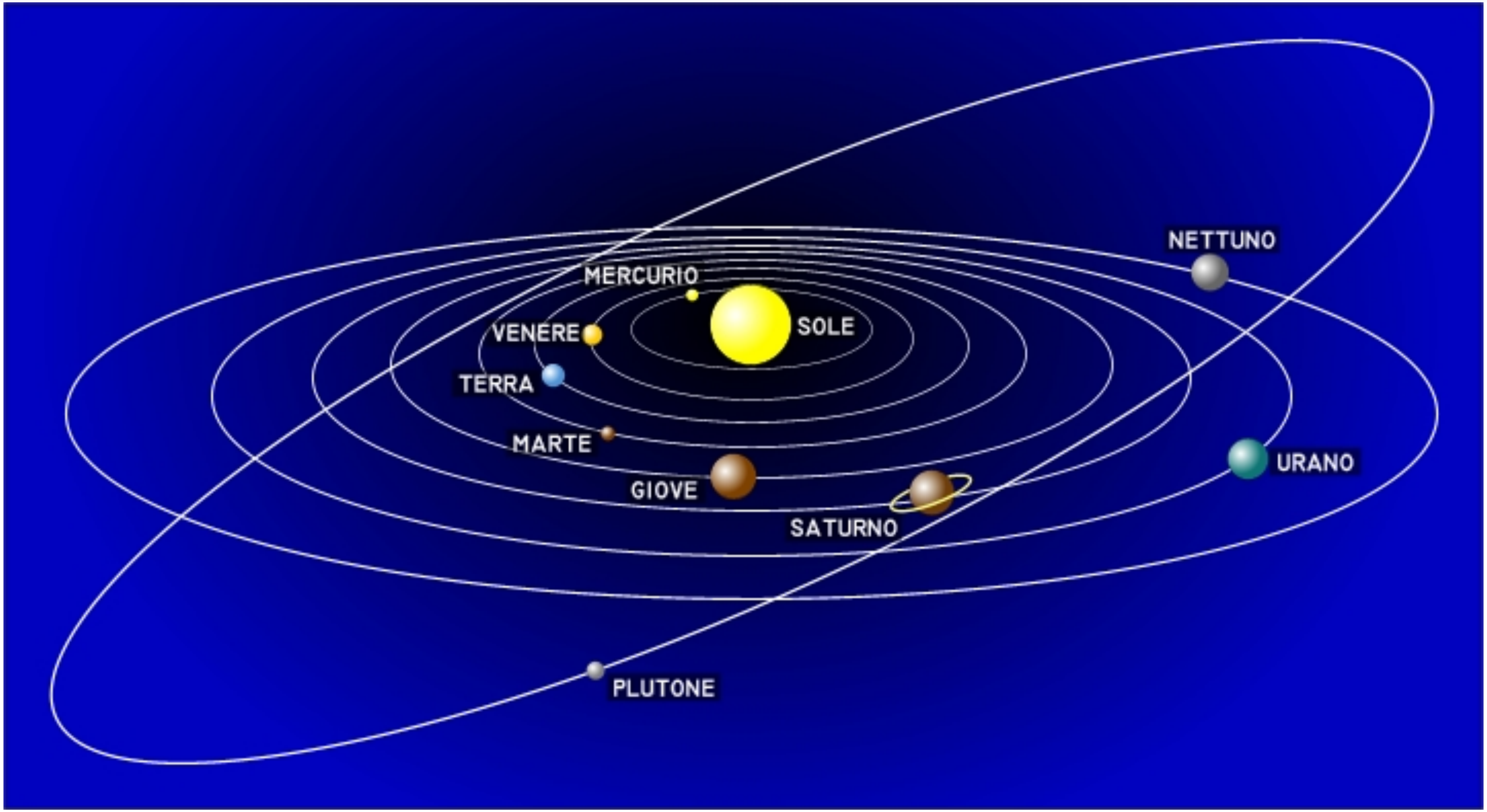
a brief review of Dark Matter searches

Marco Vignati
http://www.roma1.infn.it/people/vignati

Il sistema solare

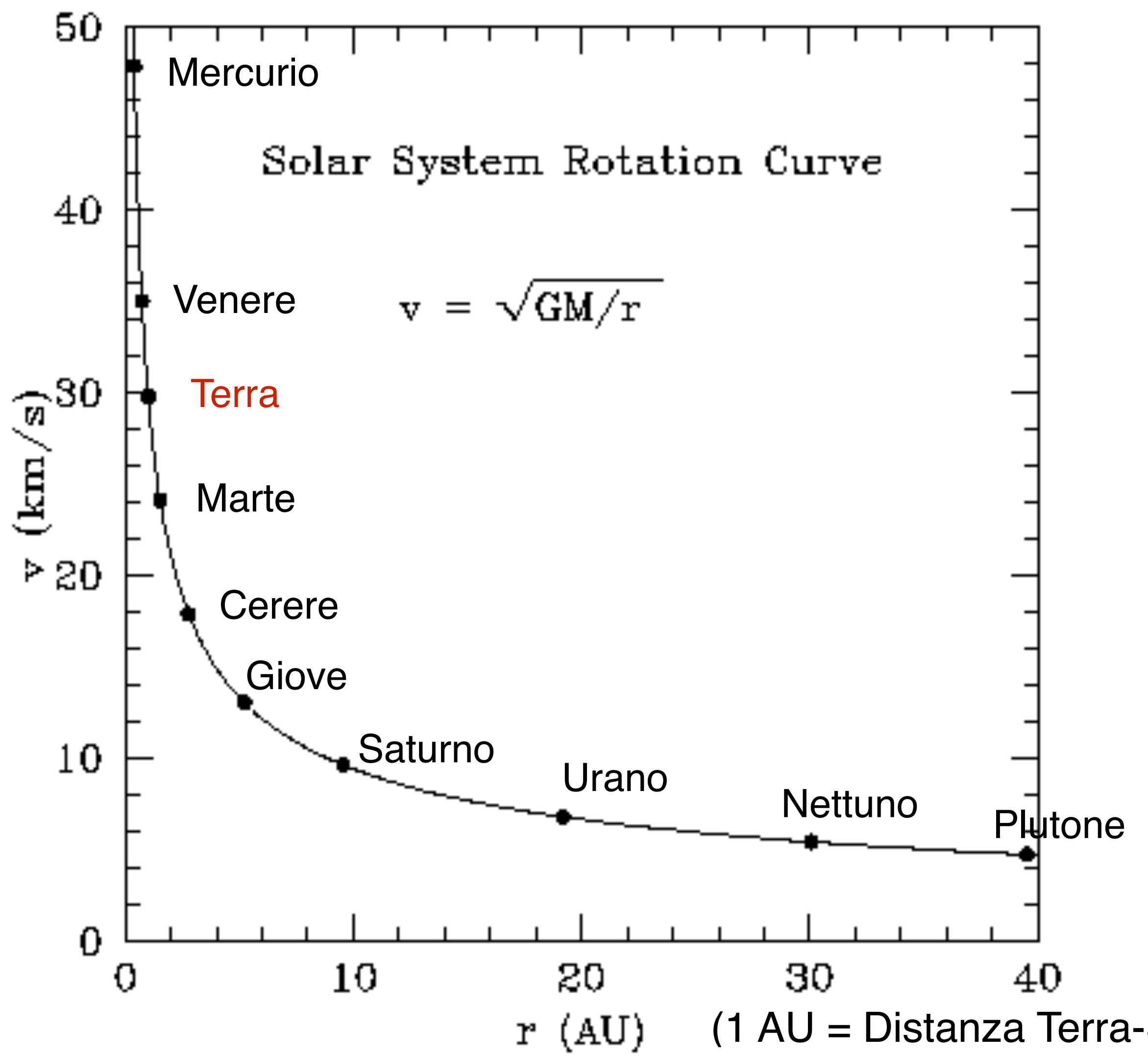


La legge della gravitazione di Newton ci dice che:

$$\text{velocità di un pianeta} = \sqrt{G_{\text{Newton}} \frac{\text{Massa del sole}}{\text{distanza dal sole}}}$$

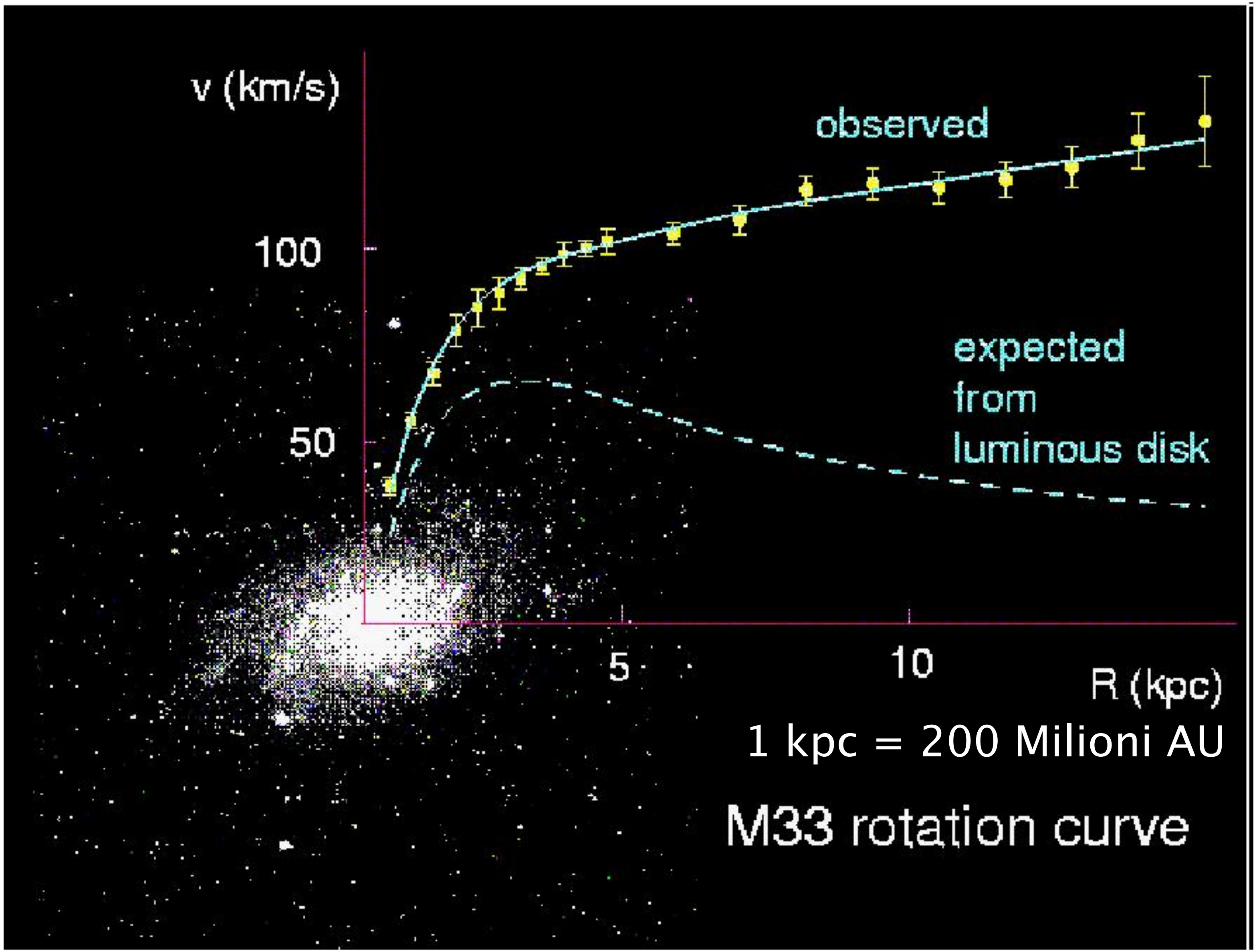
In un grafico

$$\text{velocità di un pianeta} = \sqrt{G_{\text{Newton}} \frac{\text{Massa del sole}}{\text{distanza dal sole}}}$$



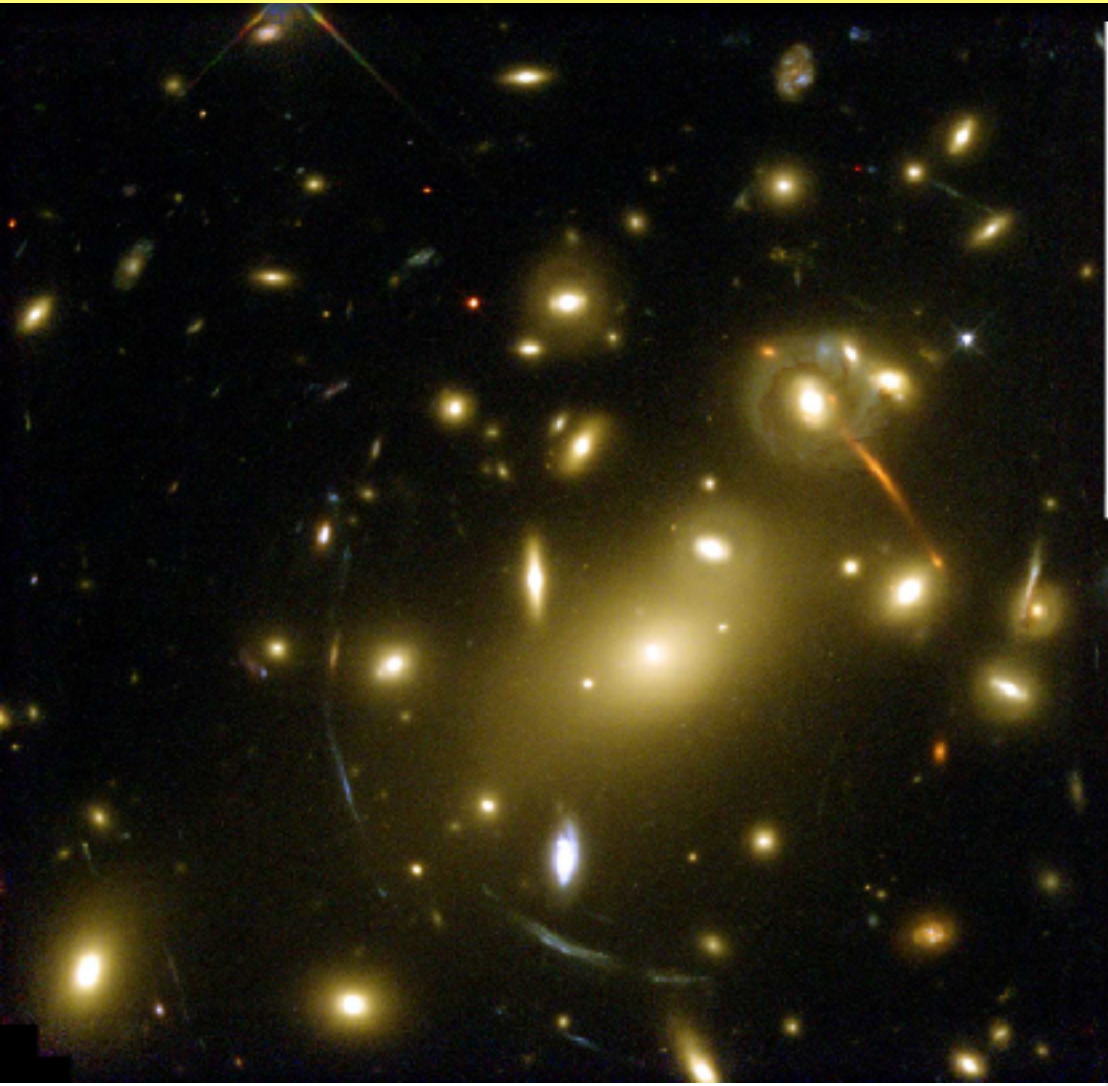
(1 AU = Distanza Terra-Sole)

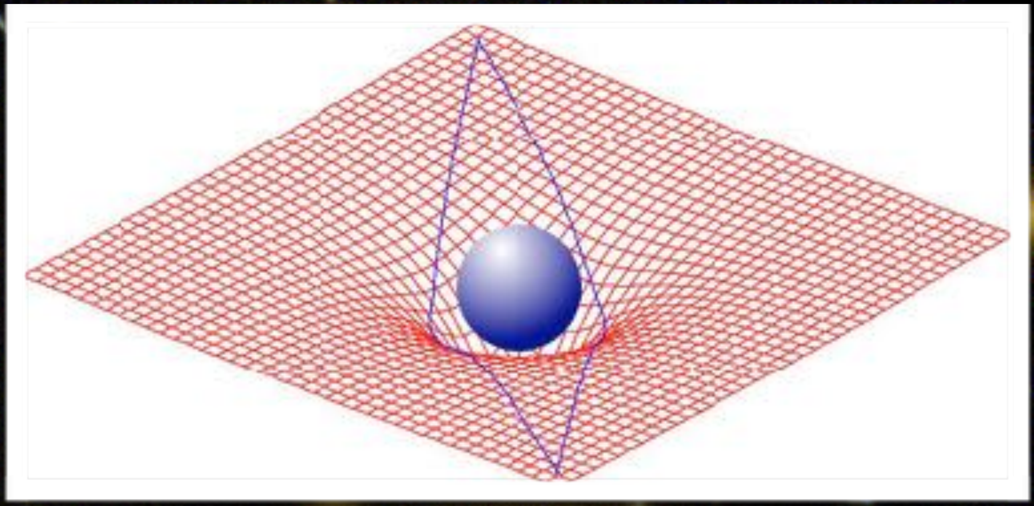
Velocità di rotazione in una galassia

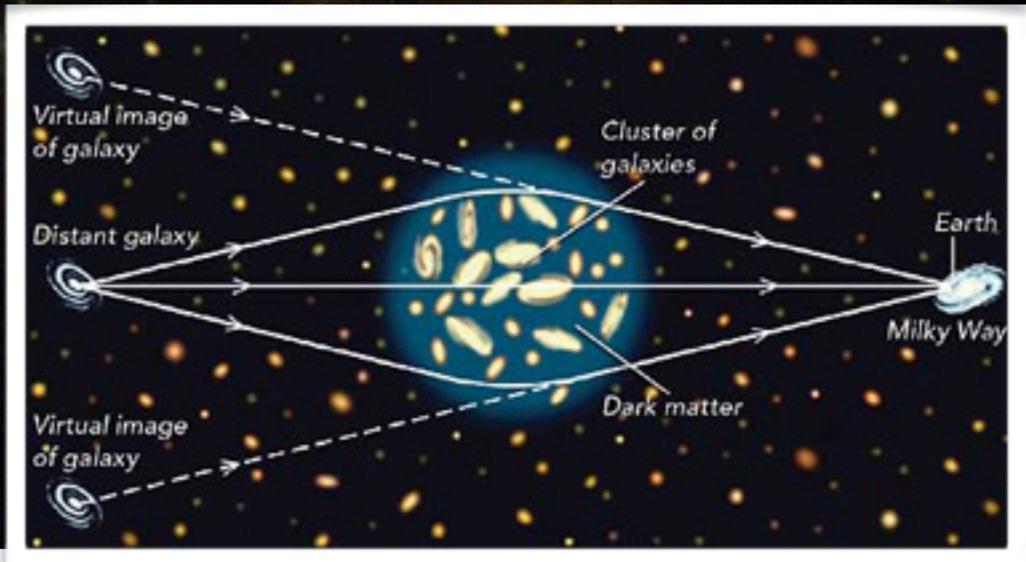


È come se ci fosse della materia in più di cui vediamo gli effetti gravitazionali ma che è invisibile.

Lenti gravitazionali







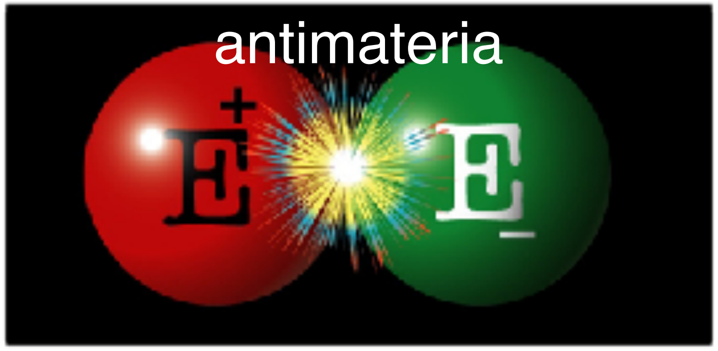
Questo metodo viene utilizzato per tracciare la mappa della materia oscura nell'Universo.

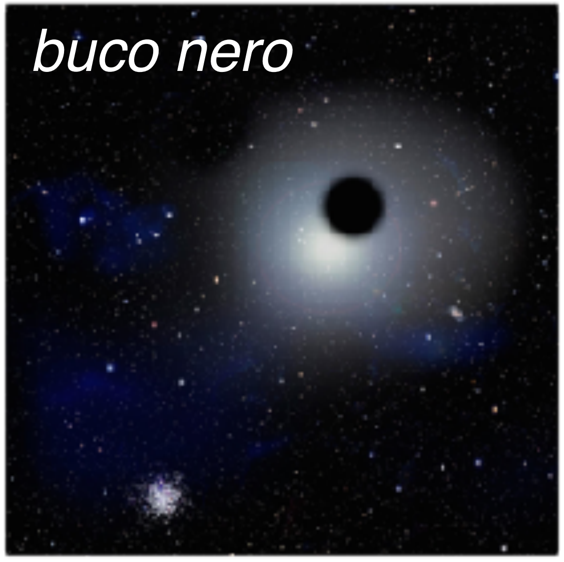
Cosa è la Materia Oscura?

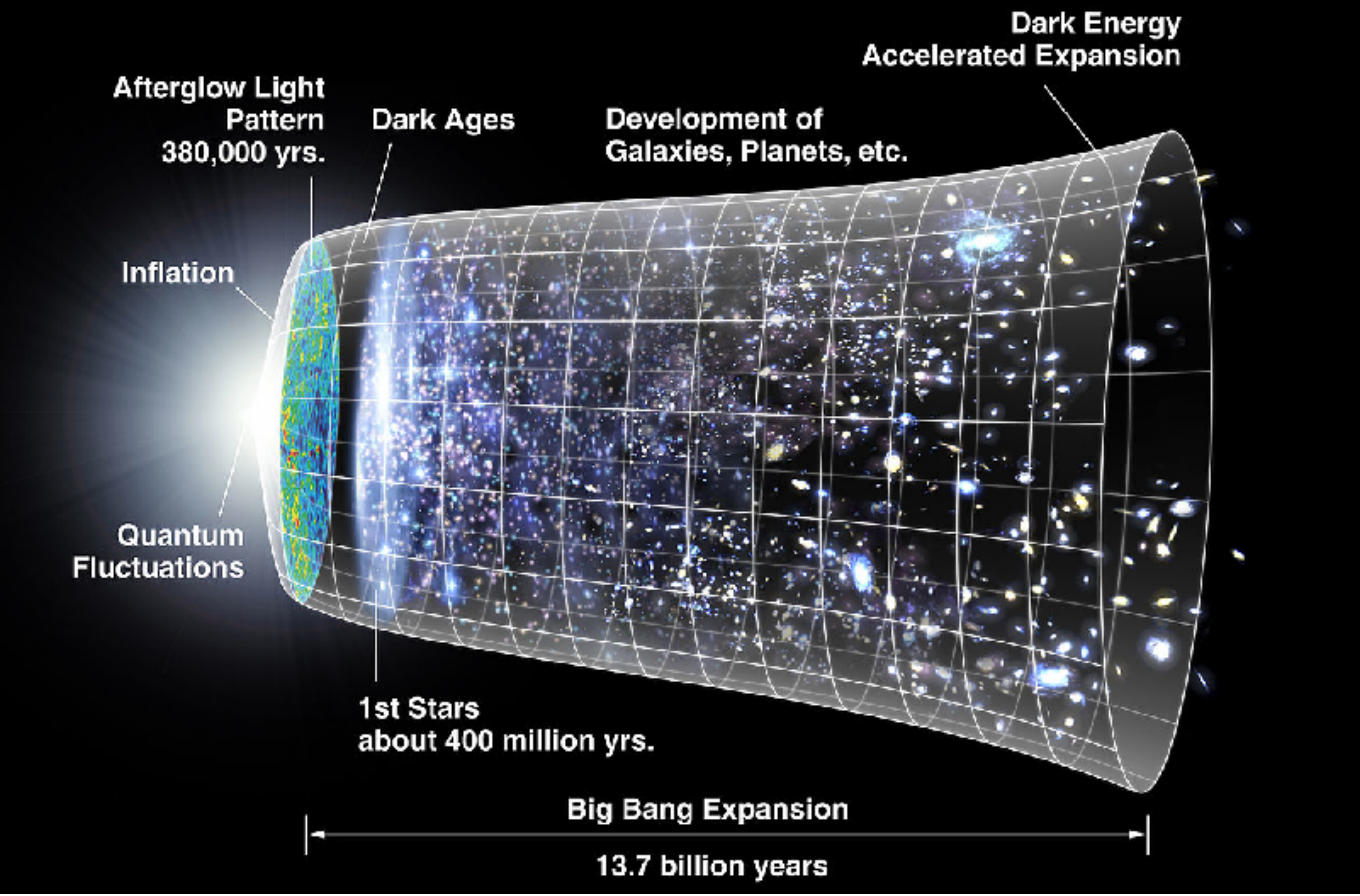
Cosa sappiamo:

- Interagisce molto poco con la materia ordinaria.
- Non emette e non assorbe luce.
- Siamo sensibili solo agli effetti gravitazionali.

Cosa non è:

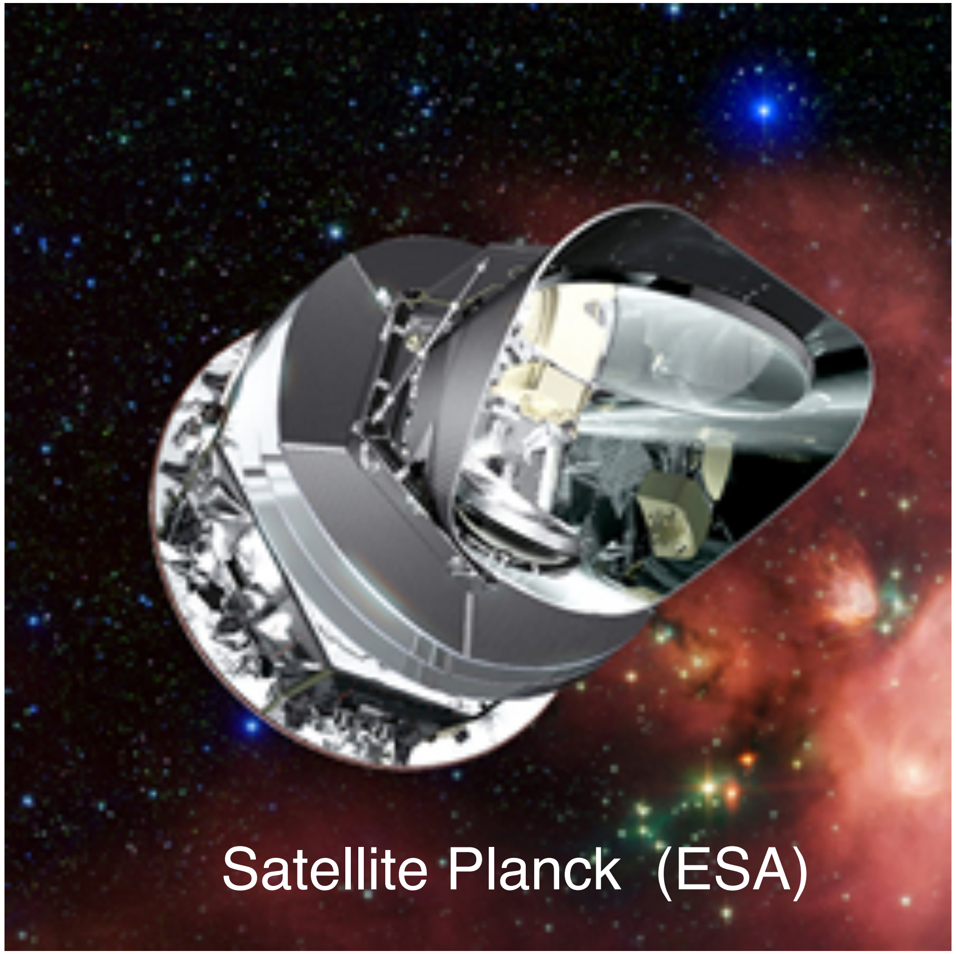


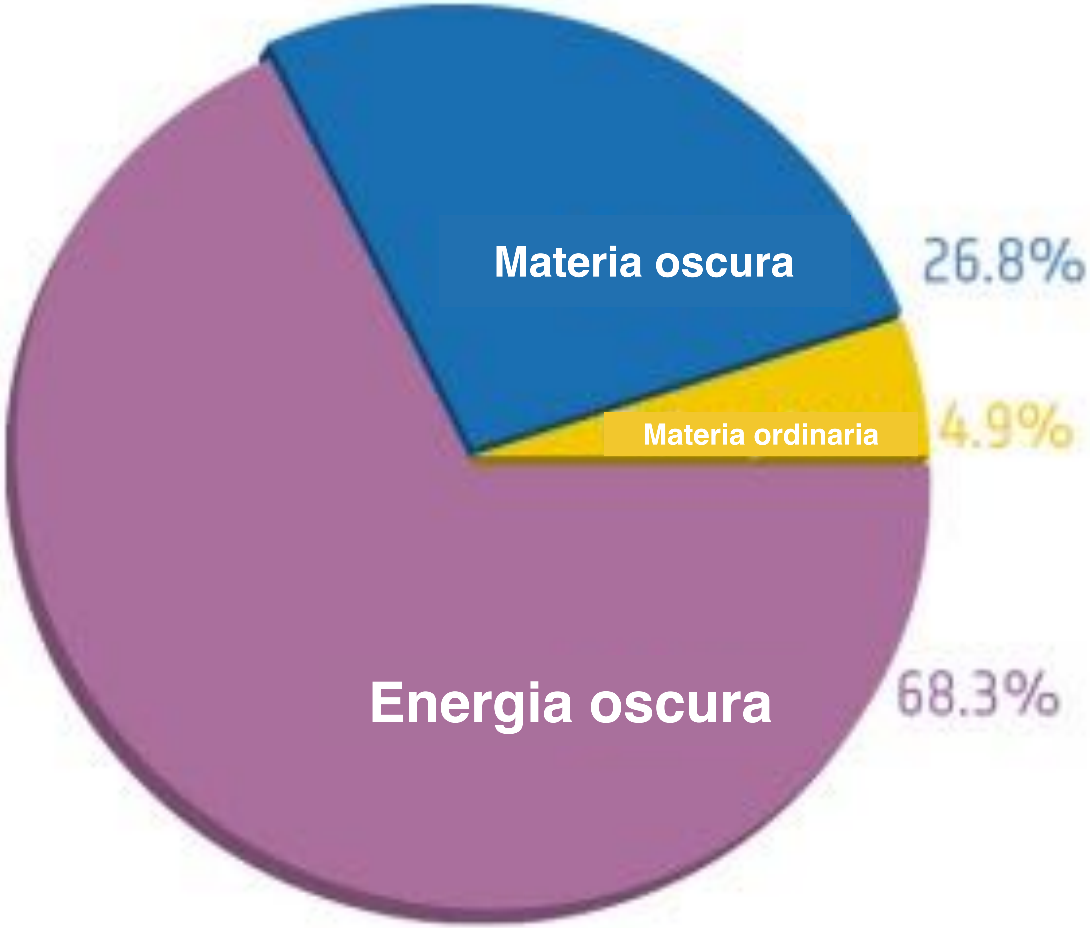




La materia oscura ha ricoperto un ruolo determinante nella formazione delle Galassie.

La composizione dell'Universo





Cosa è l'energia oscura? Non ne abbiamo idea!
Per ora ci concentriamo sulla materia oscura.

Cosa è la Materia Oscura?

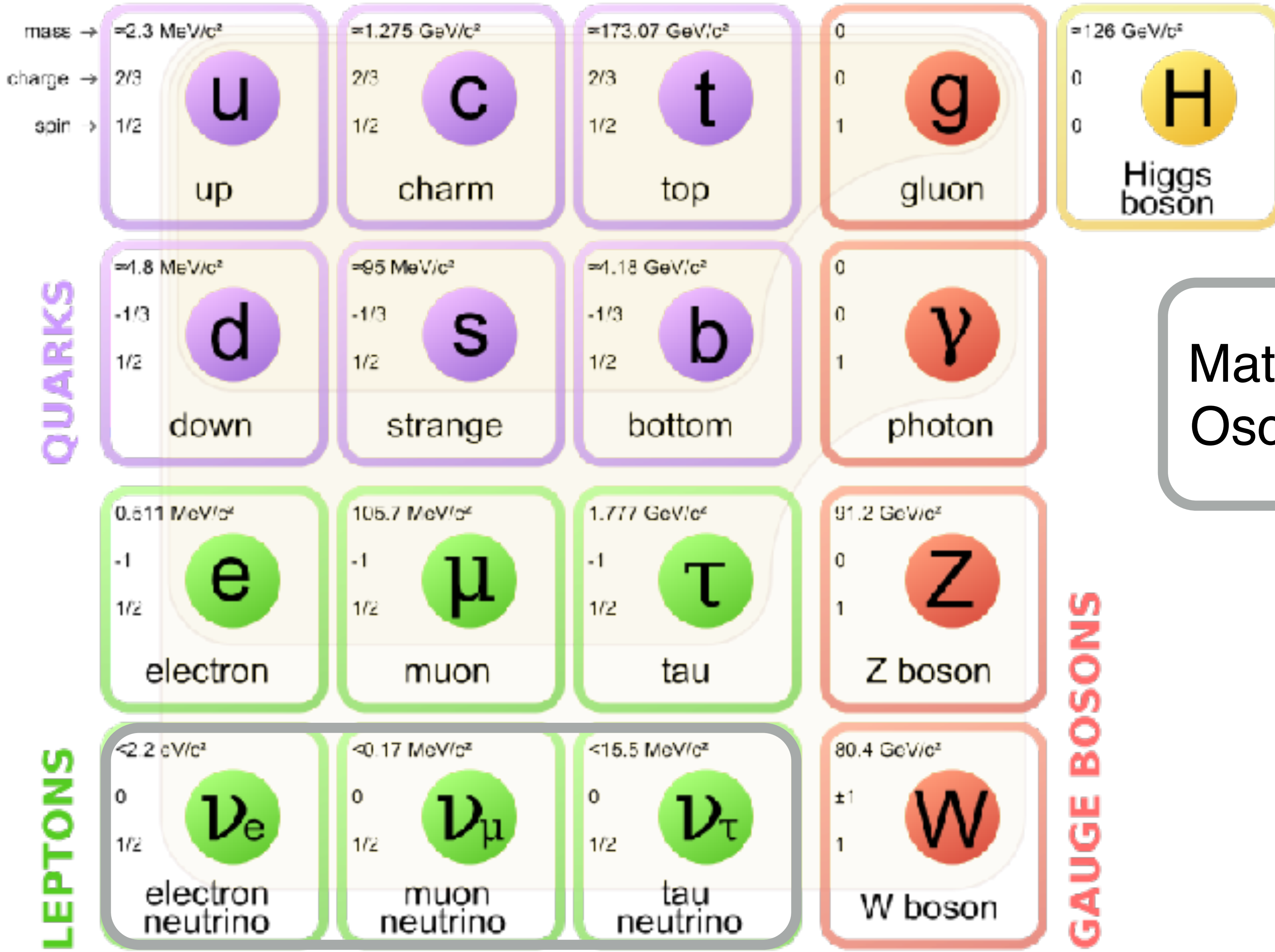
Cosa sappiamo:

- Interagisce molto poco con la materia ordinaria.
- Non emette e non assorbe luce.
- Siamo sensibili solo agli effetti gravitazionali.
- Non è la materia ordinaria, l’antimateria o un buco nero.

Cosa potrebbe essere:

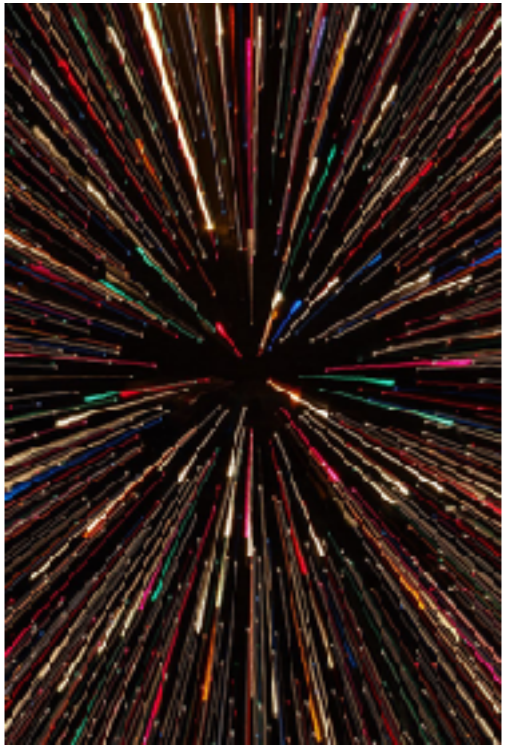
- Non esiste: le leggi della gravitazione non sono esatte (MoND).
- Una nuova particella?

Il modello standard



Materia Oscura

Una nuova particella?

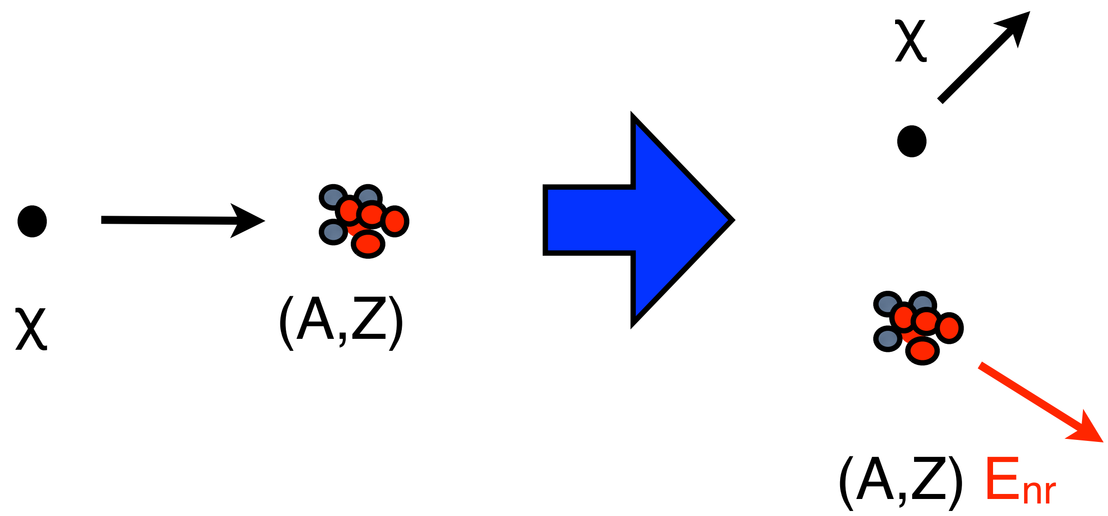


- Problemi:
  - Non sappiamo cosa sia, quindi non sappiamo quale è il modo giusto per vederla.
  - Bassa densità. Circa 1 protone equivalente in 3 cm^3.
  - È in grado di attraversare la terra senza interagire.

- Almeno 2 ipotesi:
  - Particella leggera (Assione) che può interagire con i campi magnetici.
  - Particella pesante (WIMP).

WIMP detection principle

Elastic scattering off nuclei, measure nuclear recoil energy E_{nr}:



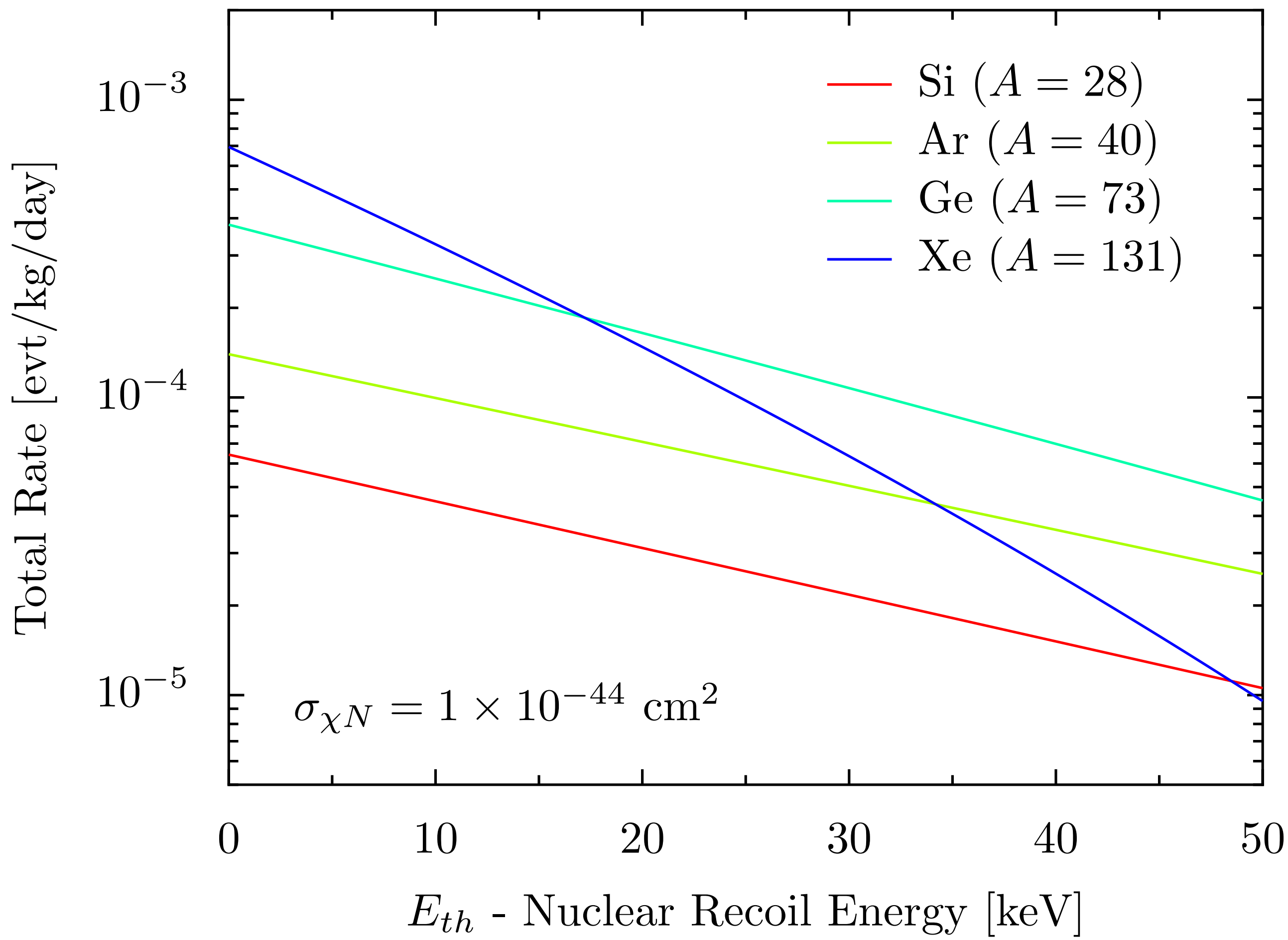
Spin dependent (SD) or spin independent (SI) interaction:

For m_χ = 100 GeV and A = 100:

- $\sigma_{SI} = 10^{-40} - 10^{-48}$ cm^2
- Rate = 10^{-2} - 1 events / (kg day)
- E_{nr} = 0 - 25 keV

The WIMP signal (SI)

Exponential-like shape, increasing at low E (similar to many bkgs...)



Demands O(keV) thresholds and backgrounds close to zero.

All experiments operated in low radioactivity environments and deep underground.

Counting rate annual modulation

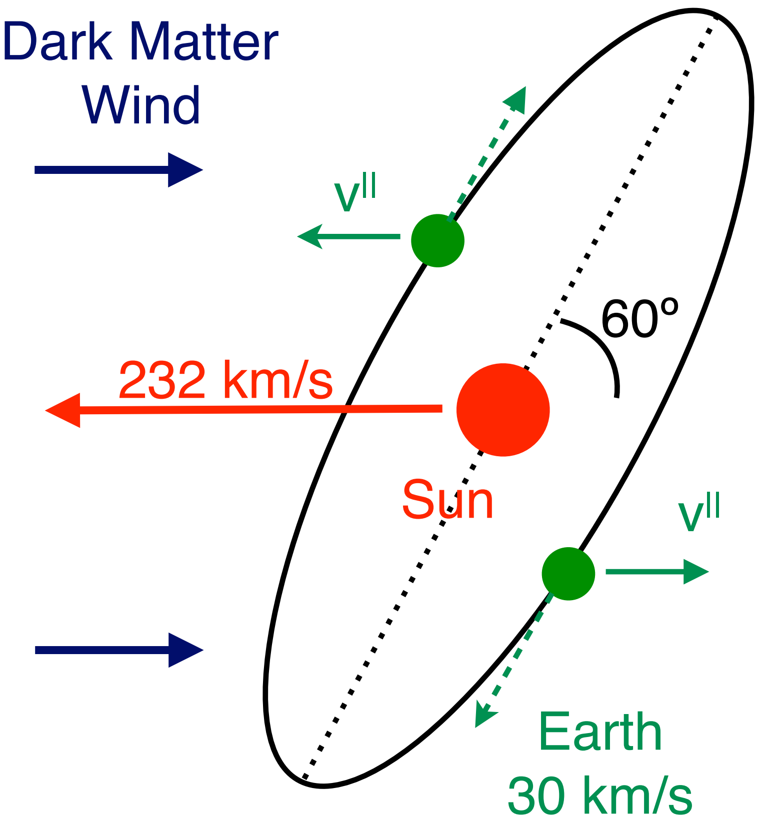
Earth velocity combines to solar system velocity in the galaxy.

Dark matter “wind” in the heart rest frame is modulated:

$$v(t) = v_{\rm sun} + v_{\rm orb}^{||} \cos[\omega(t - t_0)]$$

and affects the counting rate:

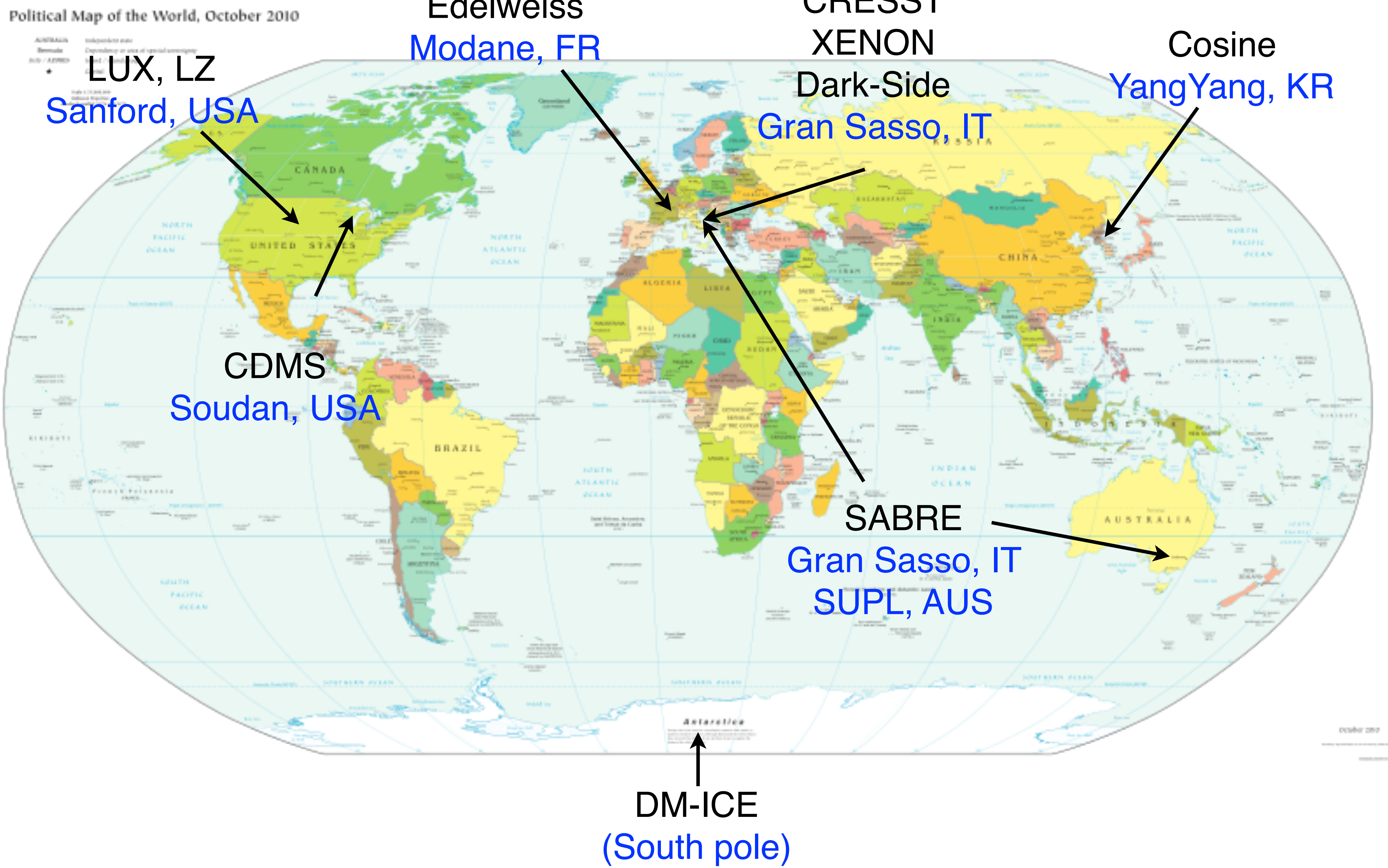
$$S(E,t) = S_0(E) + S_m(E)\cos[\omega(t - t_0)]$$



Distinctive modulation signal features:

T = 1 year t_0 = 2nd June

Pro: model independent **Con:** requires detector stability and bkg control.

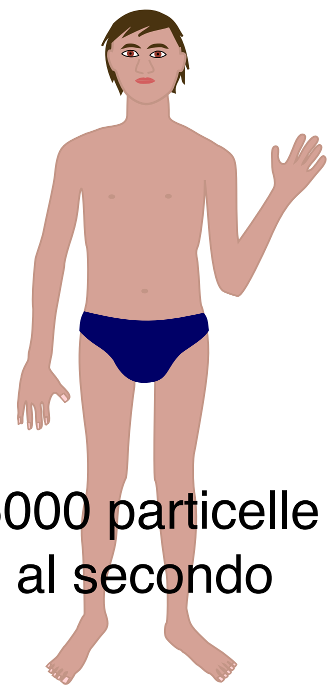

Political Map of the World, October 2010
LUX, LZ
Sanford, USA
Edelweiss
Modane, FR
DAMA/LIBRA
CRESST
XENON
Dark-Side
Gran Sasso, IT
Cosine
YangYang, KR
CDMS
Soudan, USA
SABRE
Gran Sasso, IT
SUPL, AUS
DM-ICE
(South pole)
CANADA
UNITED STATES
BRAZIL
CHINA
AUSTRALIA
INDIA

Rivelazione di WIMP

L'urto WIMP-Nucleo, se avviene, avviene molto raramente:

- **1 urto all'anno in 1 ÷ 100 kg di materiale.**

Questi segnali possono essere nascosti dal **fondo**: urti indotti da altri eventi naturali. Uno tipo di fondo è la radioattività (particelle α β γ).



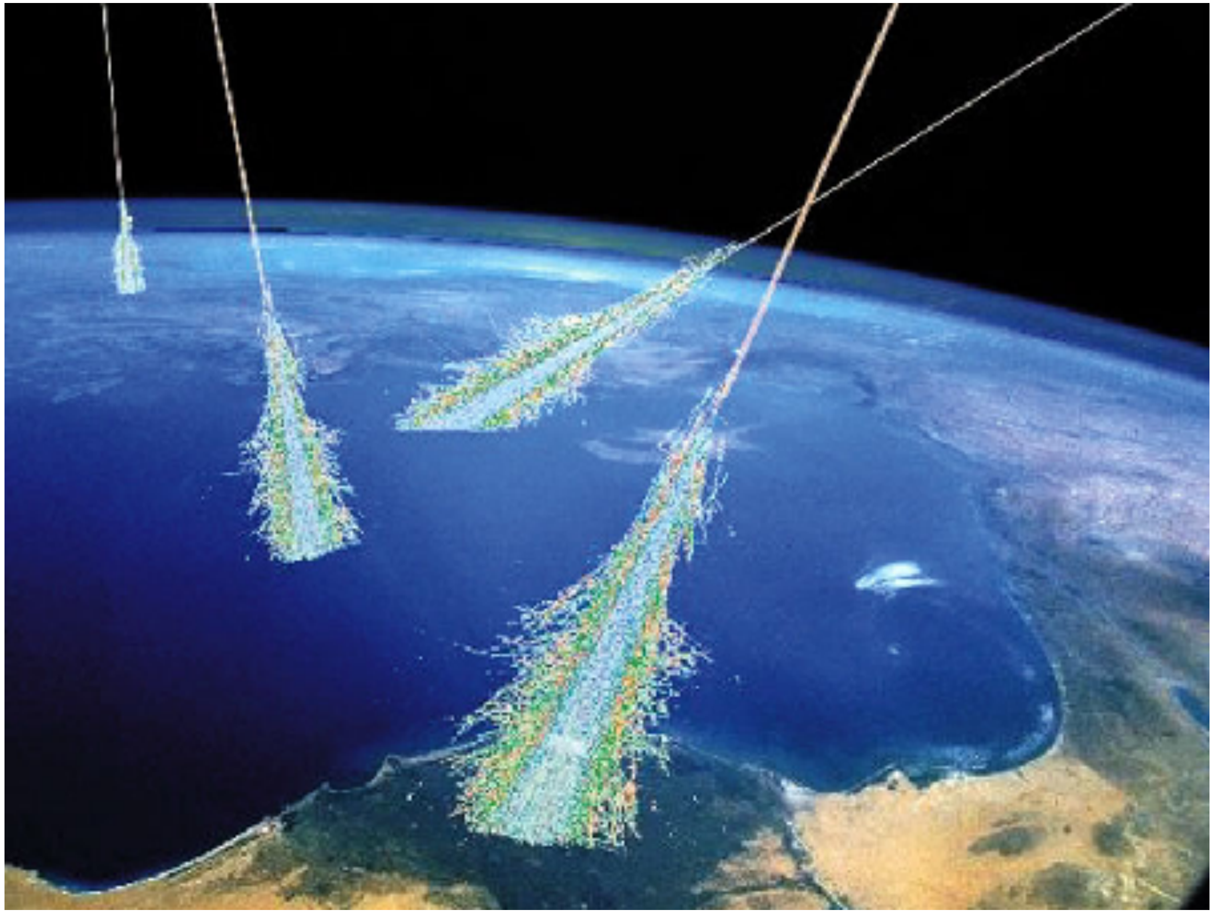
Aria

20 particelle al secondo per m^3

Bisogna lavorare in ambienti a bassa radioattività.

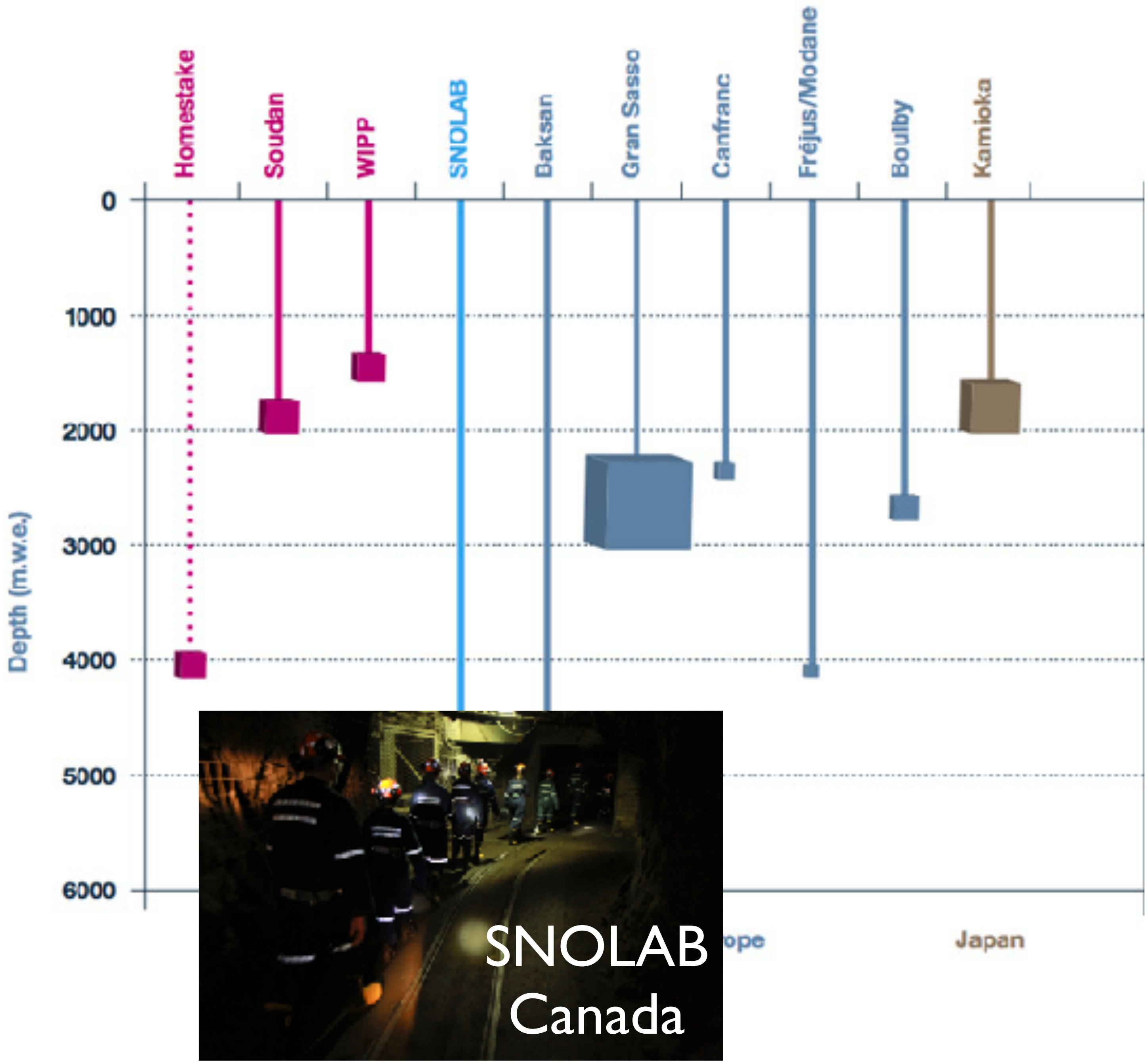
Raggi cosmici

Particelle (principalmente protoni) generate dalle stelle e dalle galassie che collidono con l'atmosfera terrestre, producendo altre particelle.

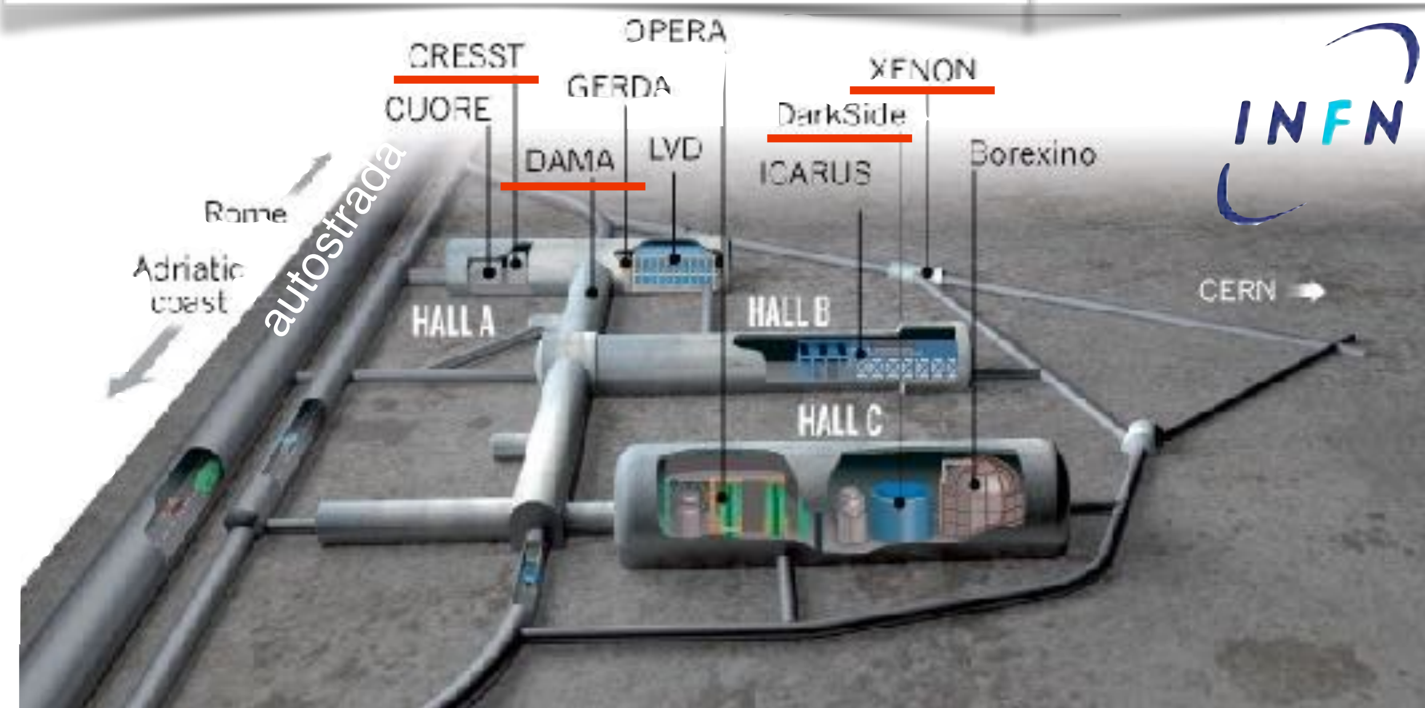


Si misurano circa: 1 milione di particelle / (m^2 ora) sulla terra.

Laboratori sotterranei



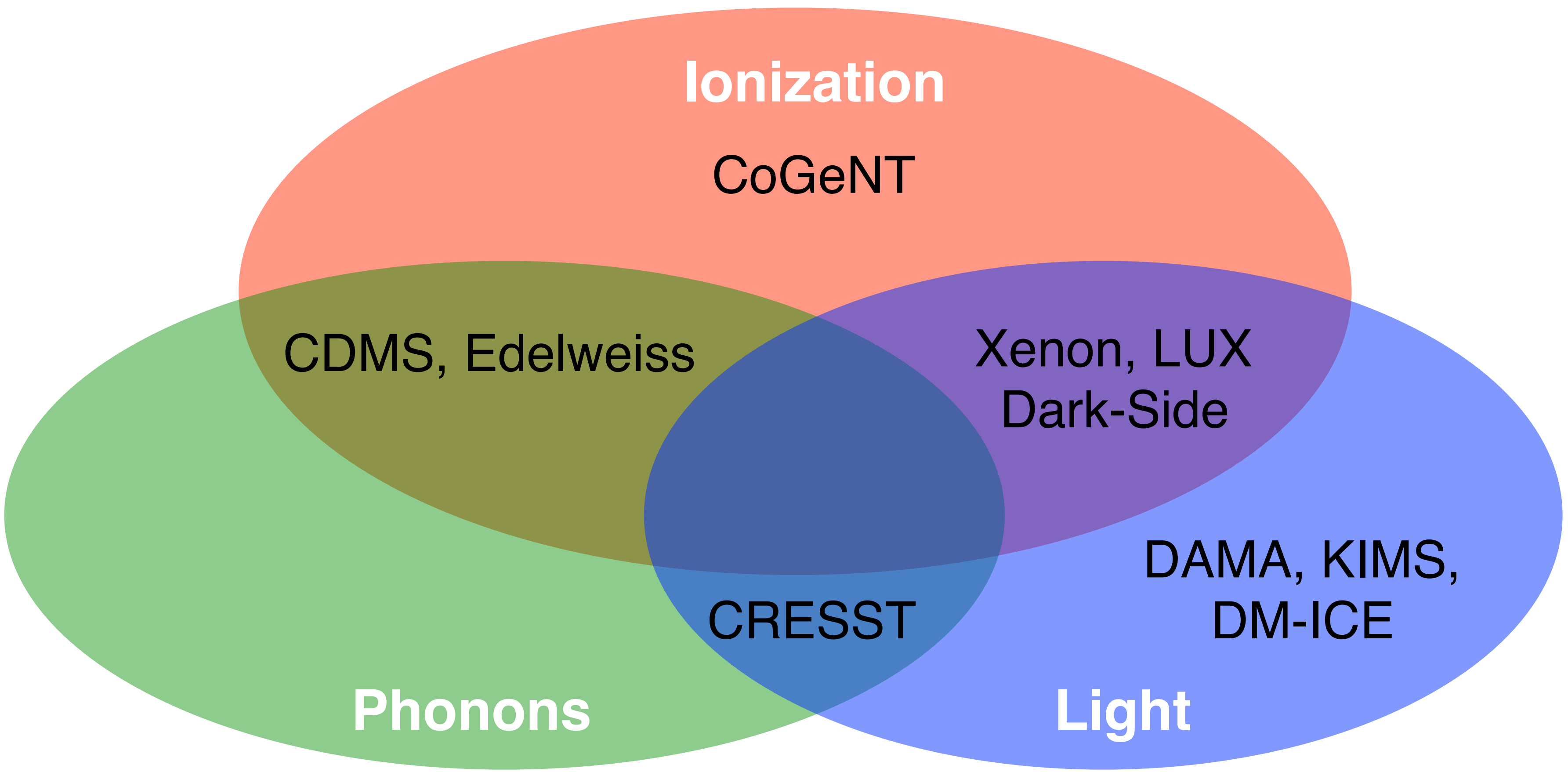
Laboratori del Gran Sasso



Esperimenti
per la ricerca
di Materia Oscura

Detection channels

The combination of different techniques allows one to discriminate between electron and nuclear recoils, and thus to reduce the β/γ background.



Energy calibrations are done with γ sources (electron recoils).

The relative calibration of nuclear recoils (keV_{ee} ➡ keV_{nr}), the quenching factor (QF), must be known with accuracy

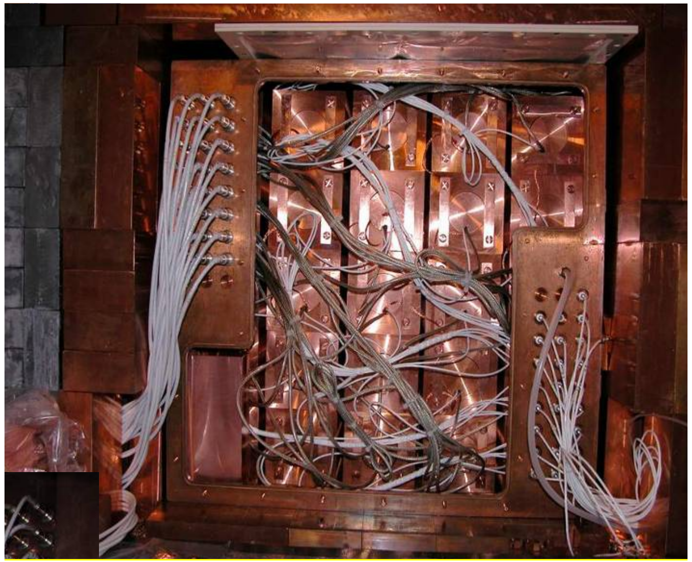
DAMA/LIBRA

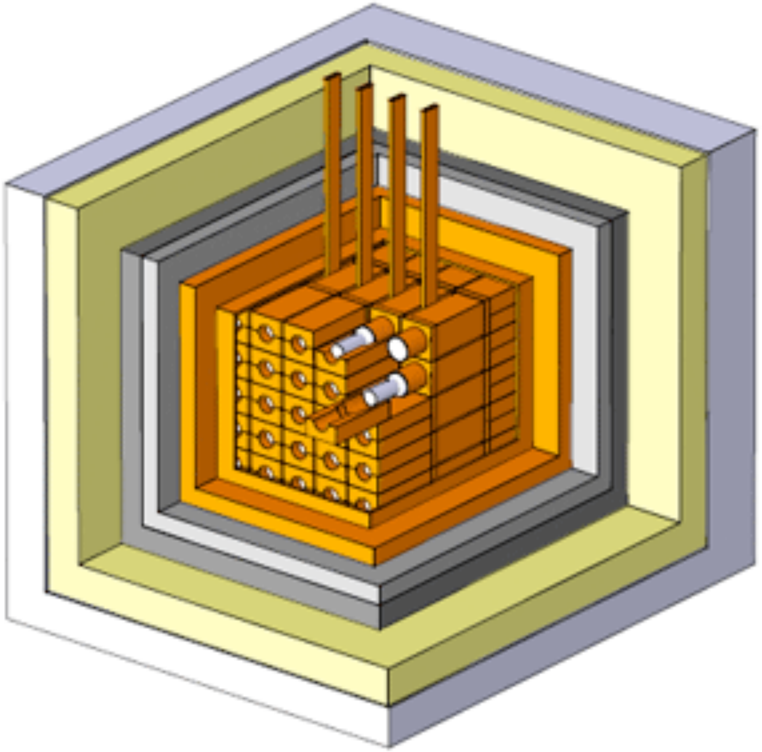
25 NaI crystals, 9.70 kg each

- QF: Na (30%), I (10%)
- High radiopurity: ^{232}Th and ^{238}U (ppt), ^{40}K (<20 ppb)

Dual read-out of each crystal via PMTs (noise reduction via coincidence), 5.5-7.5 photoelectrons/keVee

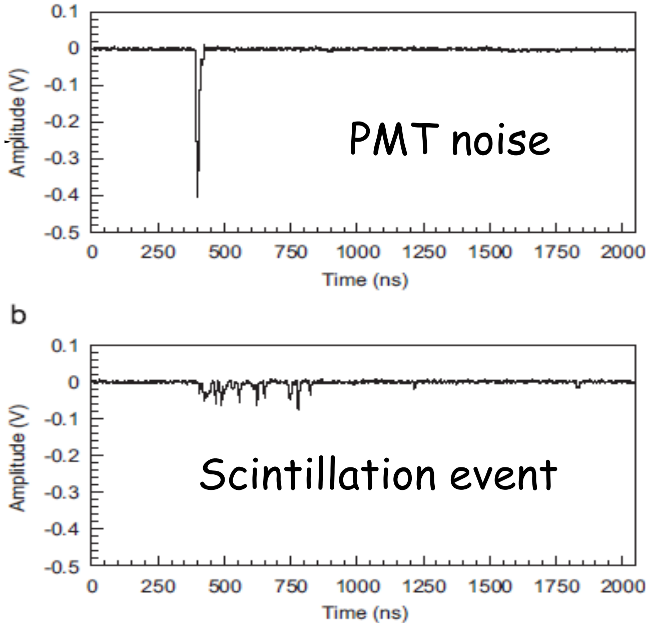
- Energy threshold: 2 keVee
- Granularity: select single crystal events

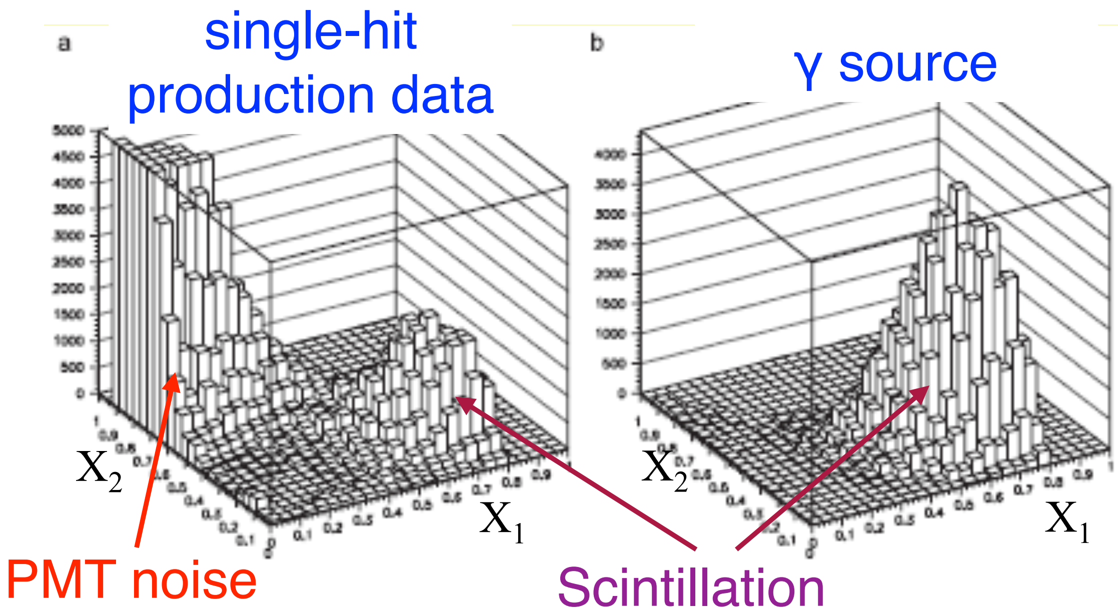




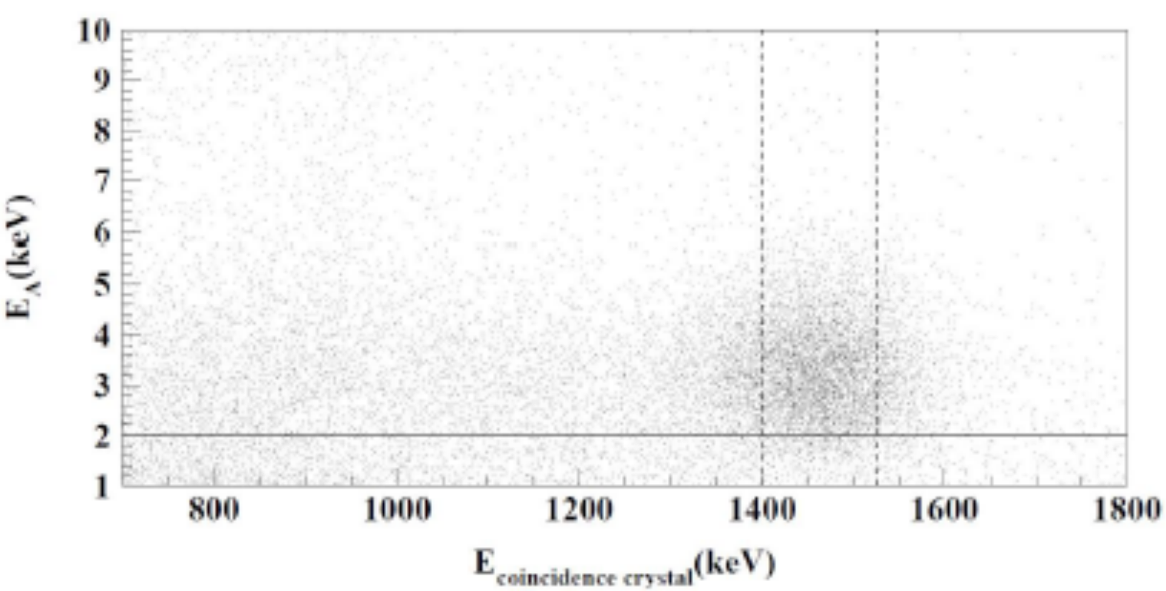
DAMA/LIBRA - data analysis

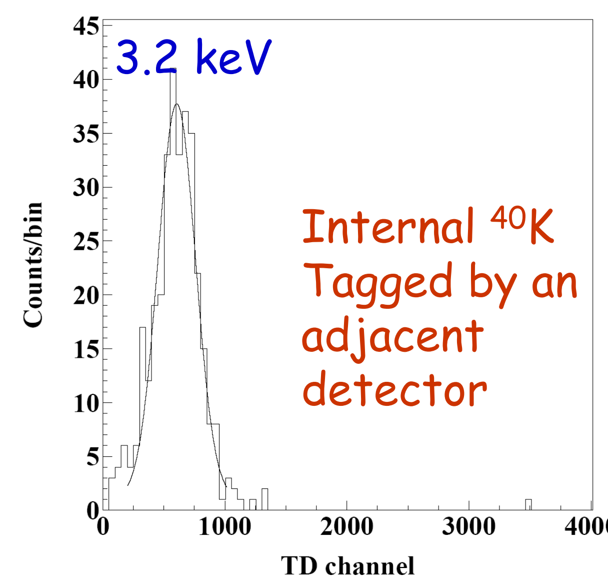
Pulse shape cuts to reject PMT noise events:





Low energy calibration with ^{241}Am and ^{133}Ba, check with ^{40}K

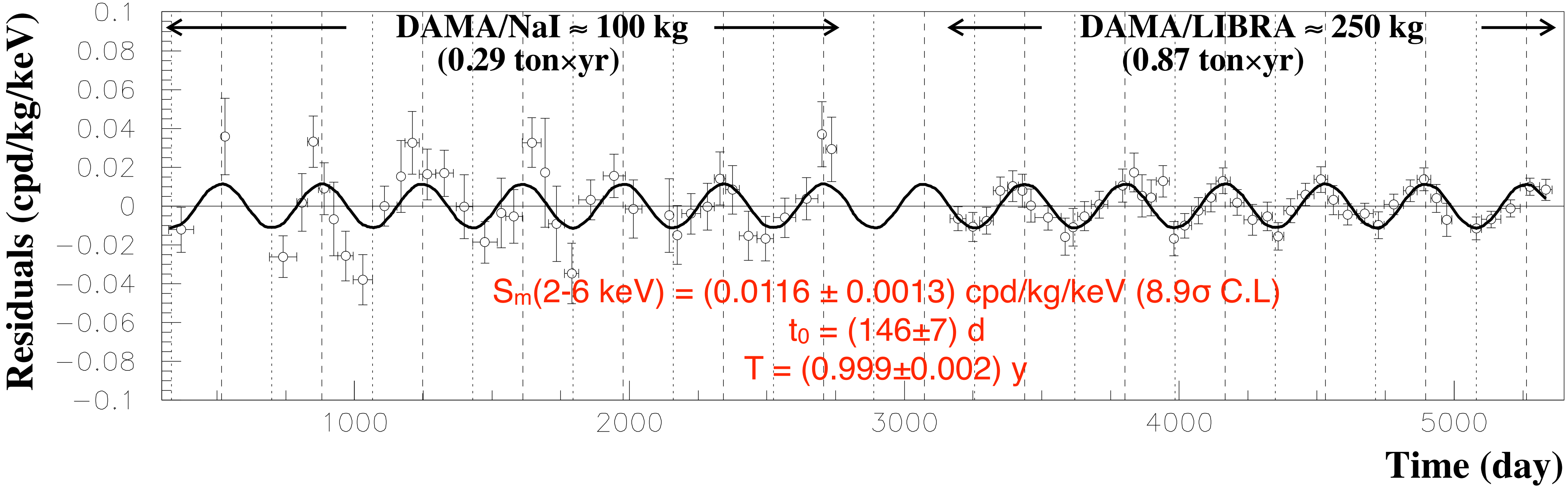


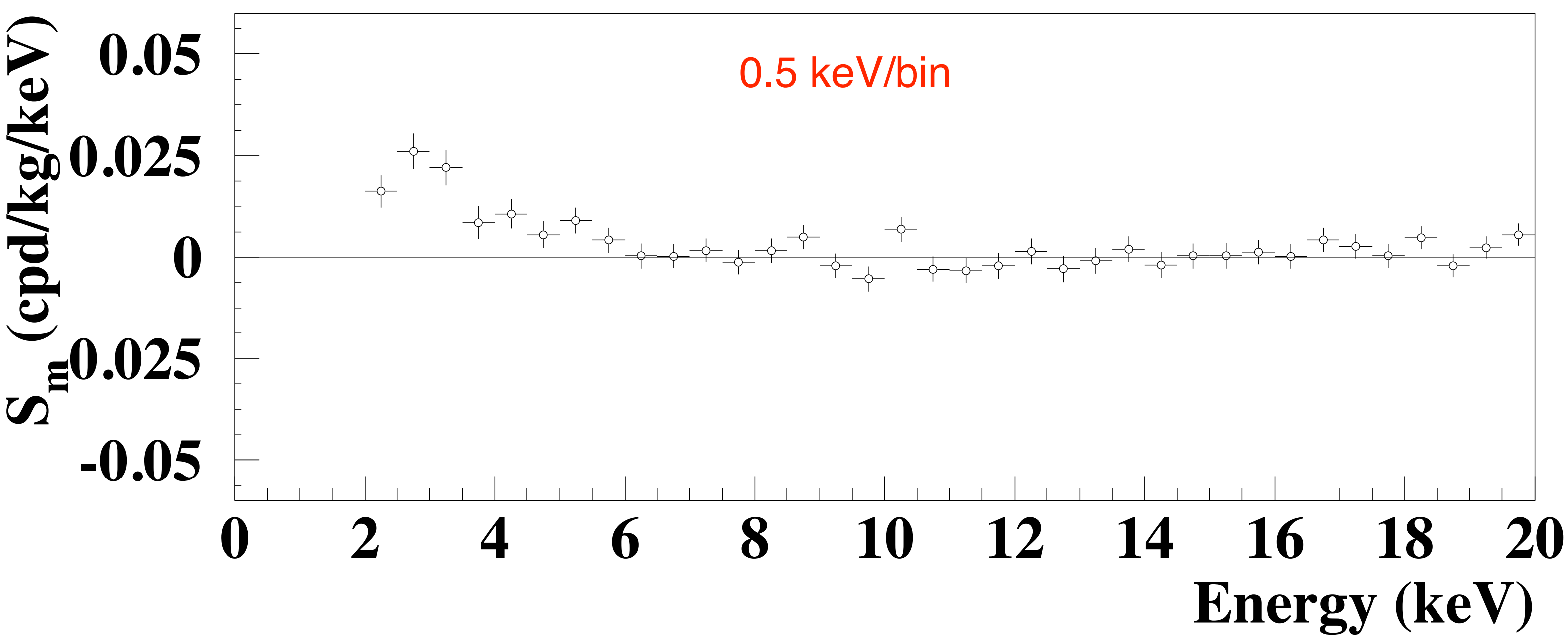


DAMA/LIBRA - result

Eur. Phys. J. C 56 (2008) 333 and 67 (2010) 39

2-6 keV





DAMA/LIBRA - checks

R. Cerulli at IDM2012

Source	Main comment	Cautious upper limit (90%C.L.)
RADON	Sealed Cu box in HP Nitrogen atmosphere, 3-level of sealing, etc.	**<2.5×10^{-6} cpd/kg/keV**
TEMPERATURE	Installation is air conditioned+ detectors in Cu housings directly in contact with multi-ton shield→ huge heat capacity + T continuously recorded	**<10^{-4} cpd/kg/keV**
NOISE	Effective full noise rejection near threshold	**<10^{-4} cpd/kg/keV**
ENERGY SCALE	Routine + intrinsic calibrations	**<1-2 ×10^{-4} cpd/kg/keV**
EFFICIENCIES	Regularly measured by dedicated calibrations	**<10^{-4} cpd/kg/keV**
BACKGROUND	No modulation above 6 keV; no modulation in the (2-6) keV *multiple-hits* events; this limit includes all possible sources of background	**<10^{-4} cpd/kg/keV**
SIDE REACTIONS	Muon flux variation measured at LNGS	**<3×10^{-5} cpd/kg/keV**

+ they cannot satisfy all the requirements of annual modulation signature

→ **Thus, they cannot mimic the observed annual modulation effect**

DAMA phase: May 26±7 μ phase @LNGS: July 6±6

SABRE

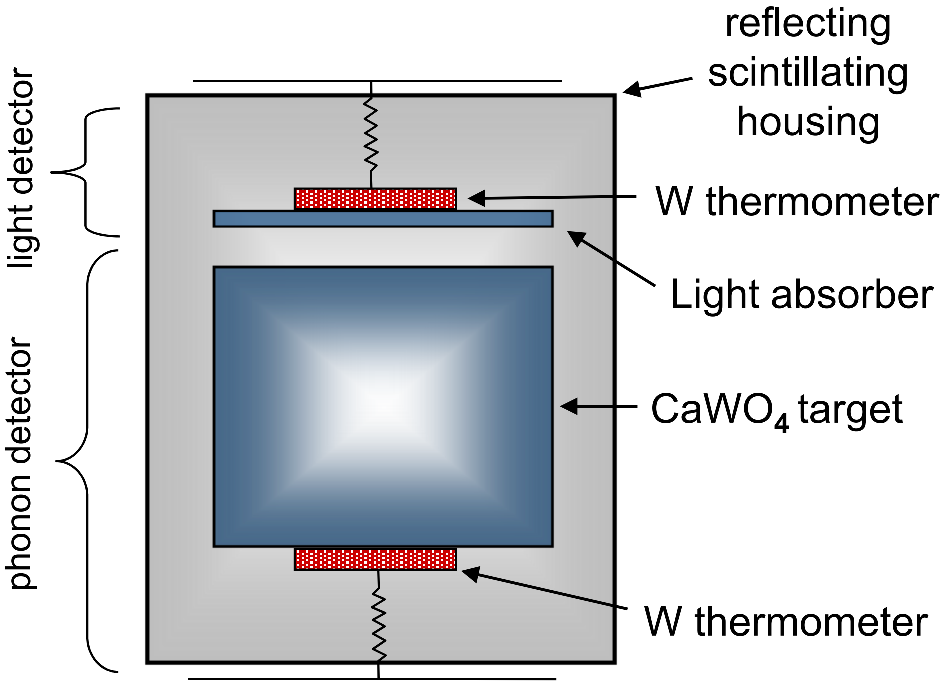
una conferma indipendente di DAMA, al Gran Sasso ed in Australia

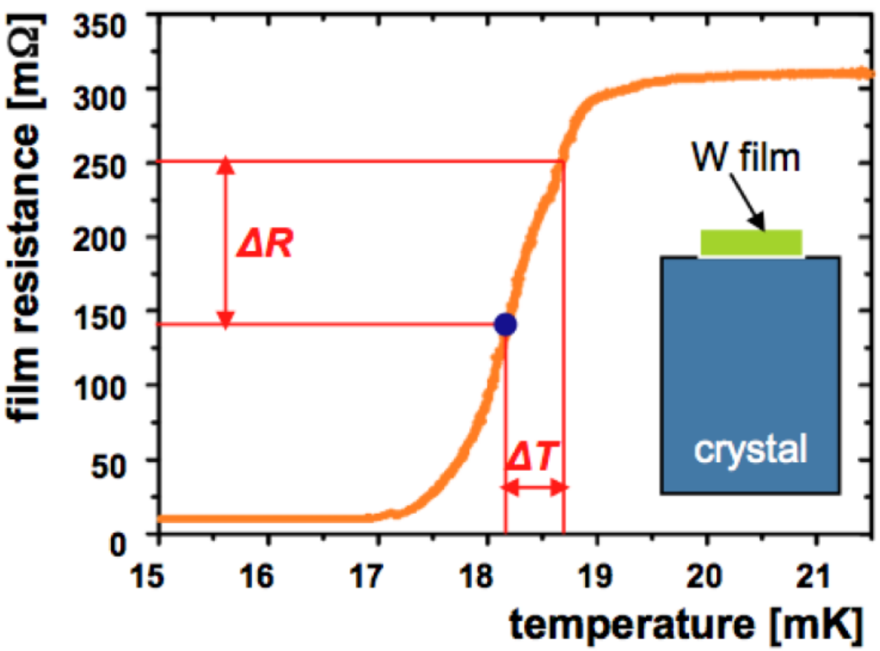
CRESST

$CaWO_4$ crystals (300g) operated as bolometers (phonon detectors):

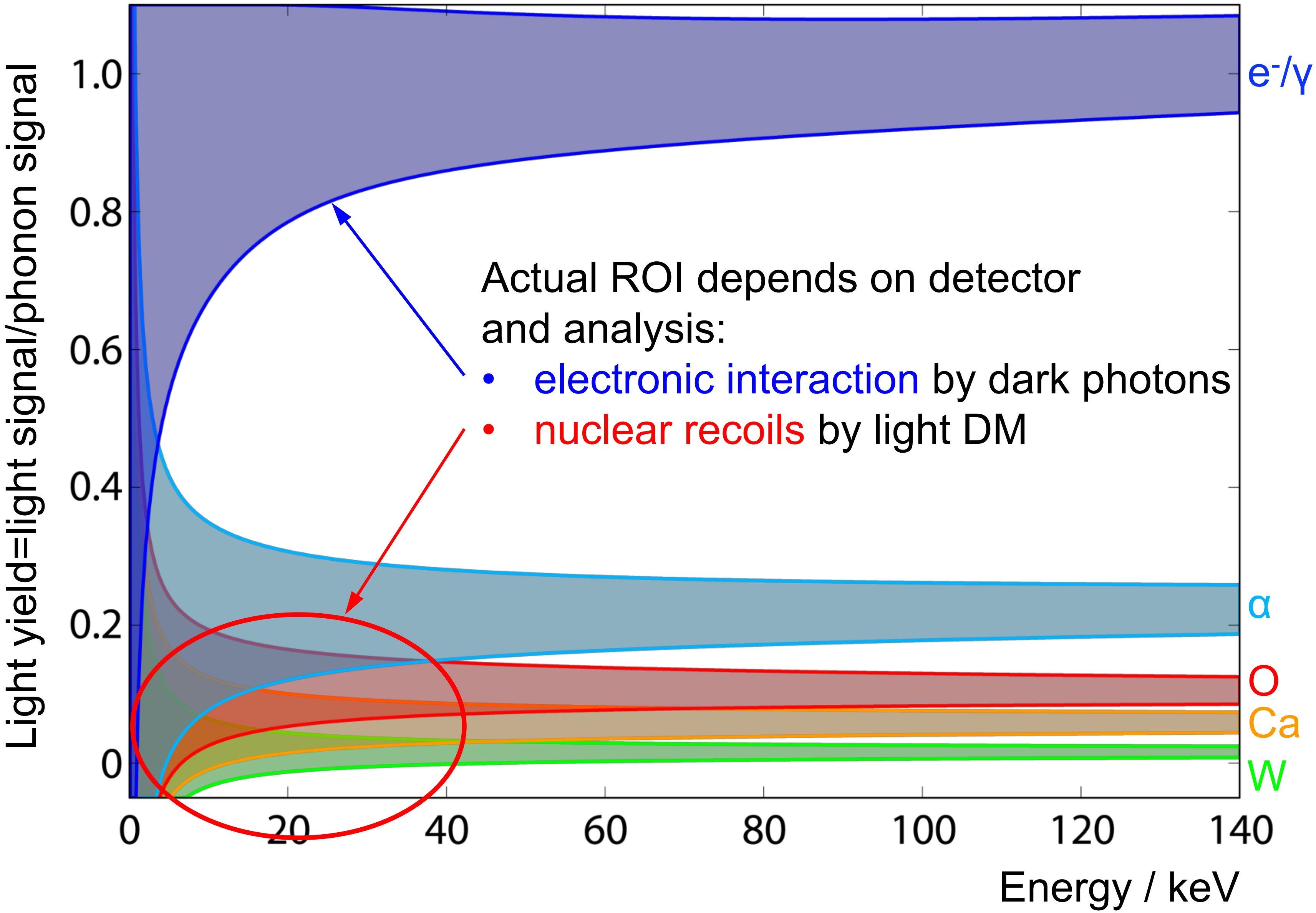
1) detect also scintillation light to discriminate nuclear recoils

2) Multi-target: sensitive to different WIMP masses:

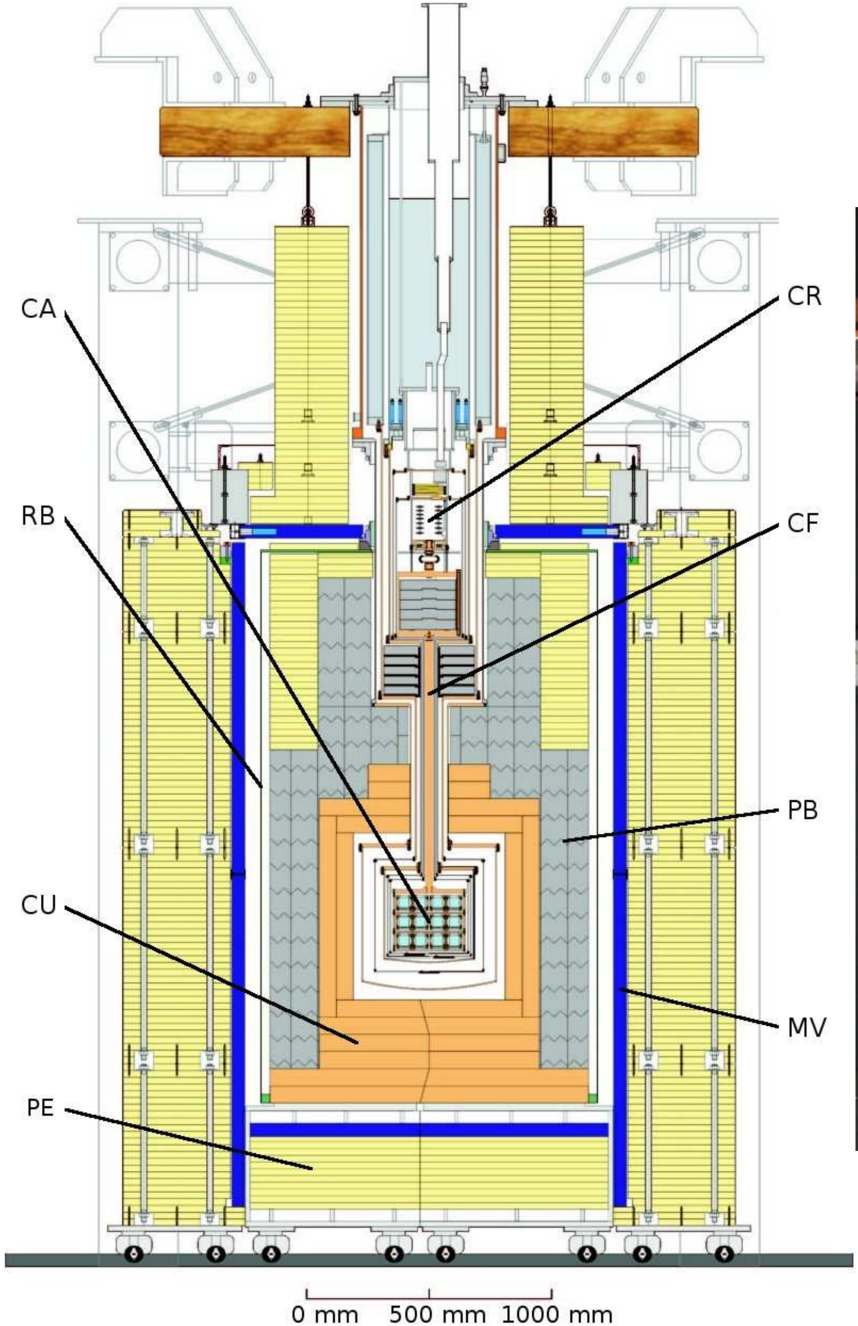




Discrimination with light detector

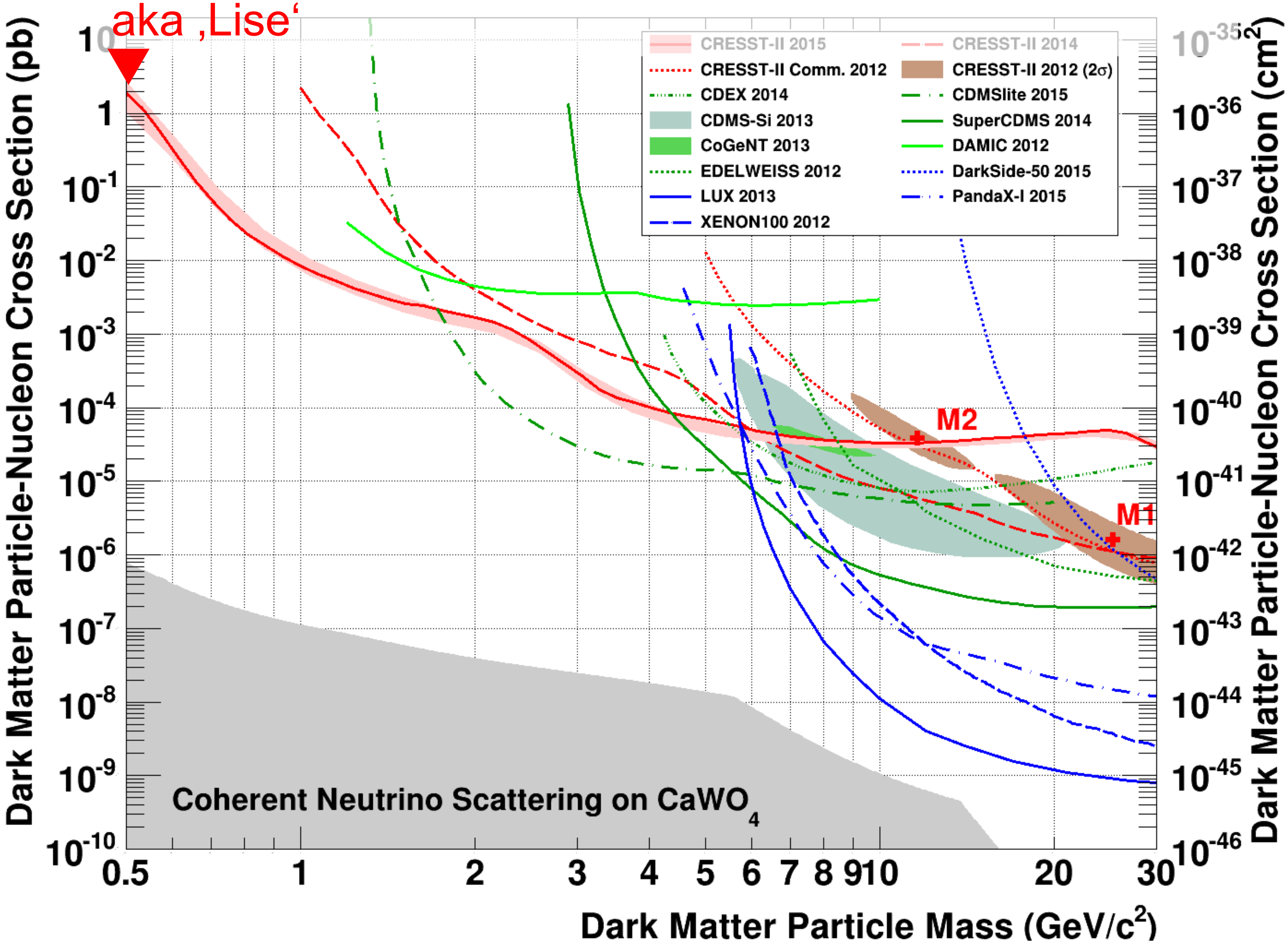


CRESST detector



CRESST: results

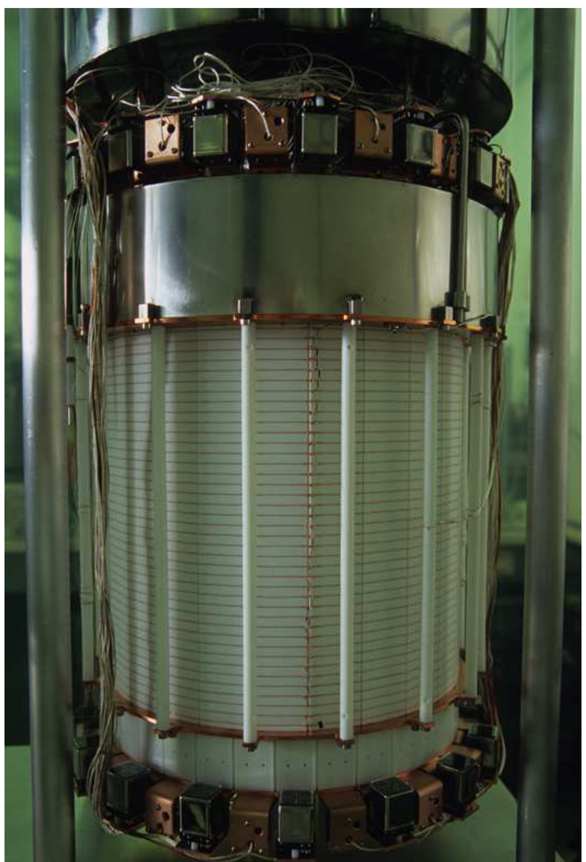
CRESST-II phase 2 (2015), Eur.Phys.J. C76 (2016)25
aka ‚Lise‘

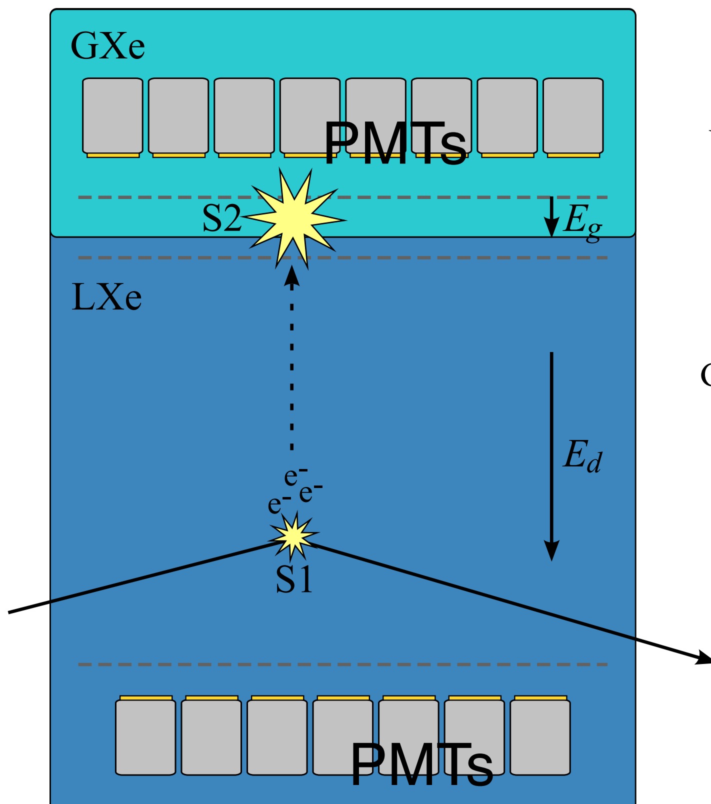


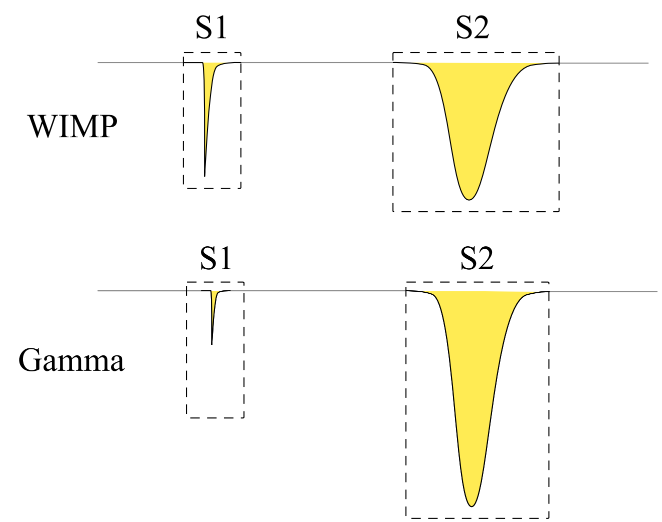
Xenon-100

- 161 kg LXe (34 kg fiducial volume).
- Dual phase TPC, detect scintillation (S1) and ionization (S2)

▸x,y and z (via S2-S1 time difference), and recoil discrimination via S2/S1 ratio





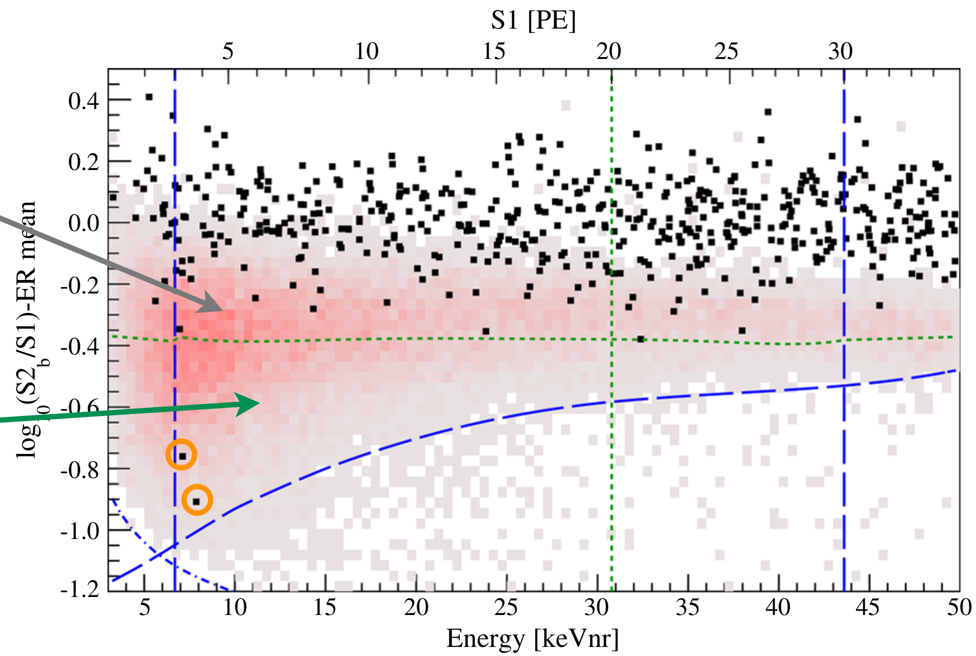


Xenon-100 - Results

Phys.Rev.Lett 109 (2012) 181301

Reference nuclear recoils from AmBe source

WIMP search region

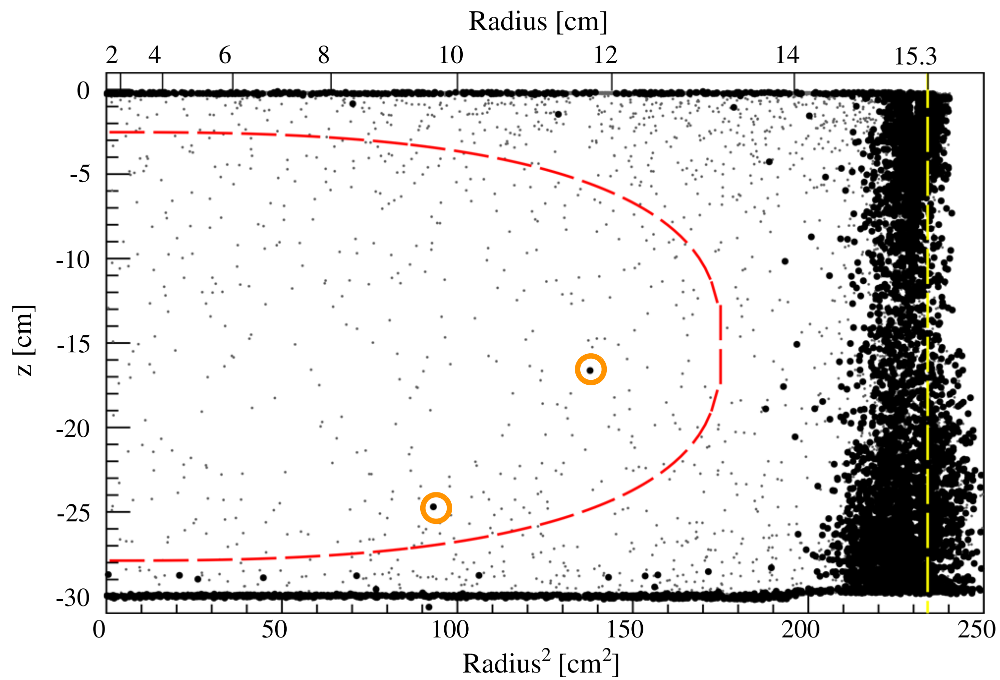


After selection:

2 candidate WIMP events

vs 1.0±0.2 of expected background

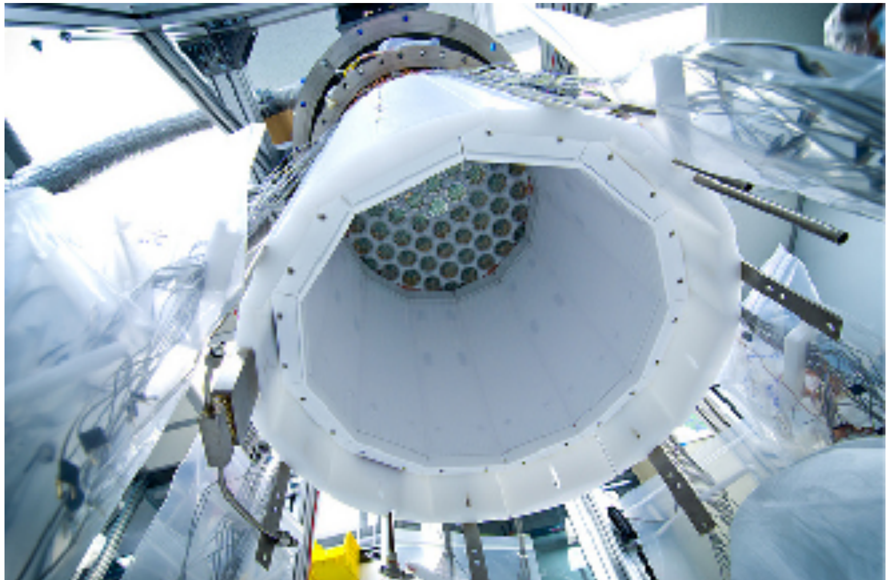
(0.8±0.2 of which are electron recoils)

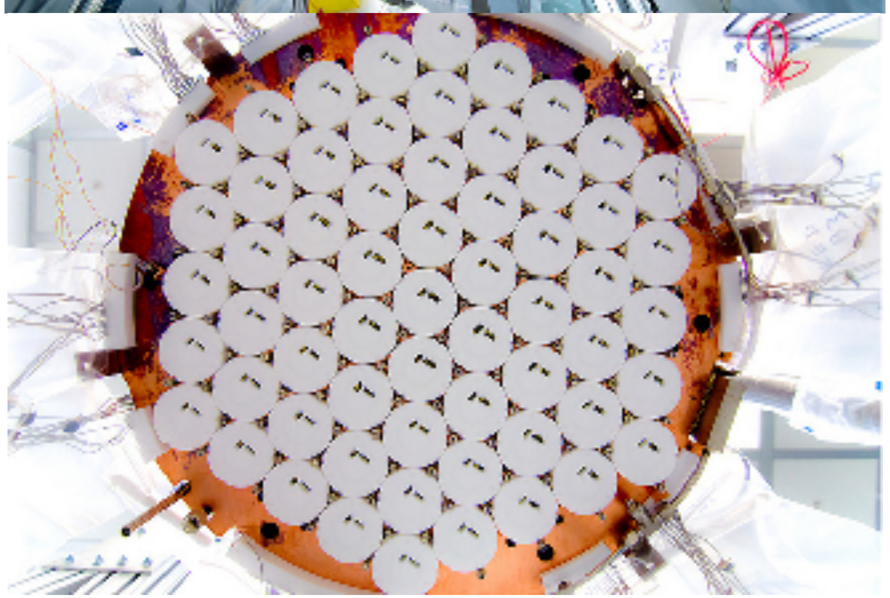


Cannot exclude the background only hypothesis ➡ Limit derived

LUX

Same technique as Xenon-100: Dual phase LXe TPC

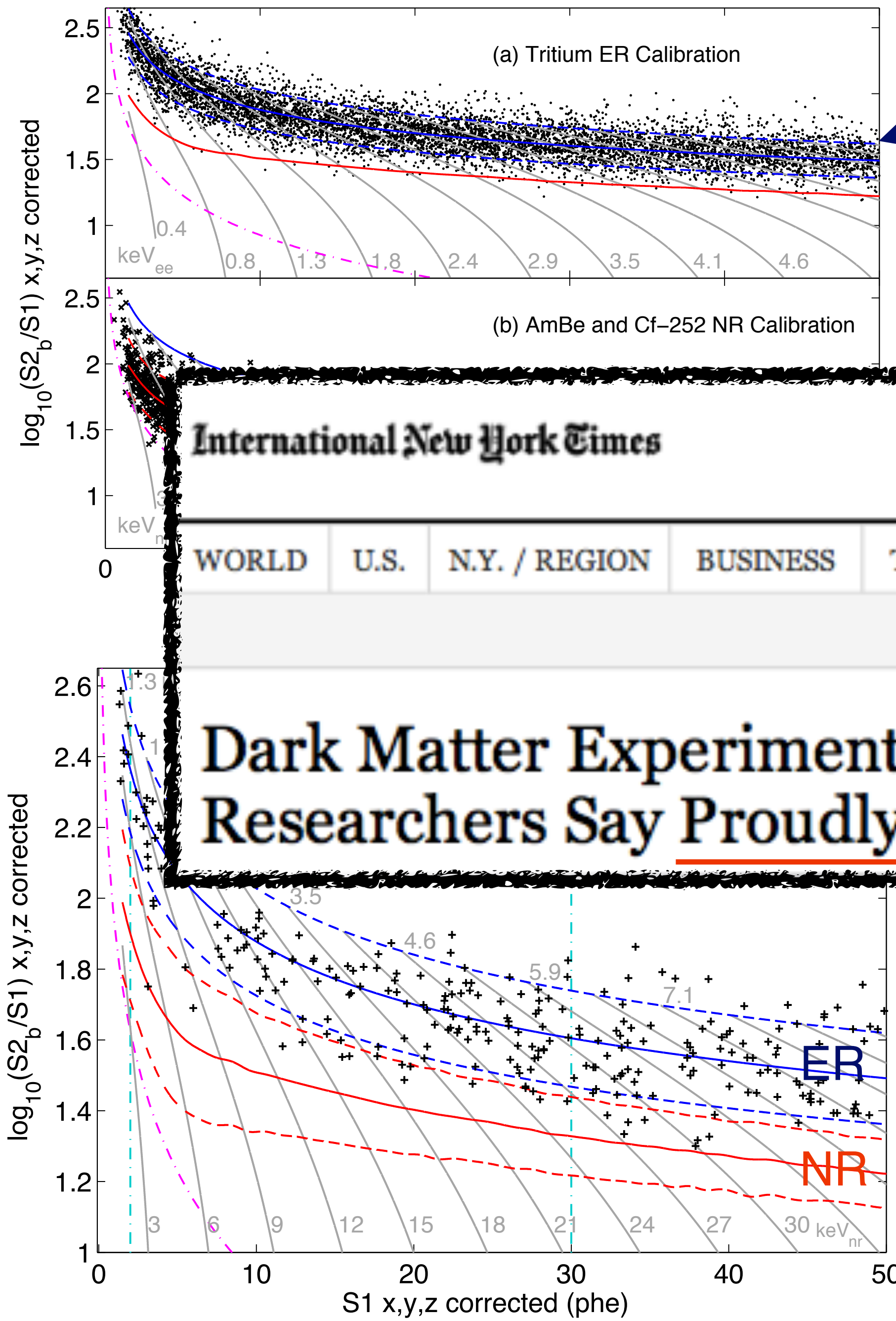




	Xenon-100	LUX
Total/Active Volume [kg]	161/62	370/250
Fiducial volume [kg]	34	118
S1 Light Yield [PhE/keVee]	2.3 (field on)	8.8 (field off)
WIMP search region [keVnr]	6.6 - 30.5	~ 3 - 18
Published live time [day]	225	85

LUX - Results

arXiv:1310.8214

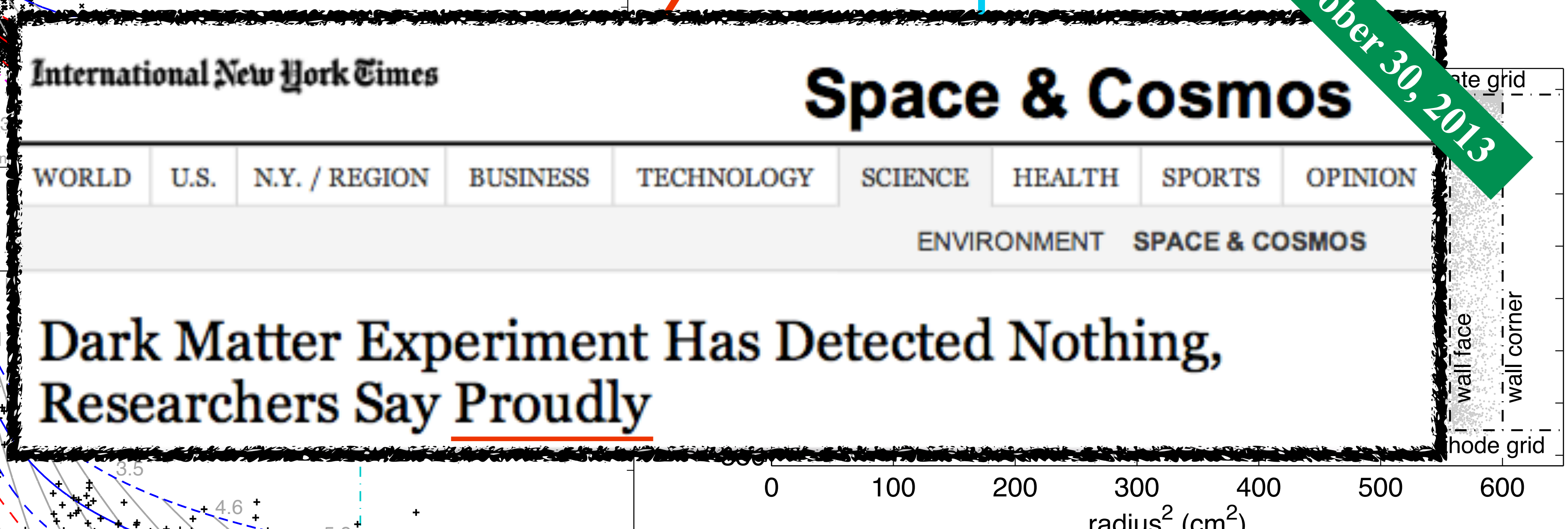


Electron recoil calibration (ER)

Nuclear recoil calibration (NR)

Fiducial volume

October 30, 2013



International New York Times

Space & Cosmos

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

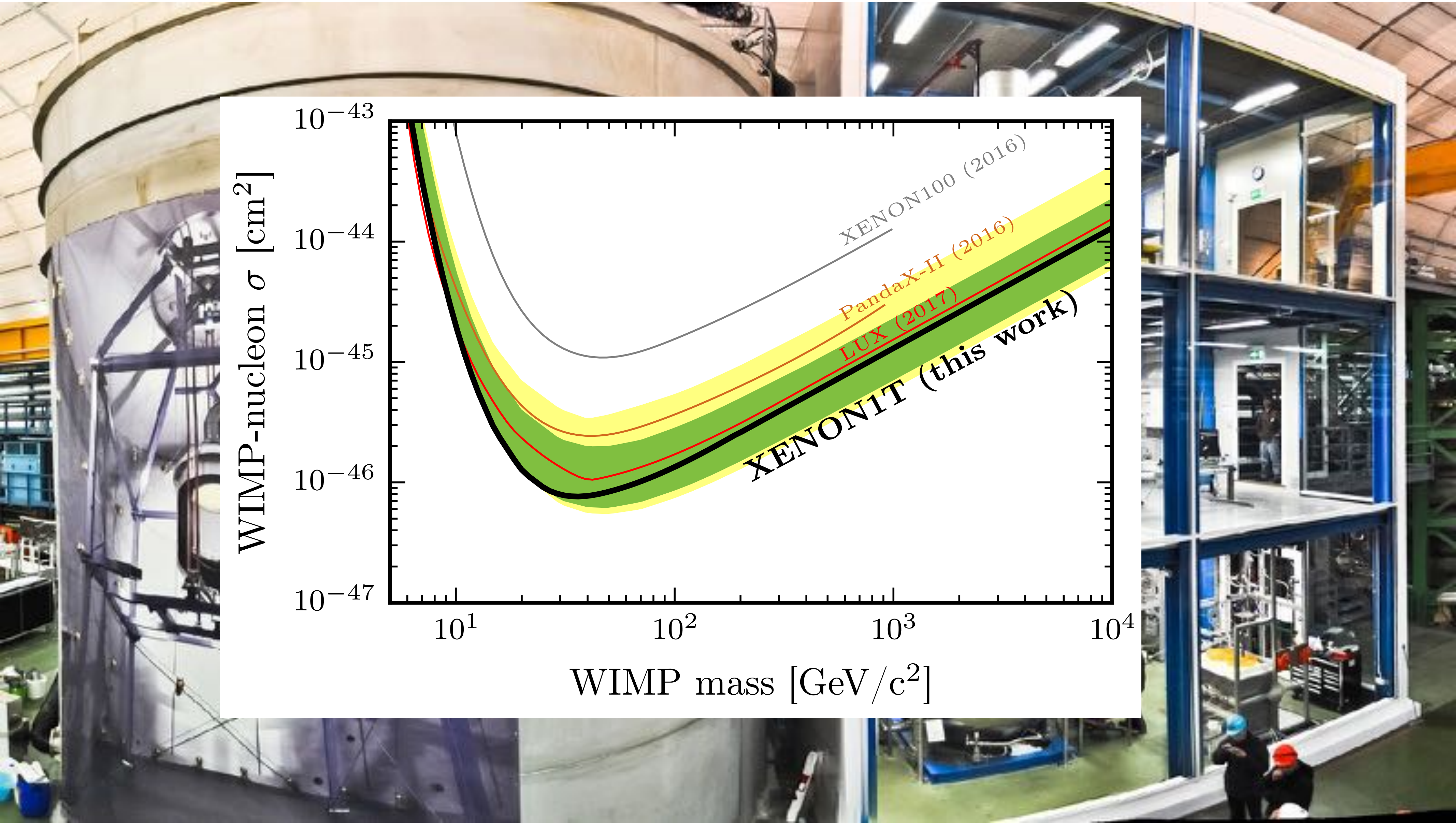
ENVIRONMENT | SPACE & COSMOS

Dark Matter Experiment Has Detected Nothing, Researchers Say Proudly

160 events observed in the fiducial volume:
- all consistent with electron recoils.
- 0.64 expected below NR mean.

Xenon 1T

- 2 Tons, 1 Ton fiducial. Taking data



Where are we going?

- Experiments with mass larger than 20 tons are expected in the '20s.