. **Period = 1 year**
3. **Phase: maximum @ ≈June 2nd**
4. **Amplitude a few percent**
5. **Only at very low energy**
6. **Hit in one crystal only**



DAMA. A first WIMP candidate



fold and make bins equal



Fitting three parameters:

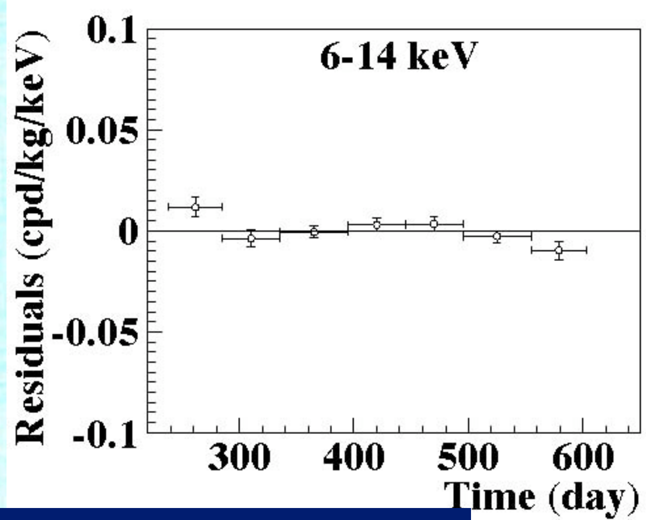
A = (0.0200 ± 0.0032) dru

t_0 = (140 ± 22) d

T = (1.00 ± 0.01) y

Statistical significance 6.3 σ

Total (const.+mod.) signal rate same order as bkg rate



Control of possible modulation fakes from *T*, Rn, noise, energy scale, efficiency, backgrounds, *μ* flux modulation

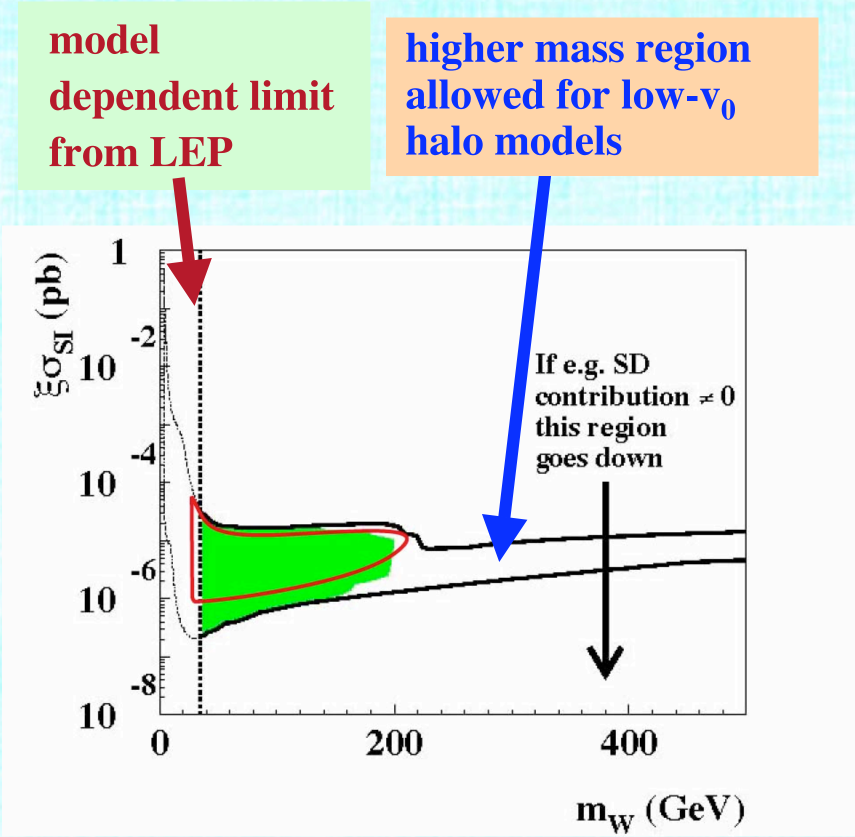
⇒ all shown to be <1%

6 signal characteristics satisfied

Model independent evidence

DAMA. Model dependent interpretation (SI)

The calculation of the signal region in the σ vs. m_W plot depends on the assumed model and on a number of unknown parameters



LIBRA is the new DAMA set up with NaI mass increased to ≈ 250 kg

improved radio-purification techniques, improved light yield

Taking data since March 2003

Thanks to Rita Bernabei

Thanks to J. Morales

ANAIS at LSC

DAMA evidence needs to be confirmed/confuted by an **independent experiment** with **NaI** scintillator of **similar mass** and in **similar background conditions**

ANAIS project at Canfranc Lab

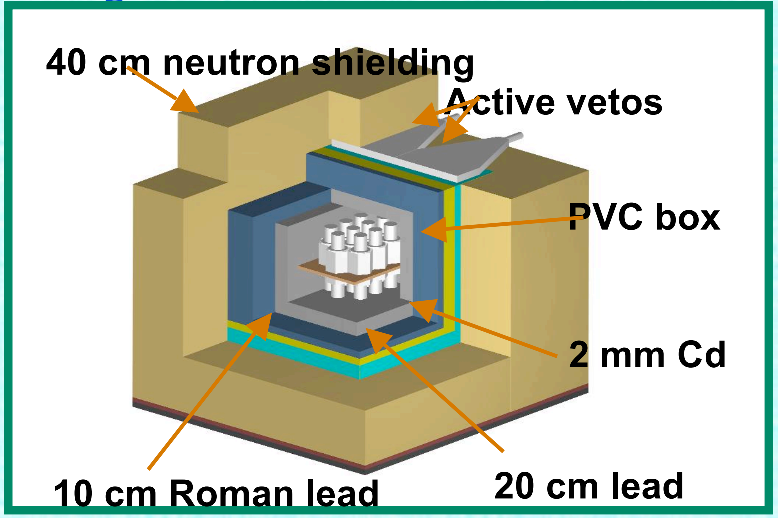
Depth = 800 m $\boldsymbol{\Phi_\mu / \Phi_\mu^0 = 10^{-5}}$

14×10.7 kg NaI crystals stored underground since 1988 (get rid of cosmogenetic activation)

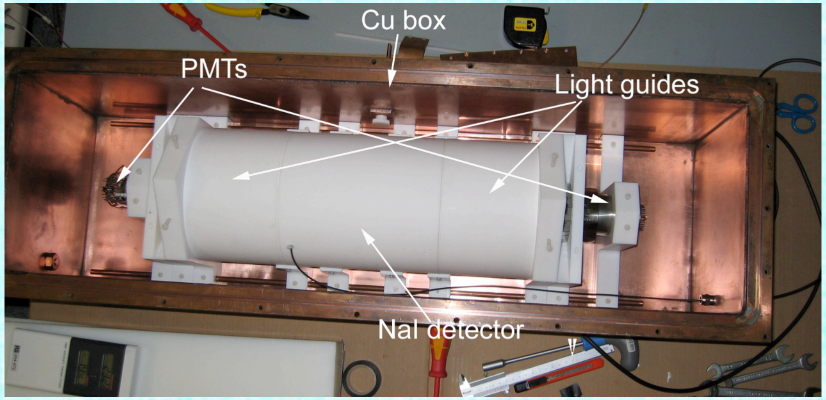
Prototype 1. A crystal viewed by a PMT only; threshold 4 keV ⇒ too high

rate @ threshold = 1 dru ⇒ OK

Tests to be competed by 2005.



Prototype 2 being developed. Two PMTs on a crystal, better screening (get rid of ^{210}Pb contamination), to check **lower threshold**



Full experiment(≈100 kg NaI) scheduled to start in 2006. Will need continuously running for several year under stable and controlled conditions

New LSC Laboratory can provide the necessary infrastructures and assistance

Cryogenic Detectors *CDMS, EDELWEISS, CRESST*

Measure the **heat deposited by the recoil**. Two experimental ways

•Wait for thermalisation and measure $\Delta T = E_{rec}/(CM)$.

•Count athermal (not in equilibrium) phonons as a function of interaction time

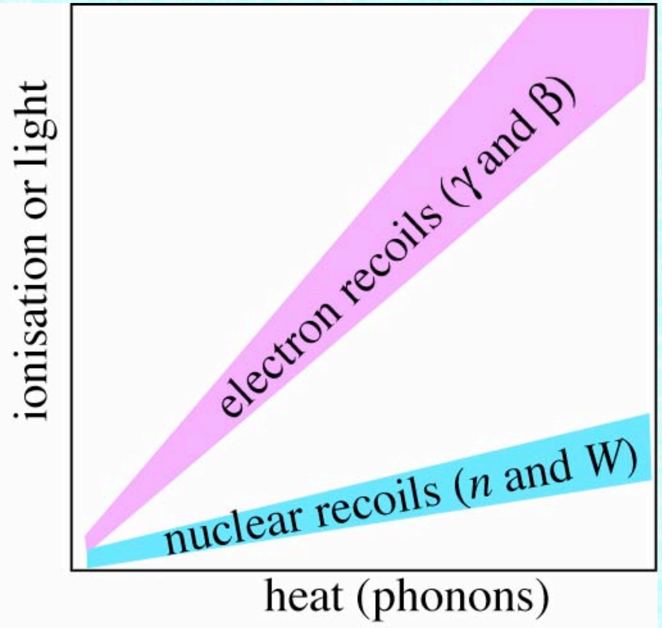
•location of the event in the detector ⇒ discriminate **surface contamination** (CDMS)

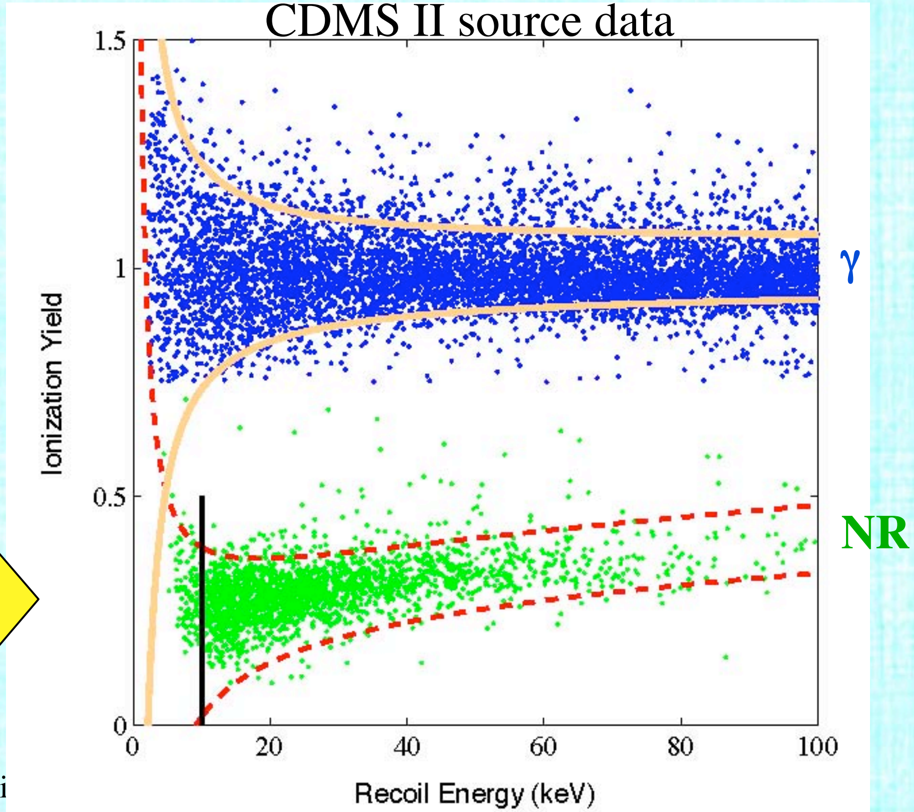
Discrimination against **neutron background** ⇒ measure a second form of energy deposit by the recoil: **ionisation** (CDMS & EDELWEISS), **scintillation light** (CRESST)

β's and γ's hit electrons ⇒ratio (ionisation or light)/heat is large

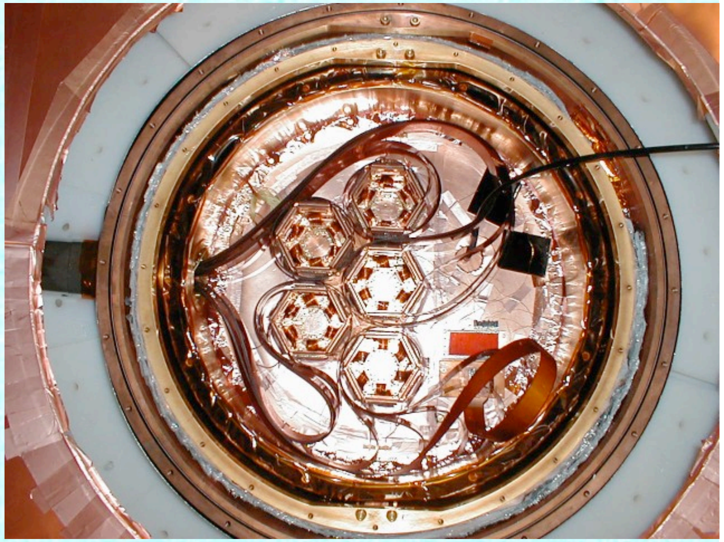
n's and W's hit nuclei ⇒ratio (ionisation or light)/heat is small

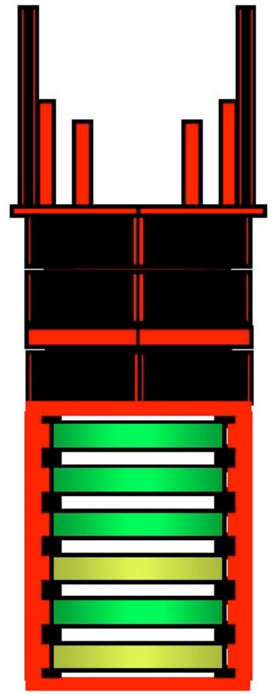
Discrimination factor ≈ 1000





CDMS at Soudan





tower1=**4 Ge ZIPs (1 kg)** + **2 Si ZIPs** (200 g)

tower2=**2 Ge ZIPs (1 kg)** + **4 Si ZIPs** (200 g)

5 towers installed

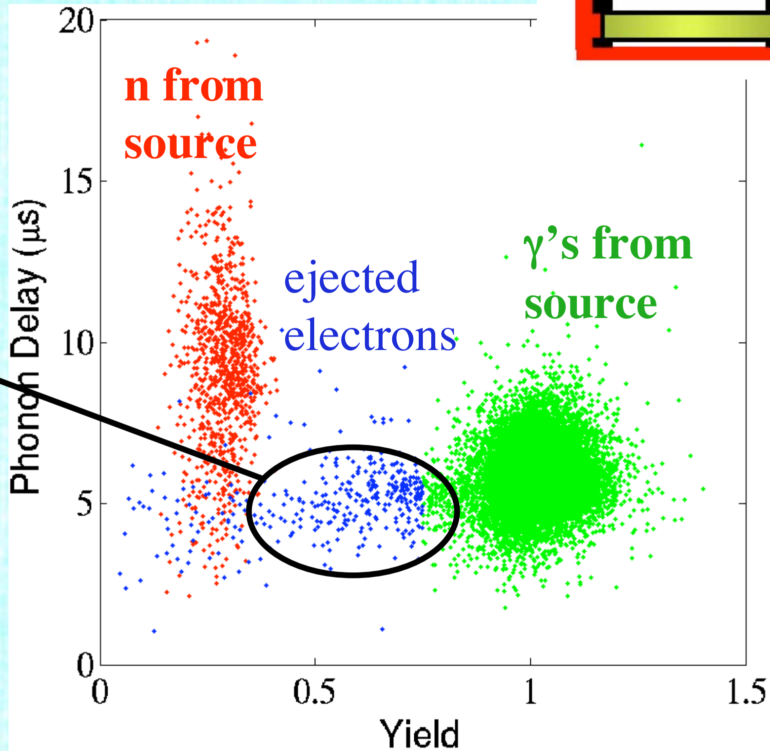
Exposures after cuts

CDMS04=Tower1	**19.4 kg d**
CDMS05=Tower1+2	**38 kg d**

Energy window E_{rec} = 10 - 100 keV

Depth=780 m; $\boldsymbol{\Phi_\mu / \Phi_\mu^0 = 10^{-5}}$

Detect phonons before complete termalization ⇒ discriminate **surface events** ⇒ Phonon start time and rise time surface events < electron recoils < nuclear recoils



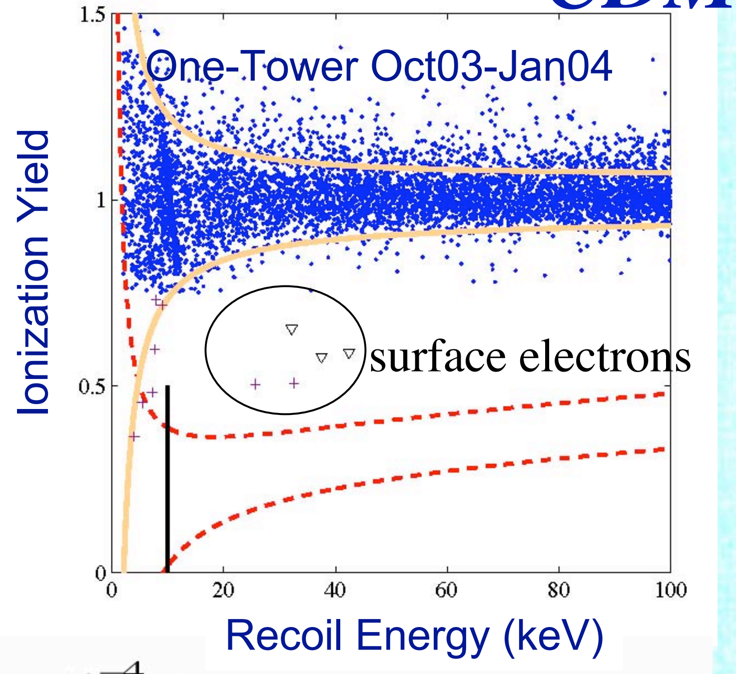
***n* vs χ discrimination**

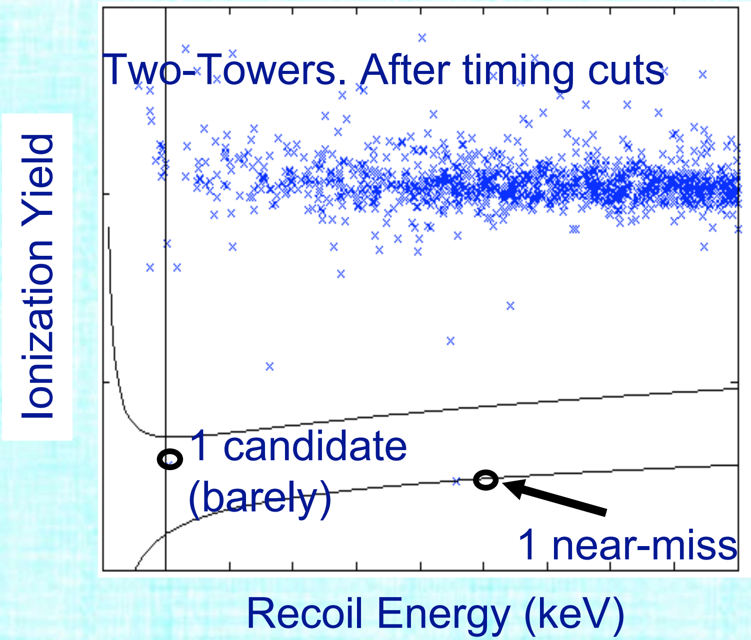
- multiple site (n) vs. single site (χ)
- Si (≈no χ) vs Ge

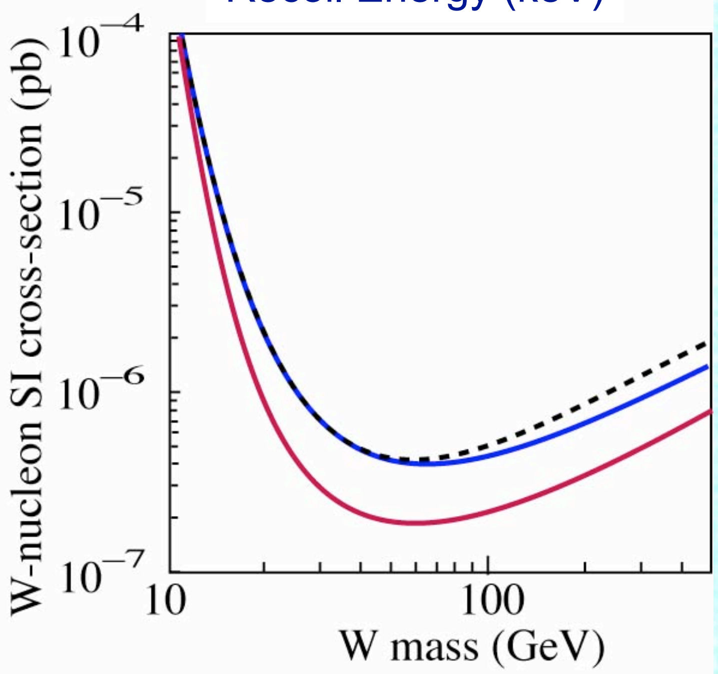
CDMS04 astro-ph/0405033
D.S. Akerib et al. Phys. Rev. Lett. **93** (2004) 211301

Thanks to Laura Baudis

CDMS II. Results





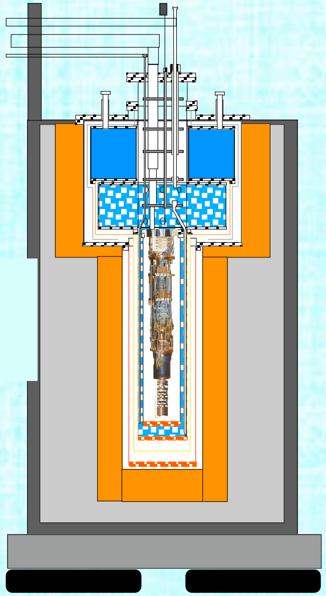


Blind analysis

CDMS 04	**0 events**
CDMS 05	**1 event**

Next 5 towers installed: Ge = 4.75 kg; Si = 1.1 kg
Will run through 2006. Sensitivity: **factor 10**
Plans for Super-CDMS in three phases ⇒ 1 t (?)
Need to improve background discrimination by100 for phase A, 1000 for B, 10000 for C

EDELWEISS at LSM



dilution cryostat
10 mK

EDELWEISS I

Ge mass ≈ 1 kg **Exposition = 62 kg d**

High purity passive shield+ pure N_2 circulation

Detect heat deposit via temperature increase

Signal window E_{rec} = 30 - 100 keV

In window: 53 events

EDELWEISS II

1° phase:Ge mass ≈ 10 kg

ready in autumn 2005

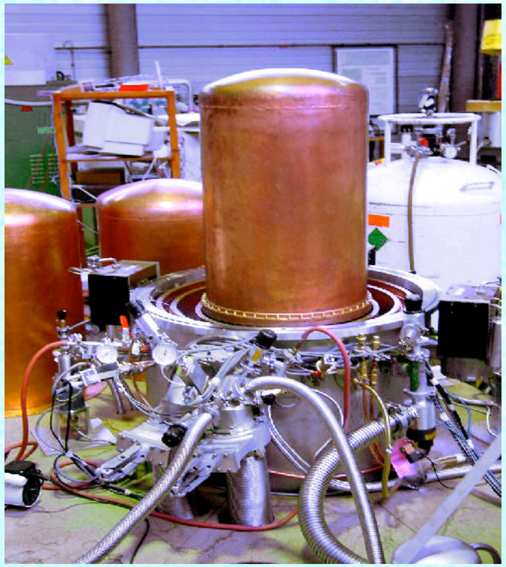
Detect athermal phonons

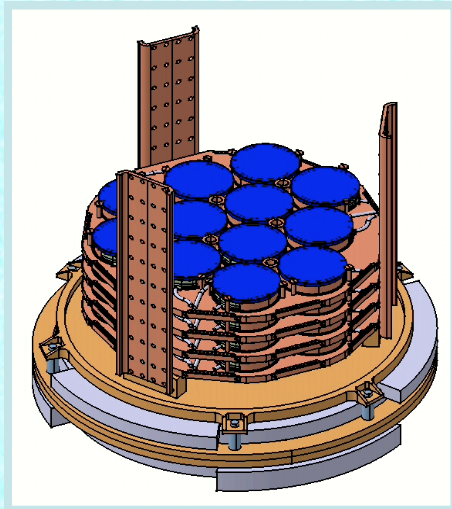
μ-veto

Final phase: ≈ 36 kg

•Sensitivity will be determined by the bkg level

dilution cryostat 100 l; up to 120 detectors (36 kg)





EDELWEISS 1

astro-ph/0503265

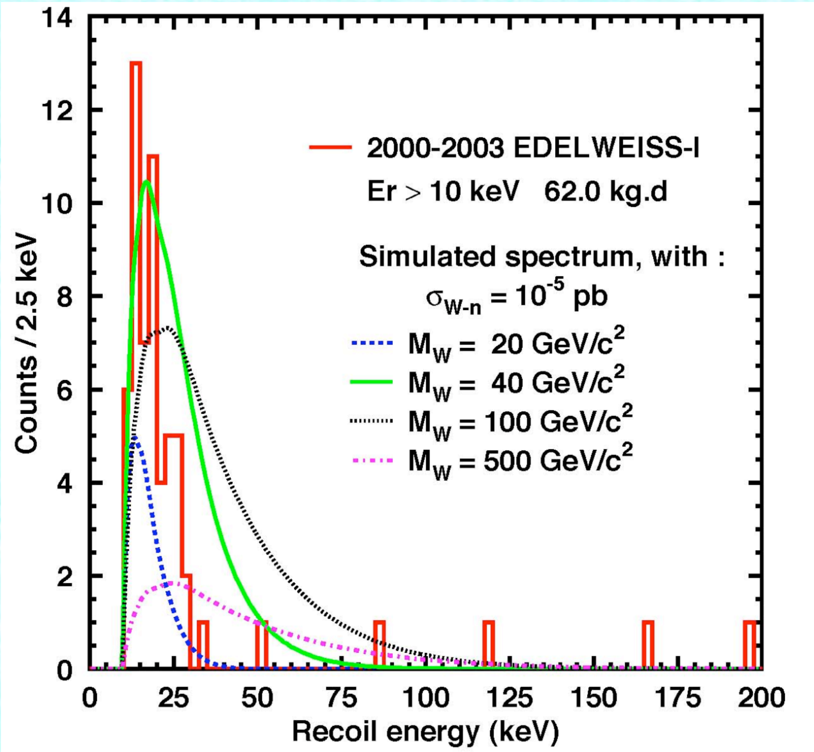
Are the 53 events signal or background?

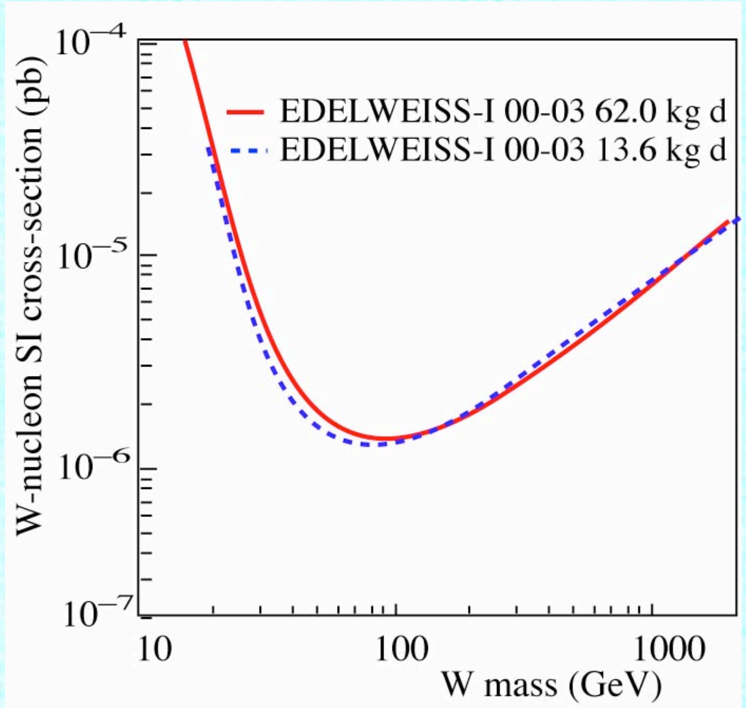
Spectrum compatible with bkg but not with a <u>single</u> m_χ <u>at 100%</u>

Not incompatible (my statement) with combination of signal+bkg (e.g. $m_\chi \approx$20-40 GeV, $\sigma \approx 0.5 \times 10^{-5}$ pb)

Complementary data ⇒ probably surface electrons & neutrons

<u>Limits was calculated using number of events and spectrum, assuming shape = WIMP with no bkg ⇒ artefact lowers limit</u>





no progress with statistics ×4 due to bkg

CRESST-II a LNGS

1° phase. $CaWO_2$ mass ≈ 2×250 g

Exposition = 20.5 kg d

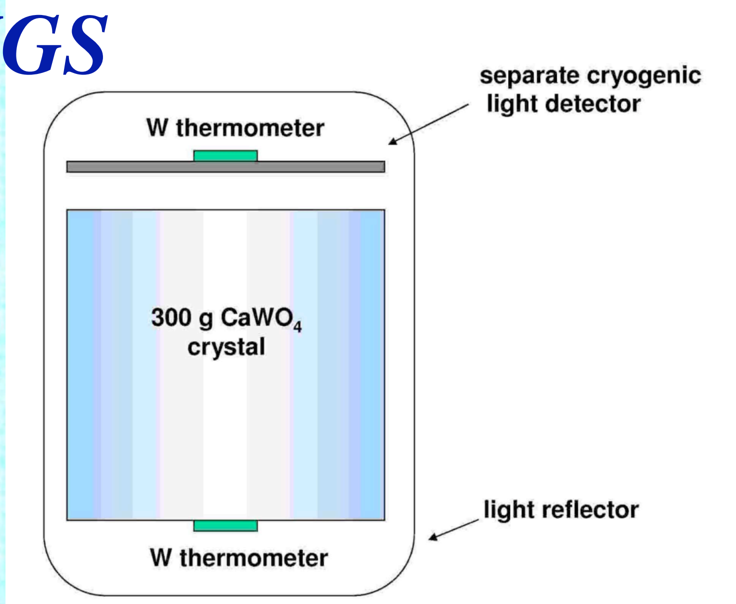
Signal window: 12-40 keV

n shield and *μ*-veto not yet installed

Bkg discrimination: detect phonons and photons

No interactions on surface electrodes

Dominant bkg: **neutrons**

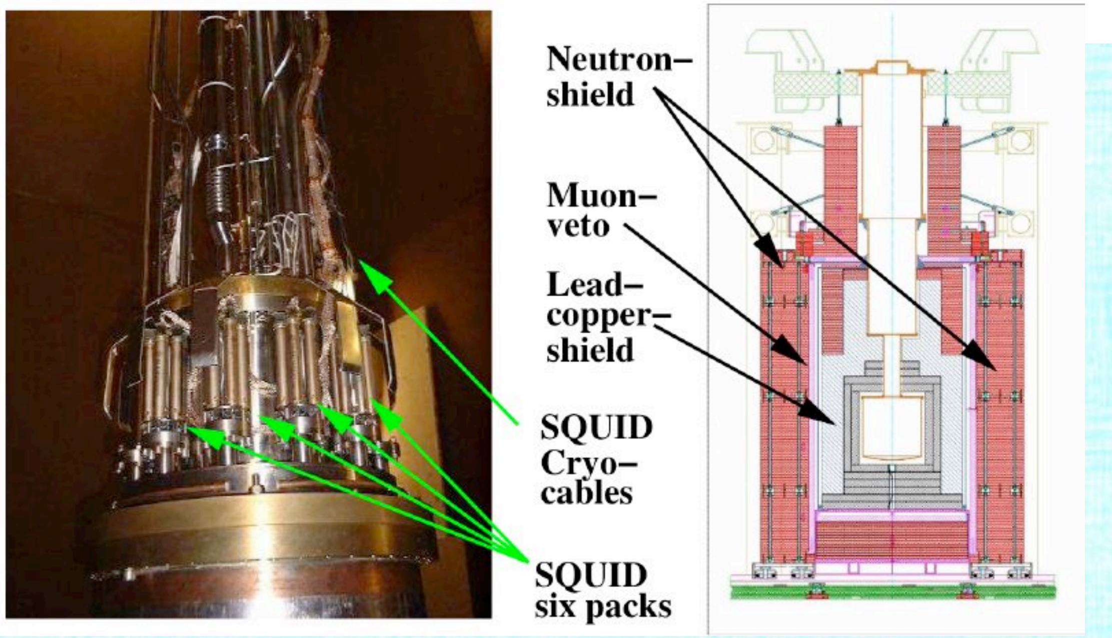


Present phase

- Shields installed
- **$CaWO_2$ mass ≈ 3 kg**
  - ready by end 2005

Next phase

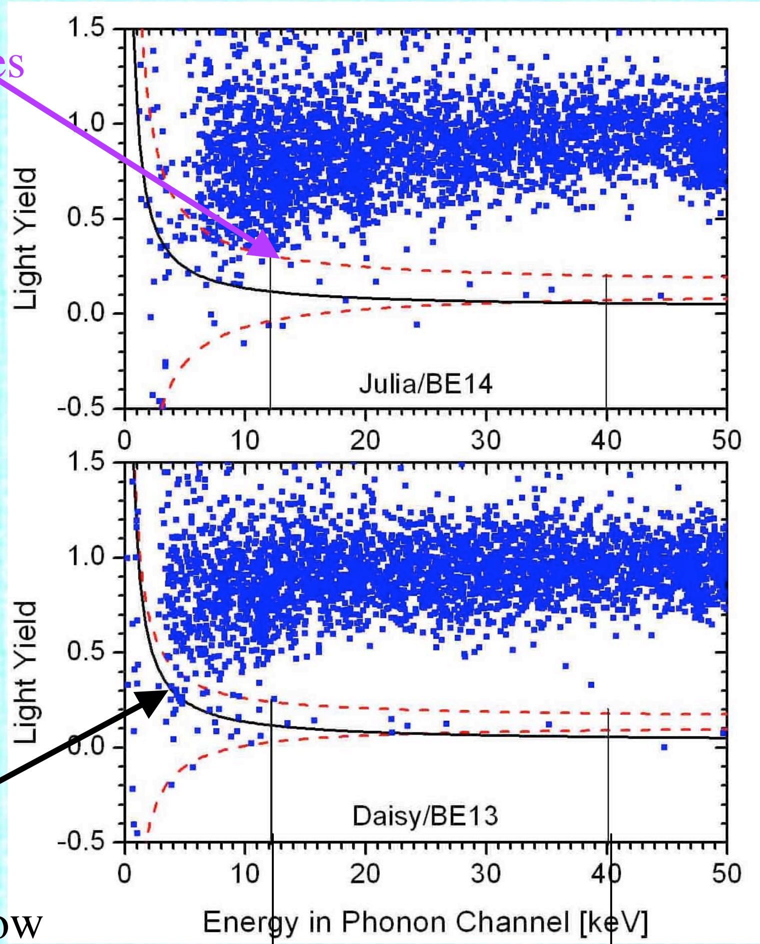
- **$CaWO_2$ mass≈ 10 kg**
  - Design sensitivity = 10^{-8} pb @ m_χ = 60 GeV



CRESST-II. Results

astro-ph/0408006

90% of nuclear recoils between dotted lines



90% of nuclear recoils below continuous lines if only on W

analysis window

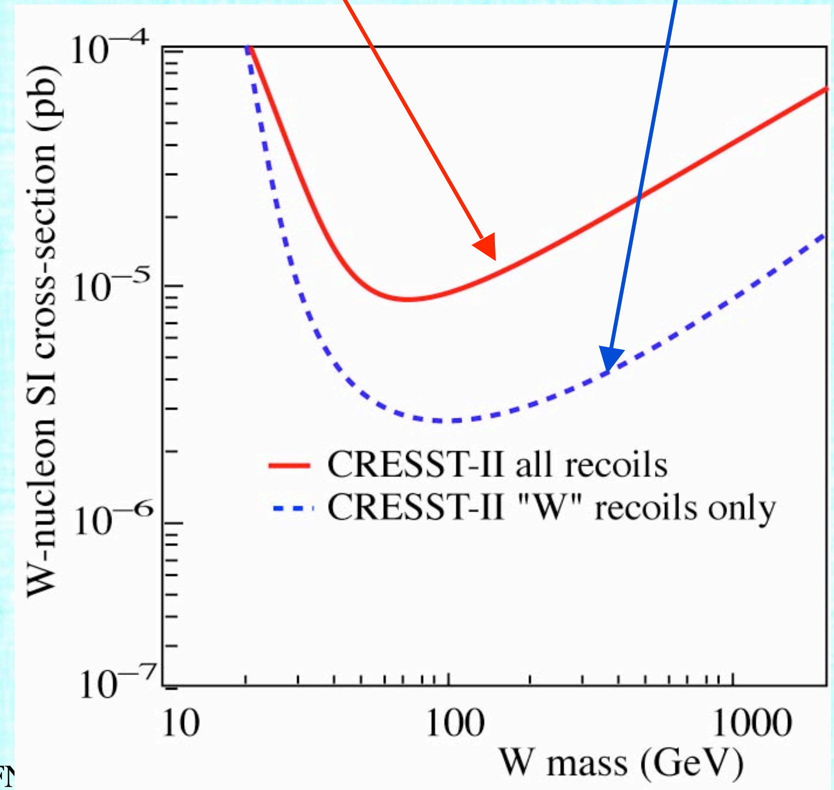
In recoil region: 7+9 events

•Continuous line

In the "only W" region: 3+0 events

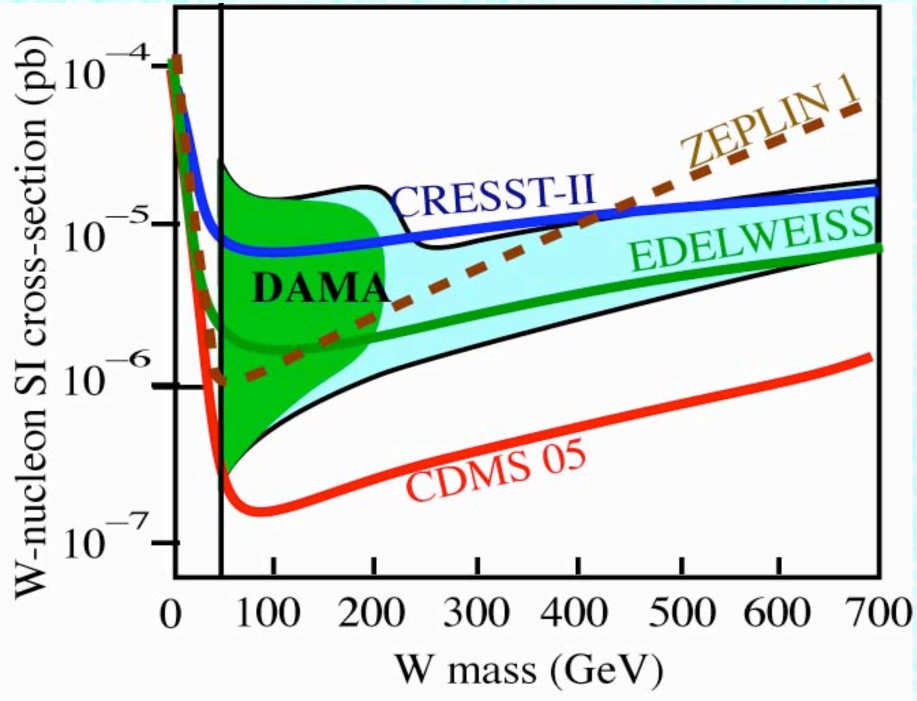
Daisy (0 events) has better resolution in light channel ⇒ less (badly measured) electron recoils in nuclear recoil region

Taking Daisy only ⇒ **dotted curve**



Model dependent comparison. SI couplings

hand made



	Exposure (kg d)	Window (keV)	Events in window
CRESST	20.5	12-40	16
EDELW	62	30-100	53
ZEPLIN	293	2-10	$\approx 10^3$
CDMS	57.4	10-100	1

- σ vs. m_χ plot is a 2D projection of a multi-dimensional parameter space (SD/SI couplings, *n*/*p* coupling, local density, local speed,…)
- χ-nucleus couplings different for different nuclides
- CDMS shows **the importance to be "background-free"**
- ZEPLIN1 is not robust (insufficient calibration, see later)
- High masses DAMA region assumes earth velocity < usual assumptions
- If SD contributions DAMA regions goes lower
- CDMS seems to contradict DAMA, but target nuclei are different, etc.

Spin-dependent Coupling

C. Savage et al. astro-ph/0408346

Assume isothermic halo model

Assume <u>spin-dependent</u> coupling

Assume nutralinos annihilate each-other

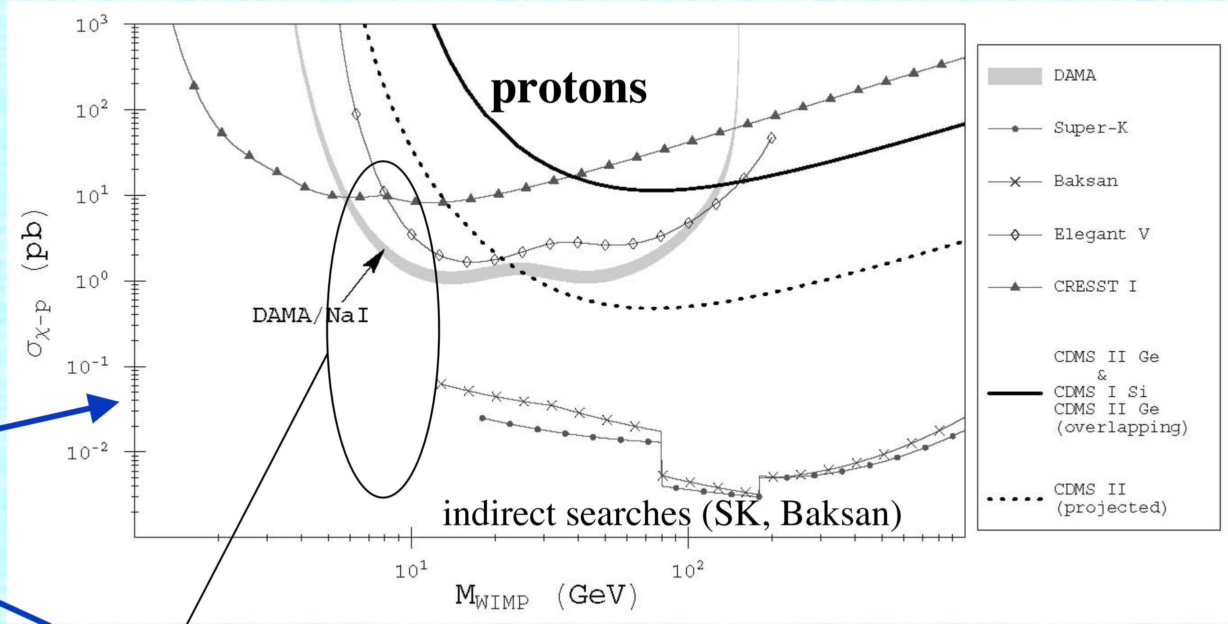
Compare experiments in extreme assumptions: coupling to protons only, to neutron only

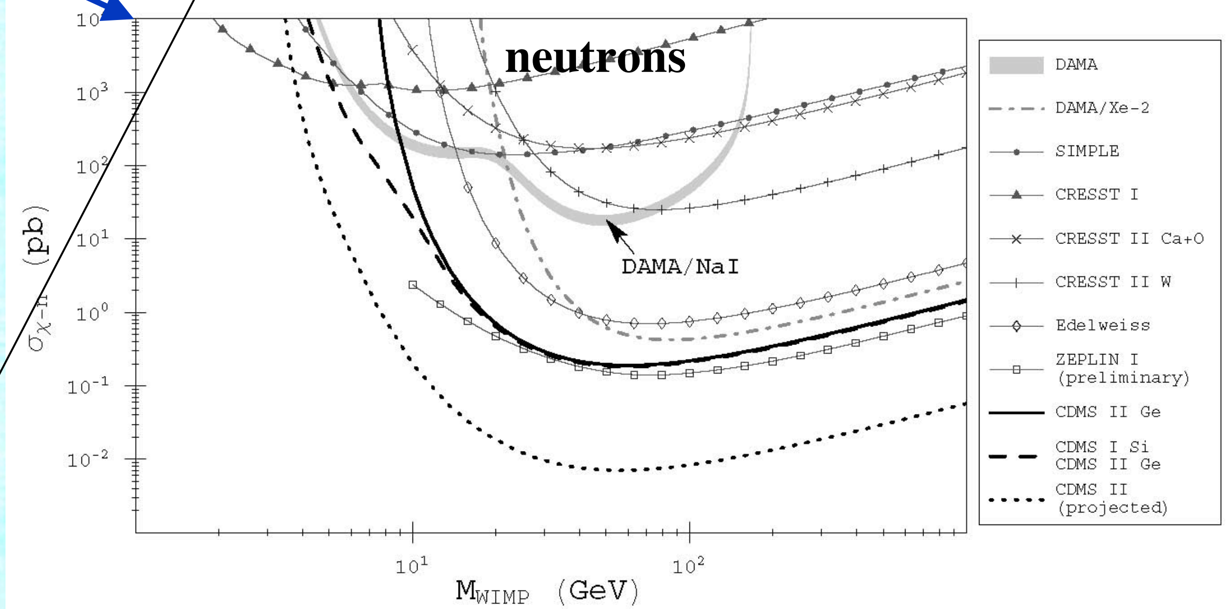
Sun is a ball of protons, having spin ⇒ **long-exposure indirect searches are two orders of magnitude more sensitive than direct ones for SD on *p***

Then general case: both χp and χn (not shown)

Include (model-dependent) limits from indirect searches. Very important in the *p*-coupling

Allowed m_χ range= 5-15 GeV

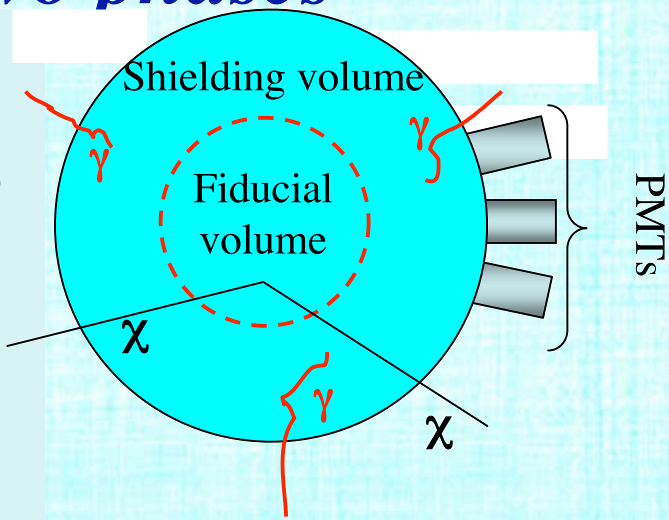




Noble Liquids one phase-two phases

Noble liquids, Xe, Ar, and Ne look very promising because

- can be easily assembled in large masses
- highly purified (0.1 ppb) from electronegative imp. (ICARUS)
- ultra-purification from radioactive imp. (BOREXINO)
- self-shielding structures can be built,
  - external liquid shields the central one **without surfaces between** ⇒ no surface contamination (but in practice..)
- Shield can be instrumented to act as a veto



- **Two-phase (Liquid & Gas)**
- **two handles to discriminate** between nuclear and electromagnetic recoil
  - **detection of primary scintillation light <u>and</u> ionisation via proportional scintillation** (Picchi et al. in 1993 (1 phase) and in 2000 (2-phases))
  - **difference in the time dependence of luminescence** for light (**slow** component from $^3\Sigma$ excimer states) and heavy recoils (**fast** component from $^1\Sigma$ states) (A. Hitachi et al. in 1983)

Pioneering work by DAMA on Xe

Projects being developed: **CLEAN, LNe**, **Xe L-phase: XMASS** (@KAMIOKA): **L-Gas Xe**: **XENON** (@LNGS), **ZEPLIN** (@Boulby) and **XMASS-2P**; **L-Gas Ar**: **WARP** (@LNGS), **DEAP** (R&D@Los Alamos)

Much R&D work already done, but experience in underground laboratories starting now

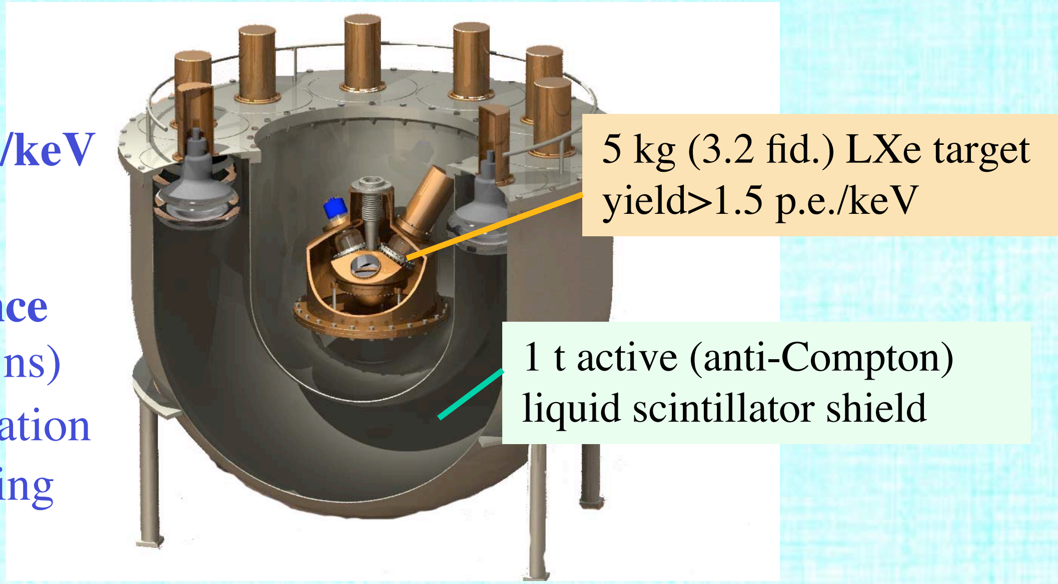
ZEPLIN 1 @ Boulby mine

Fiducial mass = 3.2 kg

Exposure = 293 kg d

Shield = liquid scintillator (≠ LXe)

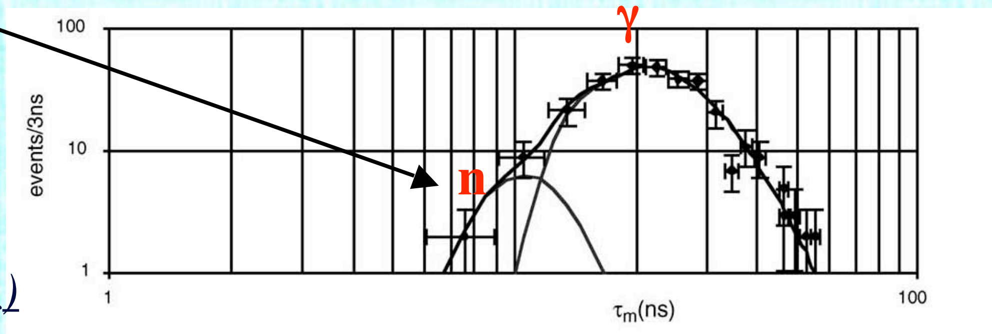
Background before discrimination ≈ 10^4/keV



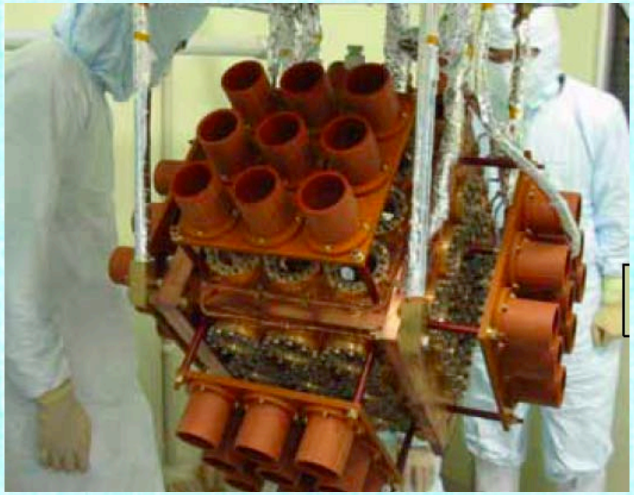
Discrimination based on the luminescence timing (electrons: 4.3 ns)/ nuclear rec.: 22 ns) distributions overlap strongly ⇒ discrimination on statistical base only, looking at the leading edge of the time distribution

⇒very good knowledge and control of the systematic uncertainties are needed and accurate calibration data, but

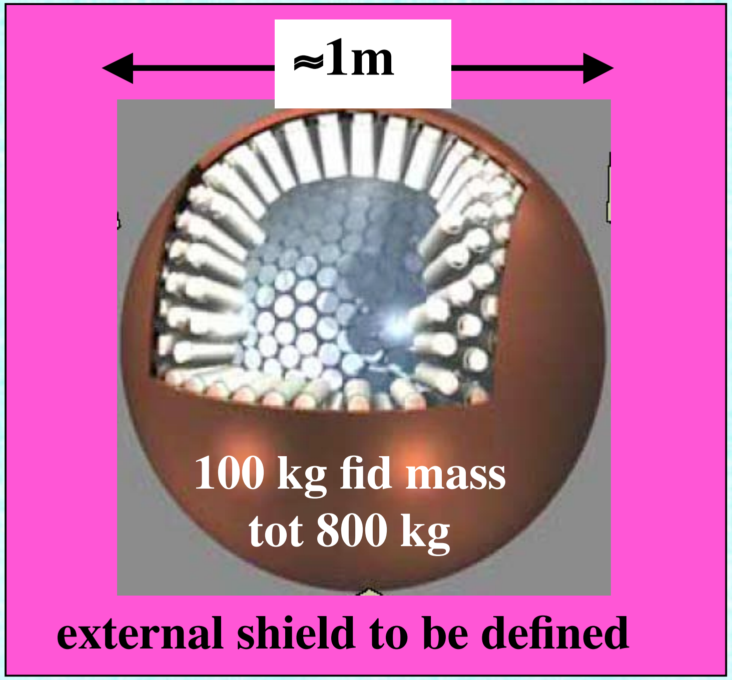
- calibration runs on surface (none in situ)
- lifetime ratio assumed energy independent
- Q_F measured only for E>8 keV$_{ee}$ (40 keV$_{rec}$) and extrapolated in the energy window



XMASS



Experience with a 3 kg prototype
•**Self shielding** level demonstrated $b=10^{-2}$ dru
•work in progress on internal backgrounds (^{238}U, ^{85}Kr)



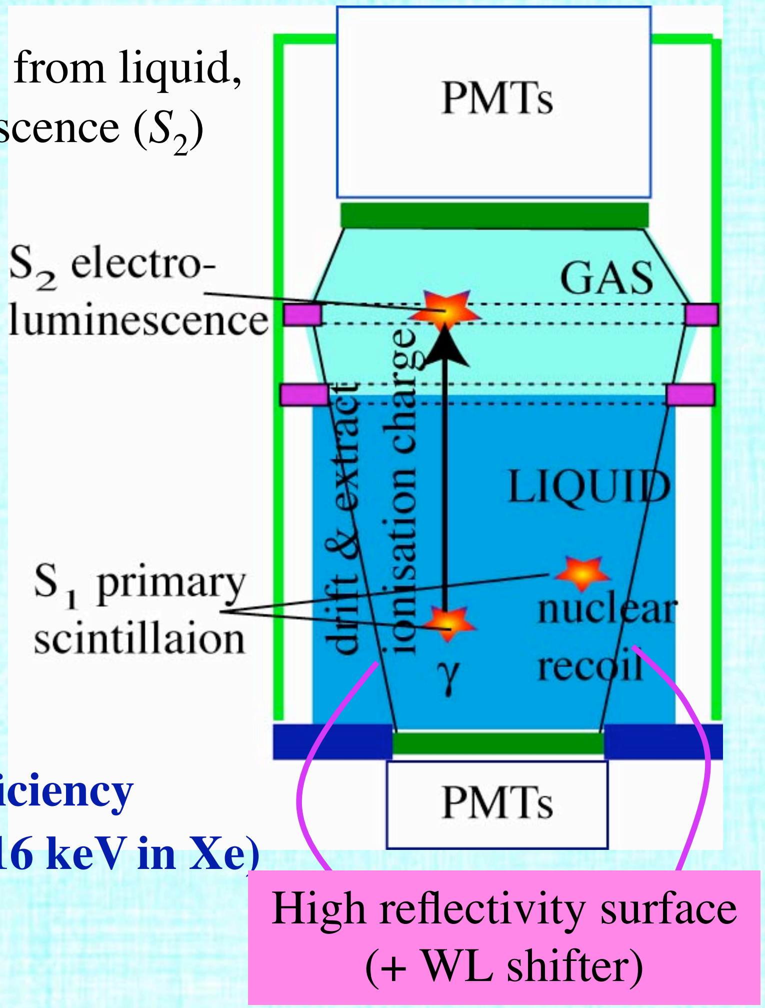
In project
spherical volume with PMs on the surface ⇒
accurate vertex reconstruction
self-shielding
•**fiducial mass: 100 kg**
•**no internal surface**
sensitivity with 0.5 t yr

"exclusion plot"	**10^{-8}-10^{-9} pb**
modulation	**10^{-7}-10^{-8} pb**

will depend on the background level that will be reached
next step 10 t fiducial mass

Discrimination with Dual phase Xe/Ar

Measure: **ionisation charge** and **scintillation light**
Charge too small to be directly detected ⇒ extract charges from liquid, accelerate them in the gas phase and detect electro-luminescence (S_2)



- *n* and χ ⇒ heavy nuclear recoil
  - primary light pulse ⇒ **appreciable S_1**
  - a few free electrons (depending on *E*) ⇒ **small S_2**
- *e* and γ ⇒ relativistic recoil
  - initial excitation gives **appreciable S_1**
  - **large** free electrons yield: **large S_2**

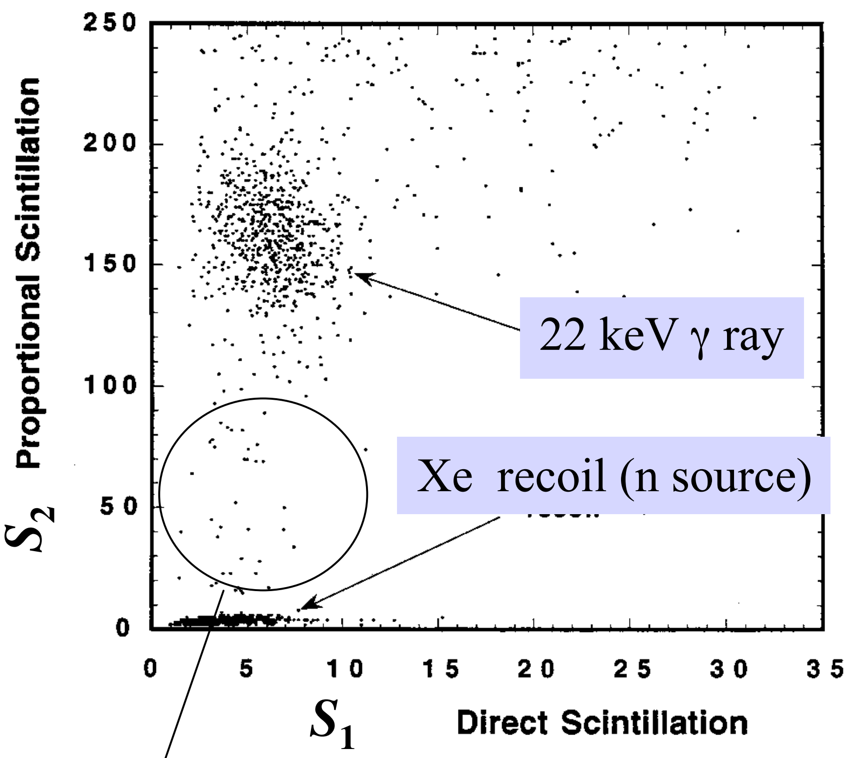
S_2/S_1 electrons >> S_2/S_1 nuclear recoils

SPECS

- **Ionisation electrons discriminate ⇒ high collection efficiency**
- **Efficient detection of primary light (≈ 200 photons @ 16 keV in Xe)**
  - No dead region
  - No disturbance to drifting electrons (*E*-field, purity)
  - Separate control of drift-field and scintillation field
- **Active volume defined by a PTFE foil** (surface contamination?)
- **Localisation of event (not to be in dirty regions: cathode, surfaces,…)**

Recoil-gamma discrimination

Kindly from Satoshi Suzuki

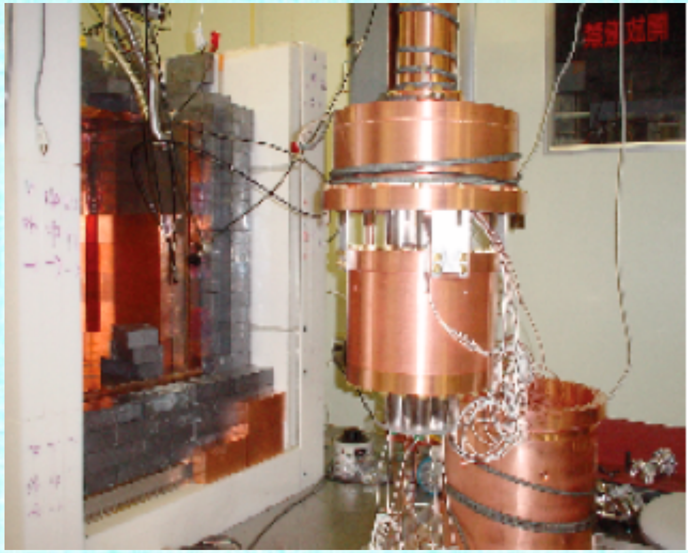


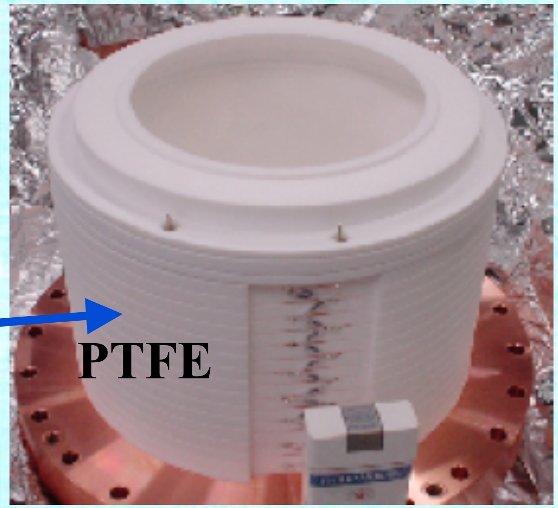
XMASS-dual phase

15 kg module @ Kamioka

reach: 10^{-8} pb

The inner chamber





Discrimination power critically depends on the fraction of background signals with very few p.e

Screening of all components (wires, race-track, PMTs, etc.)

Surface contamination possible (e.g. PTFE)

Event localisation is important

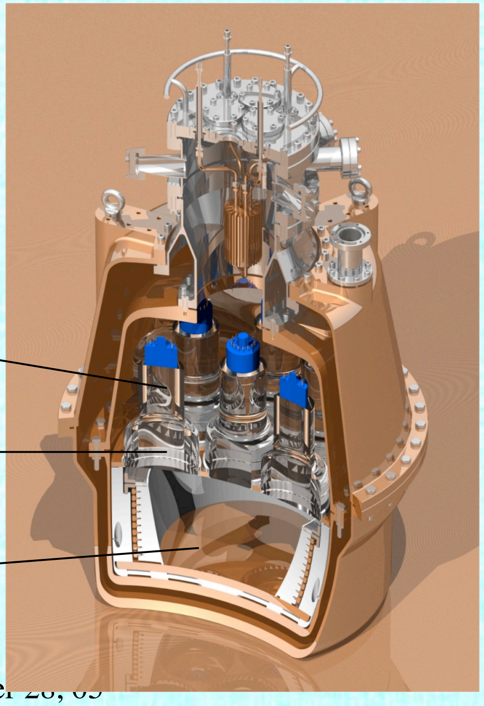
Present technologies shows > 1000 possible, but not yet acheived

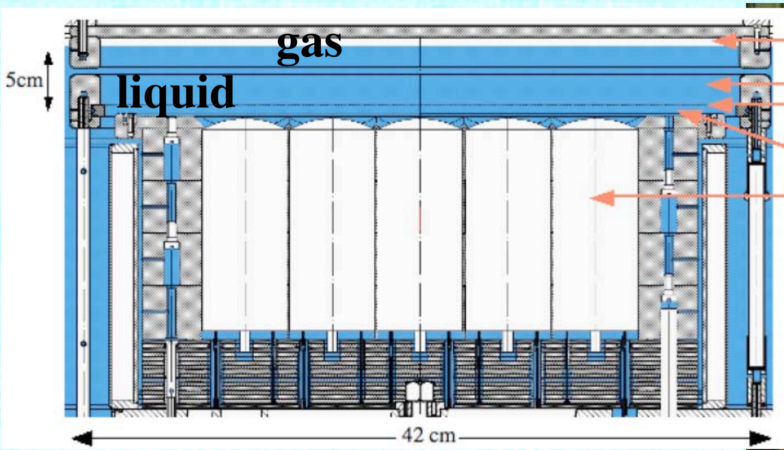
ZEPLIN@Boulby- Dual phase programme

Programme aims to ZEPLIN MAX ultimate detector 1 t sensitive mass ⇒**10^{-10} pb**
Current phase: two complementary detectors: ZII and ZIII **sensitive ≈ 10^{-8} pb**
3-D capability for event reconstruction

ZEPLIN II
- 30 kg fiducial mass
- liquid scintillator Compton veto
- Being commissioned underground

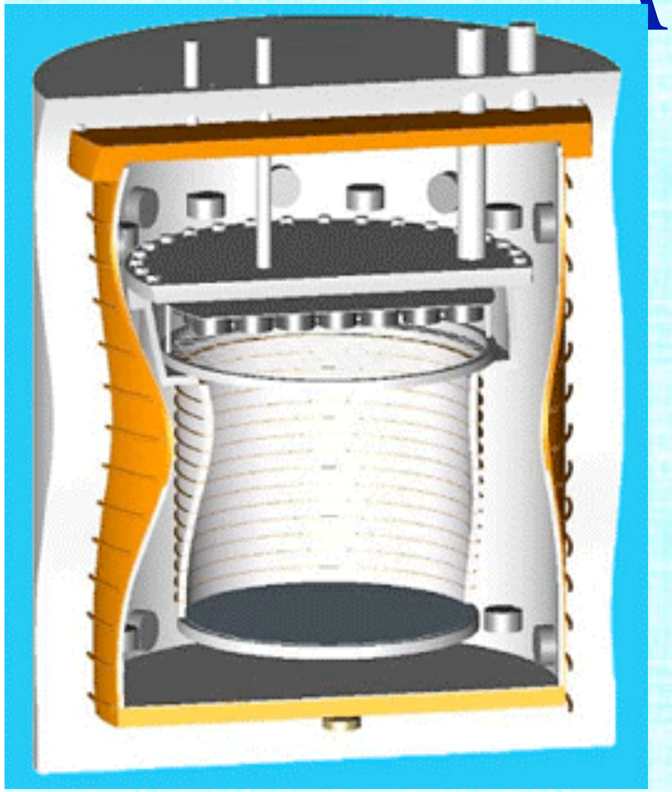
ZEPLIN III
- 6 kg fiducial mass
- PMTs in the liquid⇒ 5 times better light collection
- Good 3-D reconstruction from gas phase
- Assembled @ 85%





Thanks to Tim Sumner for information
and cfr his talk on Thursday

XENON at LNGS



Modular design: 100 kg active Xe mass units

Dual phase TPC ⇒ 3D reconstruction ⇒ exclude events in bkg contaminated locations (e.g. cathode,..)

Outer LXe = **active veto**

Threshold: E_{ee}**=16 keV**

Discrimination of e & γ vs. nuclear recoils via S_2/S_1

⇒ **≈ 1000 expected, 300 obtained**

Preliminary measurements done

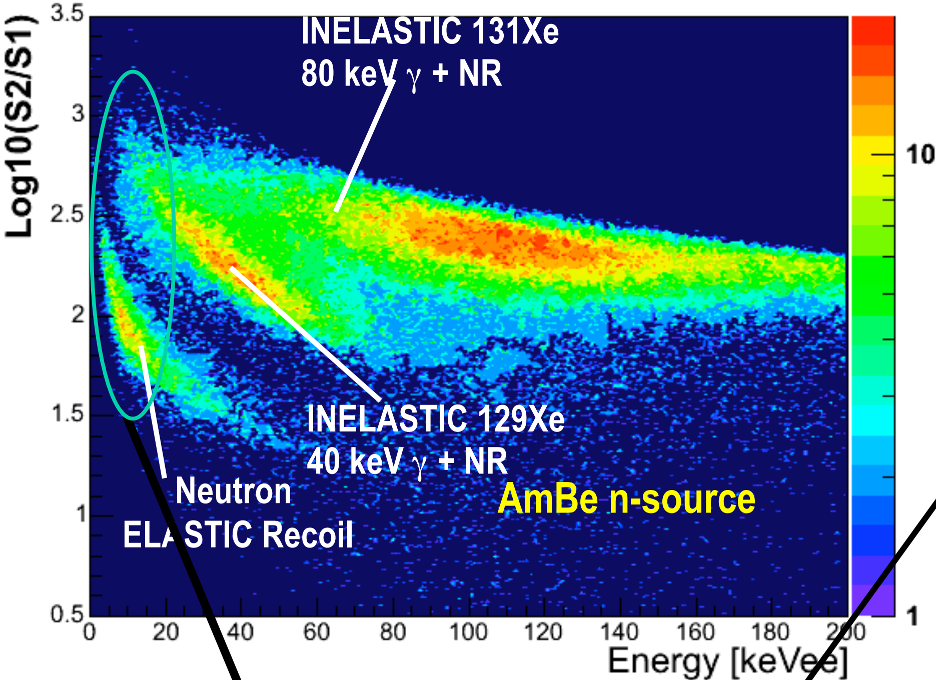
Q_F and E-field dependence of nuclear recoils (10-55 keV)

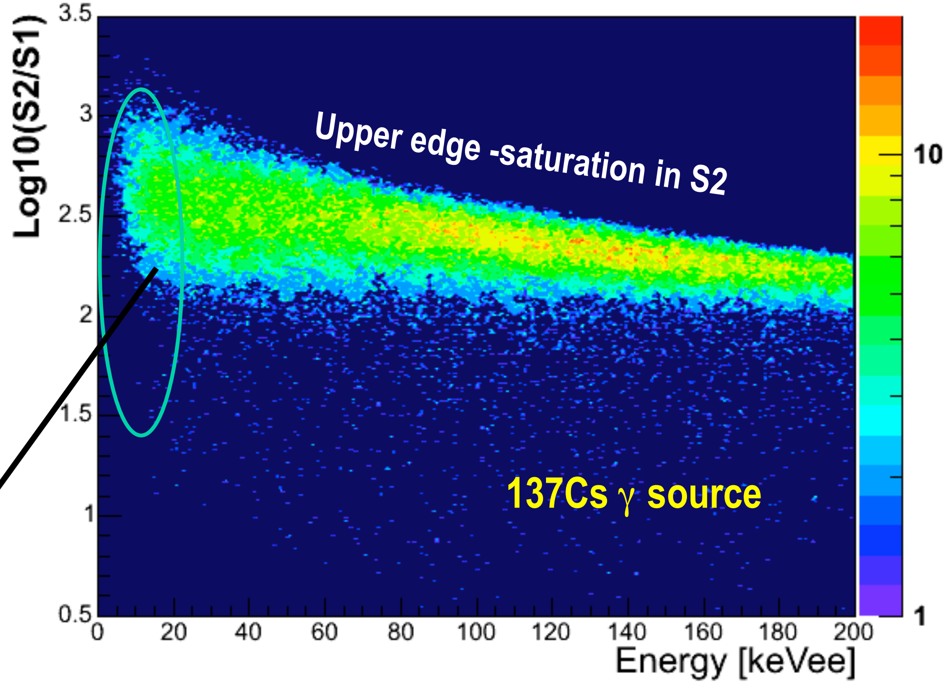
XENON-10 prototype detector to be installed at LNGS
designed to detect 4.4×10^{-4} dru @ 16 keV$_{ee}$
⇒ needs $b<10^{-4}$ **dru** ⇒ zero-background in 3 months ⇒ $\sigma \approx 10^{-8}$ pb

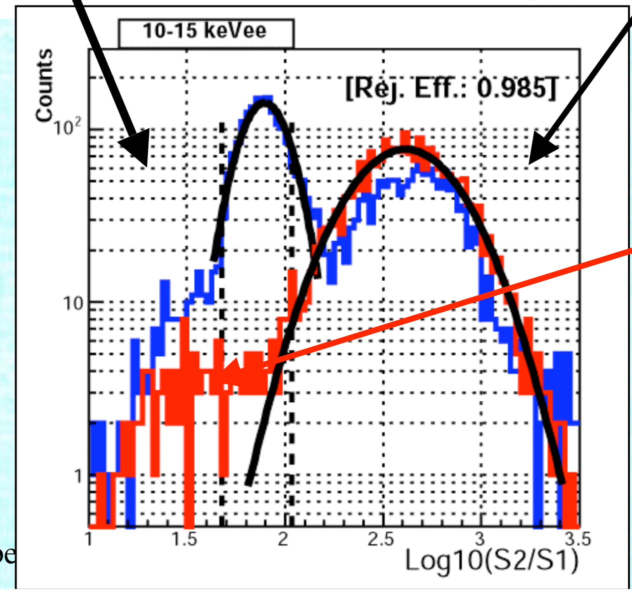
1st XENON - 100 module to be ready in 2007

- Needs $b<10^{-5}$ **dru** after rejection
- Search for annual modulation needs at least one XENON-100 continuously running under stable conditions for several years

XENON-Recoil-Gamma Discrimination







Rejection by S2/S1

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

Rejection ≈300 @ 10-15keV$_{ee}$
will improve with 3D detector

Thanks to Masaki Yamashita and Elena Aprile

Dual Phase LAr

WARP. astro-ph/0411491
DEAP Boulay, Hime astro-ph/0411358

Liquid Ar vs. Liquid Xe: pros and cons

- **–** Lighter nucleus $\Rightarrow A^2_{\mathrm{Xe}} / A^2_{\mathrm{Ar}} \approx 10$
- **+** Smaller nucleus (form factor) $\Rightarrow$ Ar can work at higher energy threshold
- **+ + Fast/slow components**
    - Xe: 4.3 ns/ 22 ns
    - **Ar: 7 ns/1600 ns $\Rightarrow$much better discrimination**
- **– –**Intrinsic background: **^{39}Ar β decay @ 1 Bq/kg**
    - isotope separation?

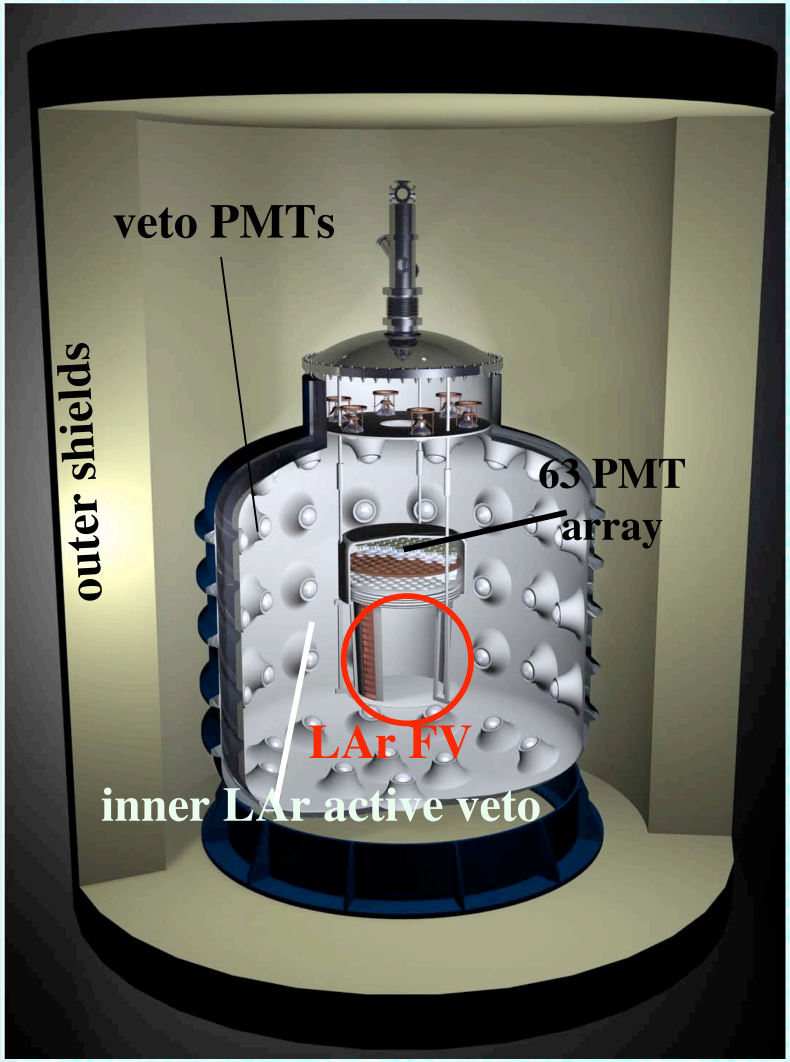
- **Q_F not yet measured in the relevant energy regions for Ar**
- ***I*(fast)/*I*(slow) not measured for nuclear recoils (different physics)**

WARP at LNGS

140 kg TPC in construction @ LNGS

Recoil energy window: 30 -100 keV_{ee}

Active veto thickness ≈ 60 cm



Surface of inner detector lined with highly reflective film + PTB (wave-length shifter)

^{39}Ar β 1 Bq/kg ⇒ <30> dru in **30 - 100 keV**

•e.g. 300 d exposure: **$=5\times10^4$ kg d** @ 0 background

⇒ ≈ 3×10^{-7} dru

•Reduction factor needed ***R* = 10^8**

•Simulations ⇒ 10^8 possible with two independent

S_2/S_1 and **fast/slow**

3 kg cell running for tests at LNGS

Conclusions and…

- One experiment (DAMA) gives model-independent positive evidence; it is the only one looking for annual modulation
- One experiment (CDMS) with event by event particle identification capabilities is background free. It gives negative evidence at a level difficult to reconcile with DAMA, within several framework models
- Final answer needs a modulation sensitive, independent, NaI experiment (ANAIS in a few years?)
- Hopefully more experiments will look for modulation (KIMS [CsI], noble liquids,…)
- Experiments not looking for modulation have reached sensitivities at the level of the most optimistic SUSY models ($\approx 10^{-6}$ - 10^{-7} pb)
- Sensitivity of all but CDMS is dominated by background

… and Perspectives

•R&D of a new generation of experiments (dual phase Xe and Ar) shows very promising perspectives, but the commissioning underground of 10 - 100 kg detectors has just started

•Detectors with 10^4 kg yr background-free exposures, if not limited by systematics (?), may reach $\approx 10^{-10}$ pb, exploring the largest fraction of the SUSY predictions space

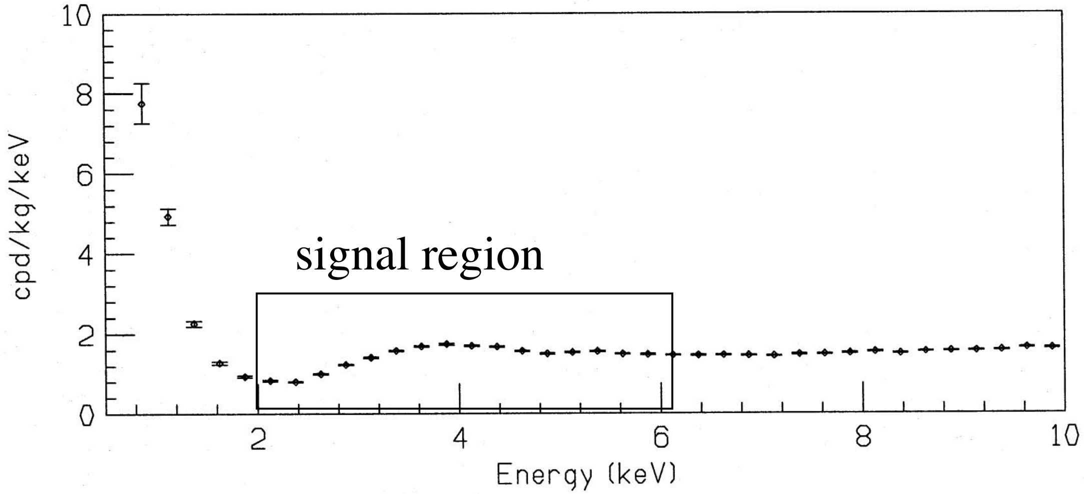
•SUSY is only a possibility, we are indeed hunting in the dark

•We must rely on complementary experimental techniques and theoretical developments

- •LHC will soon produce data on controlled production of WIMPs
- •Spectrometers and gamma telescopes on earth and in the space may observe unexpected phenomena, perhaps contributing to the dark matter mystery
- •Cosmology is progressing at a fast rate

•We must develop jointly our understanding of the microscosm and in the macroscosm in particle physics, astroparticle and cosmology

DAMA. Recoil energy spectrum



keV = keV$_{ee}$

Rate in the signal region 1-1.5 dru = time averaged signal (S_0) + background (b)
Modulation amplitude is A= 0.02
Assume $A/S_0 \approx 5\% \Rightarrow S_0 \approx 0.4$ dru
$\Rightarrow$ ***b*** **≈ 0.6 - 0.9 dru**
background rate and total signal rate are of the same order of magnitude