DAMA: Signals from the Dark Universe

IAPS @ Gran Sasso, May 7th 2015

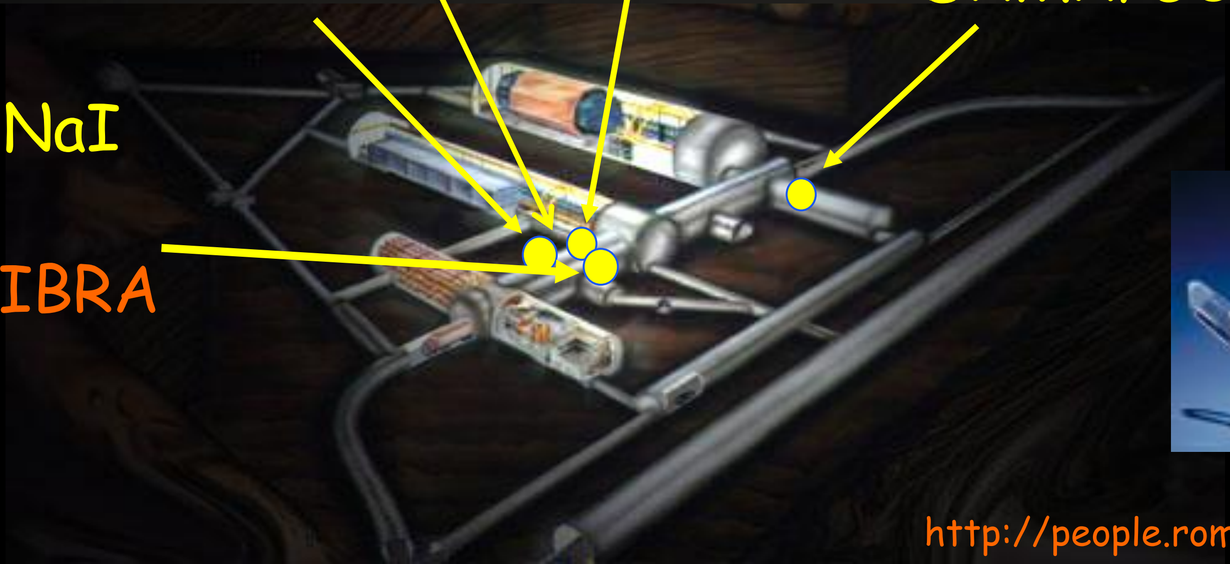
Vincenzo Caracciolo, LNGS

International Journal of Modern Physics A 28 (2013) 1330022 (**arXiv:1306.1411**)

Roma2,Roma1,LNGS,IHEP/Beijing

+ by-products and small scale expts.: INR-Kiev
+ in some studies on $\beta\beta$ decays (DST-MAE project): IIT - Ropar, India
+ neutron meas.: ENEA-Frascati

DAMA: an observatory for rare processes @LNGS



http://people.roma2.infn.it/dama

DAMA membership

Overall membership in the DAMA activities

Spokesperson: R. Bernabei

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+ in some by-product results and small scale experiments:

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+ in some studies on $\beta^+\beta^+$, EC/β^+, EC/EC decay modes (under the joint Indo-Italian DST-MAE project):

P.K. Raina, A.K. Singh,
P.K. Rath, A. Shukla
Indian Institute of Technology, Kharagpur, India.

+ in neutron measurements:

M. Angelone, P. Batistoni, M.Pillon
ENEA - C. R. Frascati, Italy

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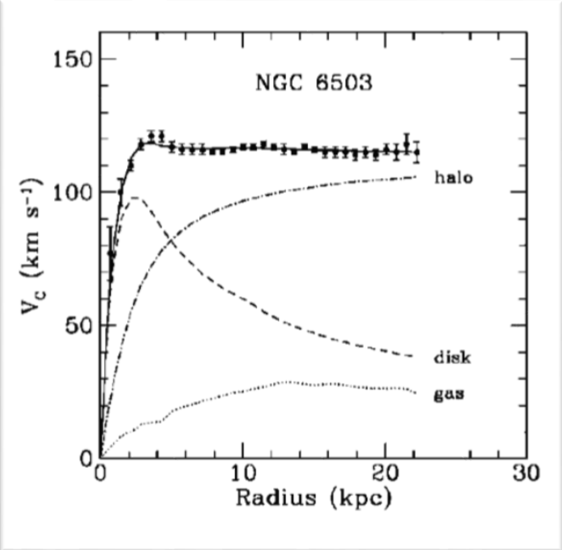
The Dark Side of the Universe: experimental evidences

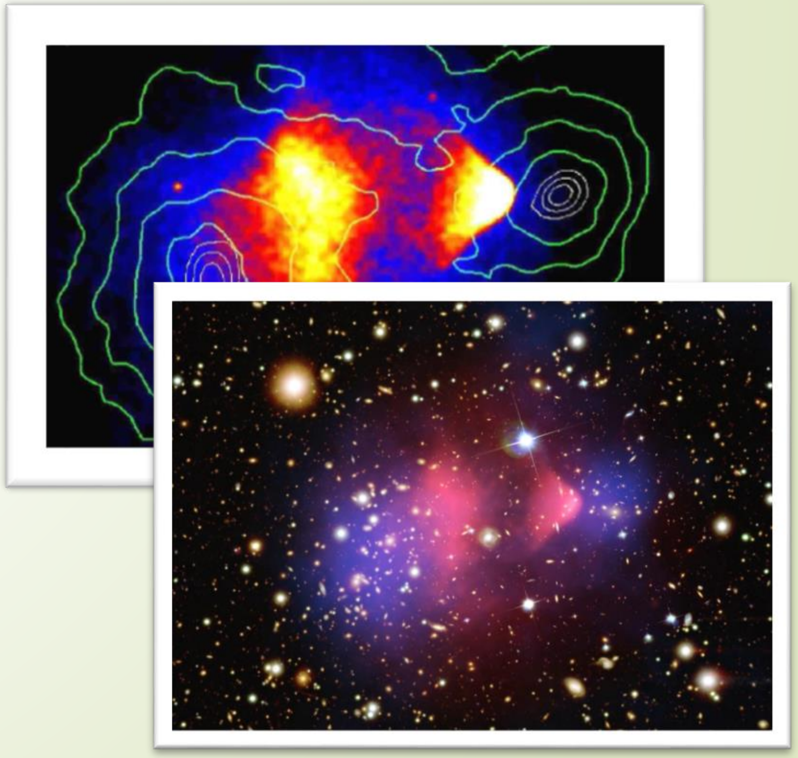
First evidence and confirmations:

1933 F. Zwicky: studying dispersion velocity of Coma galaxies
1936 S. Smith: studying the Virgo cluster
1974 two groups: systematical analysis of *mass density* vs *distance from center* in many galaxies



rotational curve of a spiral galaxy

bullet cluster



Other experimental evidences

- ✓ from LMC motion around Galaxy
- ✓ from X-ray emitting gases surrounding elliptical galaxies
- ✓ from hot intergalactic plasma velocity distribution in clusters
- ✓ …
- ✓ bullet cluster 1E0657-558

$M_{\text{visible Universe}} \ll M_{\text{gravitational effect}}$ ⇒ about 90% of the mass is **DARK**

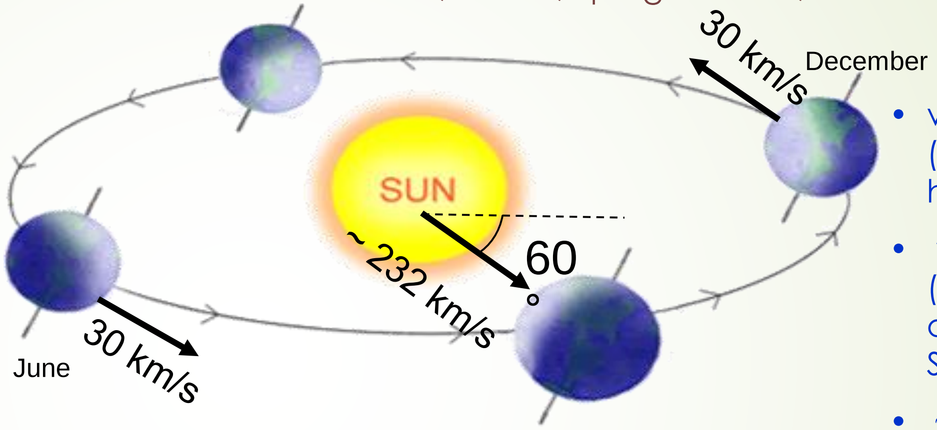
The annual modulation: a model independent signature for the investigation of DM particles component in the galactic halo

With the present technology, the annual modulation is the main model independent signature for the DM signal. Although the modulation effect is expected to be relatively small a suitable large-mass, low-radioactive set-up with an efficient control of the running conditions can point out its presence.

Requirements of the annual modulation

1) Modulated rate according cosine
2) In a definite low energy range
3) With a proper period (1 year)
4) With proper phase (about 2 June)
5) Just for single hit events in a multi-detector set-up
6) With modulation amplitude in the region of maximal sensitivity must be <7% for usually adopted halo distributions, but it can be larger in case of some possible scenarios

Drukier, Freese, Spergel PRD86; Freese et al. PRD88



- v_{sun} ~ 232 km/s (Sun vel in the halo)
- v_{orb} = 30 km/s (Earth vel around the Sun)
- $\gamma = \pi/3$, $\omega = 2\pi/T$, T = 1 year
- t_0 = 2nd June (when $v_\oplus$ is maximum)

$$v_\oplus(t) = v_{sun} + v_{orb} \cos\gamma \cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \cong S_{0,k} + S_{m,k} \cos[\omega(t-t_0)]$$

the DM annual modulation signature has a different origin and peculiarities (e.g. the phase) than those effects correlated with the seasons

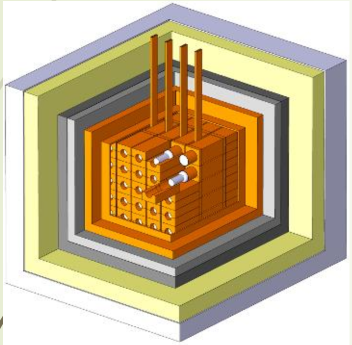
To mimic this signature, spurious effects and side reactions must not only - obviously - be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

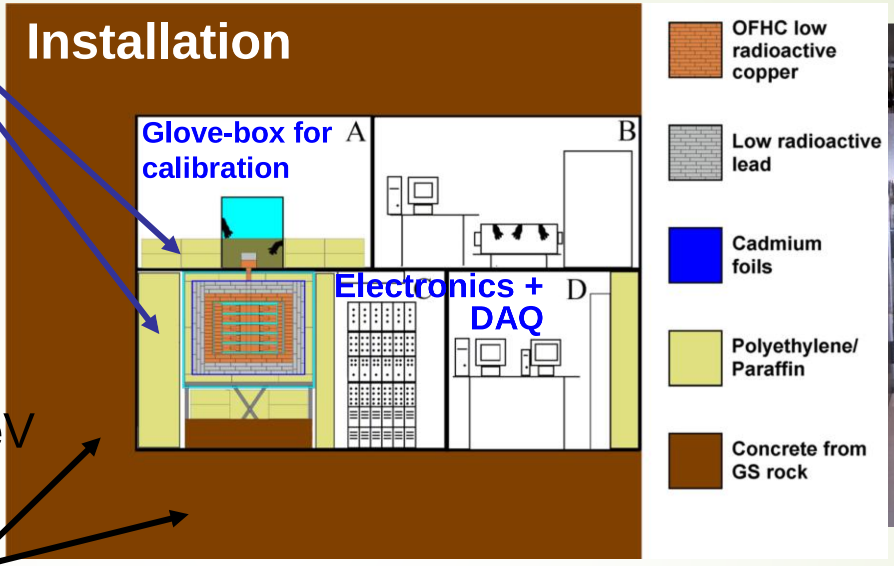
The DAMA/LIBRA set-up

For details, radiopurity, performances, procedures, etc.
NIMA592(2008)297

Polyethylene/paraffin

- 25 x 9.7 kg NaI(Tl) in a 5x5 matrix
- two Suprasil-B light guides directly coupled to each bare crystal
- two PMTs working in coincidence at the single ph. el. threshold





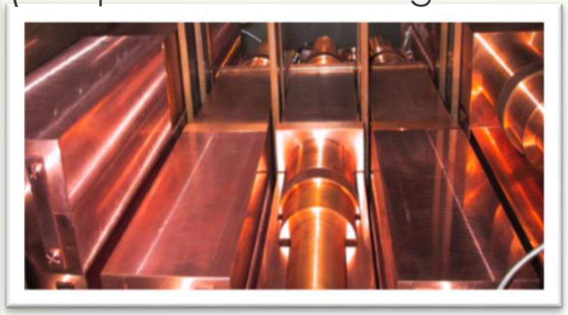
5.5-7.5 phe/keV

~ 1m concrete from GS rock

- Dismounting/Installing protocol (with "Scuba" system)
- All the materials selected for low radioactivity
- Multicomponent passive shield (>10 cm of Cu, 15 cm of Pb + Cd foils, 10/40 cm Polyethylene/paraffin, about 1 m concrete, mostly outside the installation)
- Three-level system to exclude Radon from the detectors
- Calibrations in the same running conditions as production runs
- Installation in air conditioning + huge heat capacity of shield
- Monitoring/alarm system; many parameters acquired with the production data
- Pulse shape recorded by Waweform Analyzer Acqiris DC270 (2chs per detector), 1 *Gsample/s*, 8 bit, bandwidth 250 MHz
- Data collected from low energy up to MeV region, despite the hardware optimization was done for the low energy

The DAMA/LIBRA set-up ~250 kg NaI(Tl) (Large sodium Iodide Bulk for RAre processes)

As a result of a 2nd generation R&D for more radiopure NaI(Tl) by exploiting new chemical/physical radiopurification techniques
(all operations involving - including photos - in HP Nitrogen atmosphere)



- 25 x 9.7 kg NaI(Tl) in a 5x5 matrix
- two Suprasil-B light guides directly coupled to each bare crystal
- two PMTs working in coincidence at the single ph. el. threshold

Residual contaminations in the new DAMA/LIBRA NaI(Tl) detectors: ^{232}Th, ^{238}U and ^{40}K at level of 10^{-12} g/g

The signal from only one crystal in anti-coincidence with each others is a candidate-signal to study for our purpose. We say single-hit event.
In this way the crystals work also as an active shield.

- Radiopurity, performances, procedures, etc.: NIMA592(2008)297, JINST 7 (2012) 03009
- Results on DM particles, Annual Modulation Signature: EPJC56(2008)333, EPJC67(2010)39, EPJC73(2013)2648.
  Related results: PRD84(2011)055014, EPJC72(2012)2064, IJMPA28(2013)1330022, EPJC74(2014)2827, EPJC74(2014)3196
- Results on rare processes: PEP violation: EPJC62(2009)327; CNC in I: EPJC72(2012)1920; IPP in ^{241}Am decay: EPJA49(2013)64

Calibration procedures

Complete DAMA/LIBRA-phase1

	Period	Mass (kg)	Exposure (kg×day)	$(\alpha - \beta^2)$
DAMA/LIBRA-1	Sept. 9, 2003 - July 21, 2004	232.8	51405	0.562
DAMA/LIBRA-2	July 21, 2004 - Oct. 28, 2005	232.8	52597	0.467
DAMA/LIBRA-3	Oct. 28, 2005 - July 18, 2006	232.8	39445	0.591
DAMA/LIBRA-4	July 19, 2006 - July 17, 2007	232.8	49377	0.541
DAMA/LIBRA-5	July 17, 2007 - Aug. 29, 2008	232.8	66105	0.468
DAMA/LIBRA-6	Nov. 12, 2008 - Sept. 1, 2009	242.5	58768	0.519
DAMA/LIBRA-7	Sep. 1, 2009 - Sept. 8, 2010	242.5	62098	0.515
DAMA/LIBRA–phase1	Sept. 9, 2003 - Sept. 8, 2010		379795 ≃ 1.04 ton×yr	0.518
DAMA/NaI + DAMA/LIBRA–phase1:			1.33 ton×yr	

a ton × yr experiment? done

- EPJC56(2008)333
- EPJC67(2010)39
- EPJC73(2013)2648

- calibrations: ≈96 M events from sources
- acceptance window eff: 95 M events (≈3.5 M events/keV)

- First upgrade on Sept 2008:
  - replacement of some PMTs in HP N_2 atmosphere
  - restore 1 detector to operation
  - new Digitizers installed (U1063A Acqiris 1GS/s 8-bit High-Speed cPCI)
  - new DAQ system with optical read-out installed

START of DAMA/LIBRA – phase 2

- Second upgrade on Oct./Nov. 2010
- ✧ Replacement of all the PMTs with higher Q.E. ones from dedicated developments
- ✧ Goal: lowering the software energy threshold

Fall 2012: new preamplifiers installed + special trigger modules. Other new components in the electronic chain in development

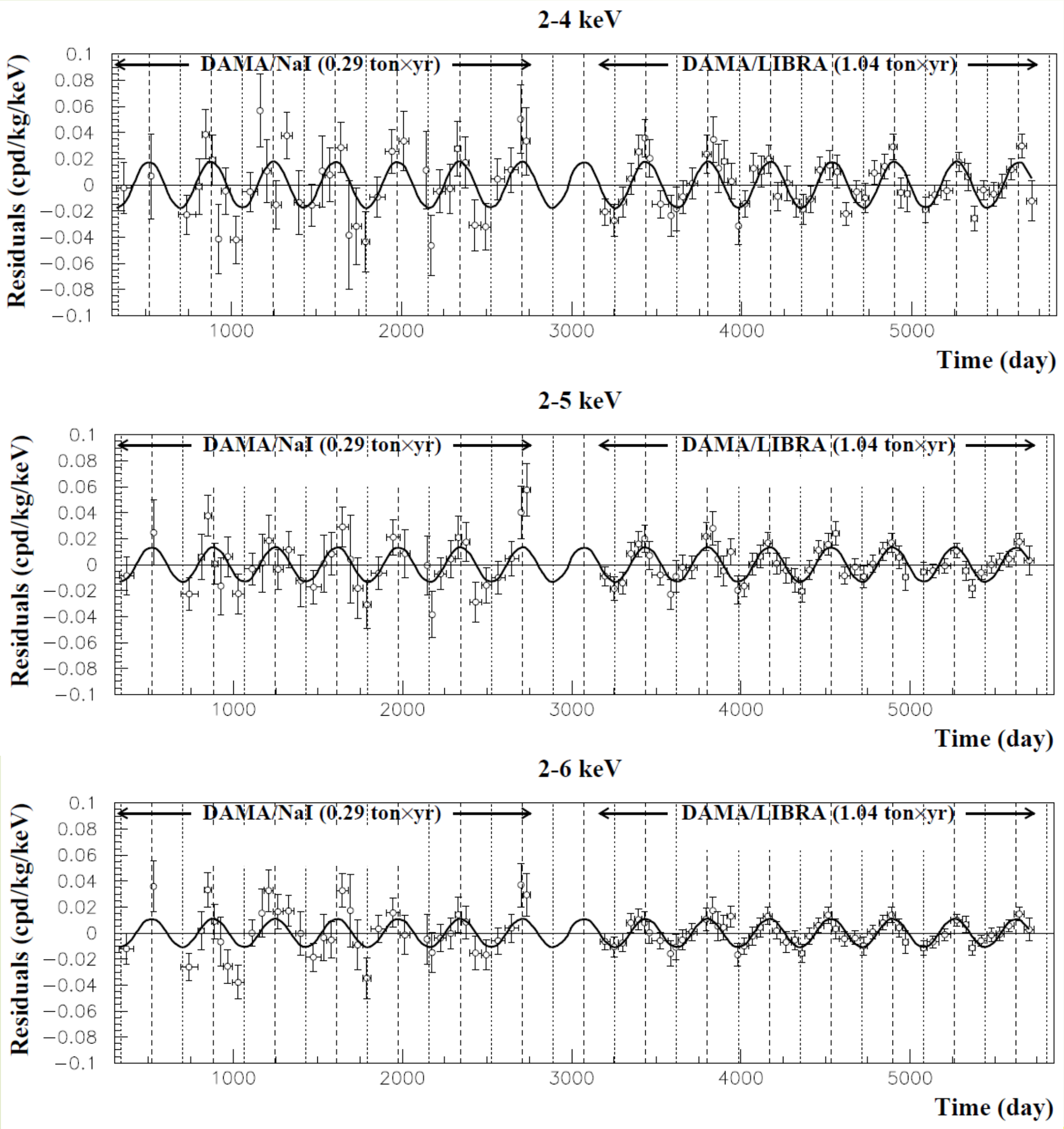
... continuously running

Model Independent DM Annual Modulation Result

experimental residuals of the single-hit scintillation events rate vs time and energy

DAMA/NaI + DAMA/LIBRA-phase1

Total exposure: 487526 kg×day = 1.33 ton×yr



$A\cos[\omega(t-t_0)]$;

continuous lines: t_0 = 152.5 d, T = 1.00 y

2-4 keV

A=(0.0179±0.0020) cpd/kg/keV

χ^2/dof = 87.1/86 **9.0 σ C.L.**

Absence of modulation? No

χ^2/dof=169/87 ⇒ P(A=0) = 3.7×10^{-7}

2-5 keV

A=(0.0135±0.0015) cpd/kg/keV

χ^2/dof = 68.2/86 **9.0 σ C.L.**

Absence of modulation? No

χ^2/dof=152/87 ⇒ P(A=0) = 2.2×10^{-5}

2-6 keV

A=(0.0110±0.0012) cpd/kg/keV

χ^2/dof = 70.4/86 **9.2 σ C.L.**

Absence of modulation? No

χ^2/dof=154/87 ⇒ P(A=0) = 1.3×10^{-5}

The data favor the presence of a modulated behavior with proper features at 9.2σ C.L.

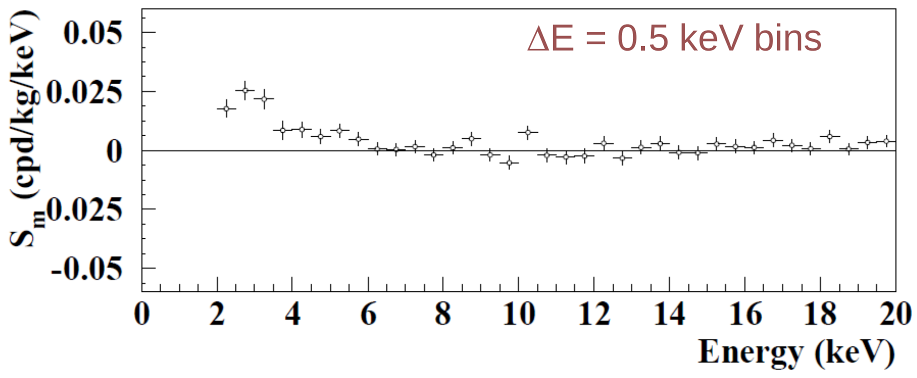
Model Independent Annual Modulation Result

DAMA/NaI + **DAMA/LIBRA-phase1** Total exposure: 487526 kg×day = **1.33 ton×yr**

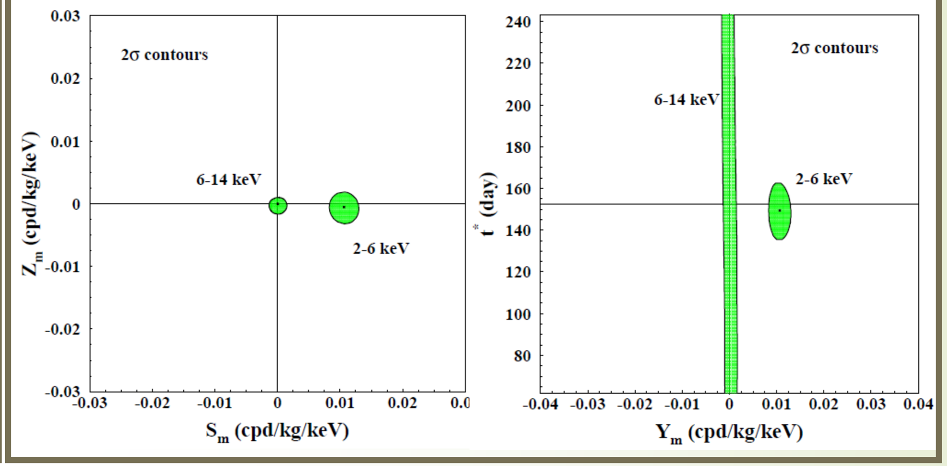
EPJC 56(2008)333, EPJC 67(2010)39, EPJC 73(2013)2648

$$R(t) = S_0 + S_m \cos[\omega(t - t_0)]$$

here $T = 2\pi/\omega = 1$ yr and $t_0 = 152.5$ day



$$R(t) = S_0 + S_m \cos[\omega(t - t_0)] + Z_m \sin[\omega(t - t_0)] = S_0 + Y_m \cos[\omega(t - t^*)]$$



- No modulation above 6 keV
- No modulation in the whole energy spectrum
- No modulation in the 2-6 keV multiple-hit events

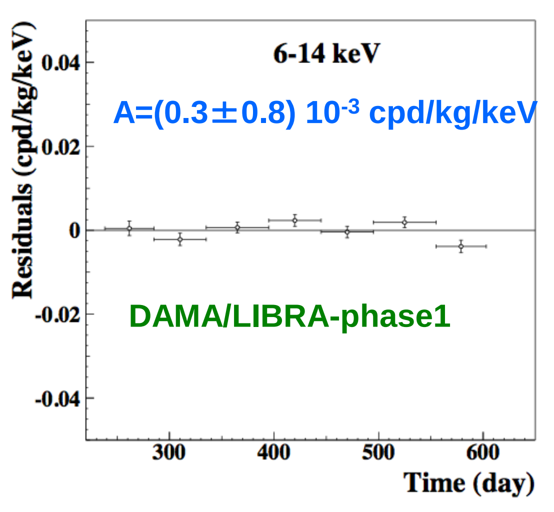
No systematics or side processes able to quantitatively account for the measured modulation amplitude and to simultaneously satisfy the many peculiarities of the signature are available.

✓ Compatibility with many low and high mass DM candidates, interaction types and astrophysical scenarios, and in particular with recent positive model dependent hints from direct or indirect searches

✓ No other experiment exists whose result can be – at least in principle – directly compared in a model-independent way with those by DAMA/NaI & DAMA/LIBRA-phase1

Rate behaviour above 6 keV

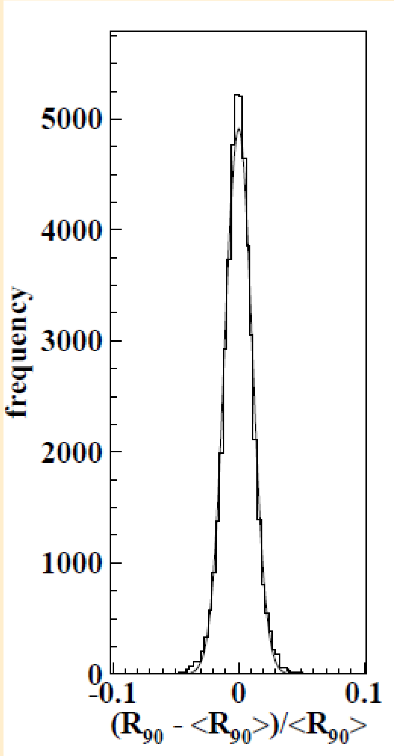
- **No Modulation above 6 keV**



Mod. Ampl. (6-10 keV): cpd/kg/keV	
(0.0016 ± 0.0031)	DAMA/LIBRA-1
-(0.0010 ± 0.0034)	DAMA/LIBRA-2
-(0.0001 ± 0.0031)	DAMA/LIBRA-3
-(0.0006 ± 0.0029)	DAMA/LIBRA-4
-(0.0021 ± 0.0026)	DAMA/LIBRA-5
(0.0029 ± 0.0025)	DAMA/LIBRA-6
-(0.0023 ± 0.0024)	DAMA/LIBRA-7

→ statistically consistent with zero

DAMA/LIBRA-phase1



σ ≈ 1%, fully accounted by statistical considerations

- **No modulation in the whole energy spectrum:**
  studying integral rate at higher energy, R_{90}
  - R_{90} percentage variations with respect to their mean values for single crystal in the DAMA/LIBRA running periods
  - Fitting the behaviour with time, adding a term modulated with period and phase as expected for DM particles:

Period	Mod. Ampl.
DAMA/LIBRA-1	-(0.05±0.19) cpd/kg
DAMA/LIBRA-2	-(0.12±0.19) cpd/kg
DAMA/LIBRA-3	-(0.13±0.18) cpd/kg
DAMA/LIBRA-4	(0.15±0.17) cpd/kg
DAMA/LIBRA-5	(0.20±0.18) cpd/kg
DAMA/LIBRA-6	-(0.20±0.16) cpd/kg
DAMA/LIBRA-7	-(0.28±0.18) cpd/kg

consistent with zero

+ if a modulation present in the whole energy spectrum at the level found in the lowest energy region → R_{90} ~ tens cpd/kg → ~ 100 σ far away

No modulation above 6 keV
This accounts for all sources of bckg and is consistent with the studies on the various components

Multiple-hits events in the region of the signal

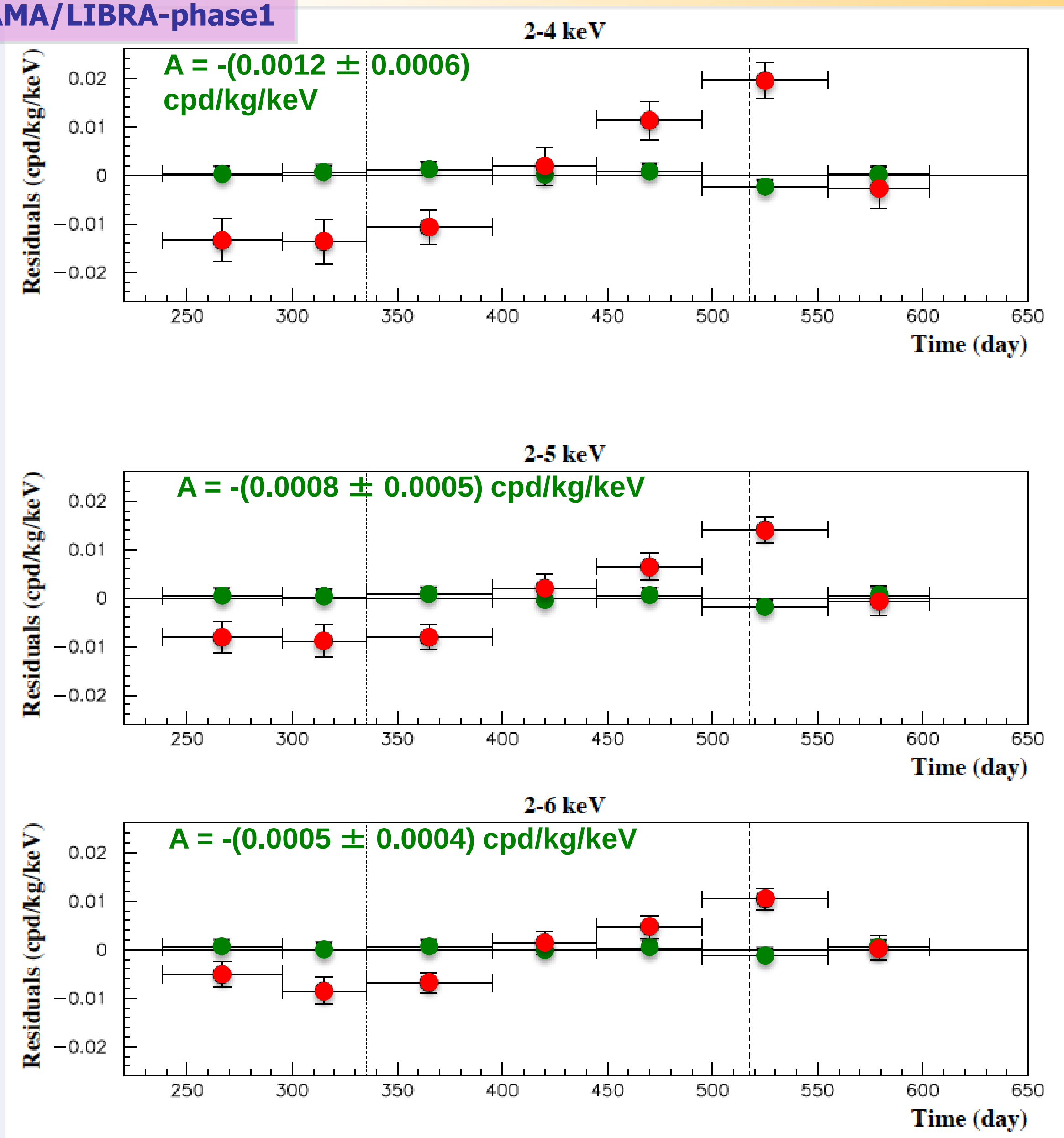
DAMA/LIBRA-phase1

- Each detector has its own TDs read-out → pulse profiles of *multiple-hits* events (multiplicity > 1) acquired (exposure: 1.04 ton×yr).
- The same hardware and software procedures as those followed for *single-hit* events

signals by Dark Matter particles do not belong to *multiple-hits* events, that is:

multiple-hits events = Dark Matter particles events "switched off"

Evidence of annual modulation with proper features as required by the DM annual modulation signature:
- present in the ***single-hit*** residuals
- absent in the ***multiple-hits*** residual



This result offers an additional strong support for the presence of Dark Matter particles in the galactic halo, further excluding any side effect either from hardware or from software procedures or from background

Summary of the results obtained in the additional investigations of possible systematics or side reactions – DAMA/LIBRA-phase1

(NIMA592(2008)297, EPJC56(2008)333, J. Phys. Conf. ser. 203(2010)012040, arXiv:0912.0660, S.I.F.Atti Conf.103(211), Can. J. Phys. 89 (2011) 11, Phys.Proc.37(2012)1095, EPJC72(2012)2064, arxiv:1210.6199 & 1211.6346, IJMPA28(2013)1330022)

Source	Main comment	Cautious upper limit (90%C.L.)
RADON	Sealed Cu box in HP Nitrogen atmosphere, 3-level of sealing, etc.	$<2.5\times10^{-6}$ 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	$<1\text{-}2\times10^{-4}$ 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	$<3\times10^{-5}$ cpd/kg/keV

+ they cannot satisfy all the requirements of annual modulation signature

Thus, they cannot mimic the observed annual modulation effect

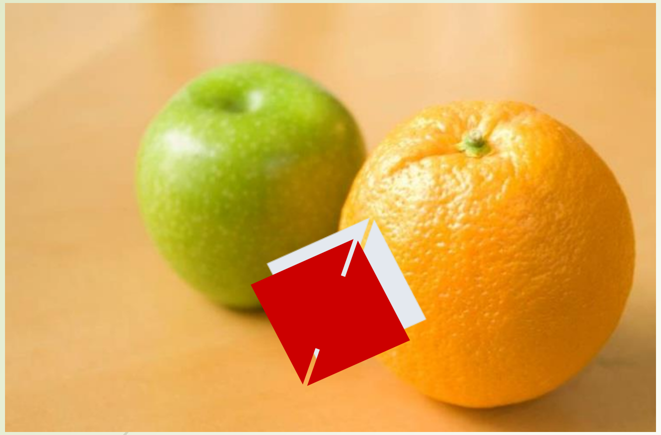
Model-independent evidence by DAMA/NaI and DAMA/LIBRA

well compatible with several candidates (in many possible astrophysical, nuclear and particle physics scenarios)

- Neutralino as LSP in various SUSY theories
- Various kinds of WIMP candidates with several different kind of interactions Pure SI, pure SD, mixed + Migdal effect +channeling,… (from low to high mass)
- a heavy ν of the 4-th family
- Pseudoscalar, scalar or mixed light bosons with axion-like interactions
- WIMP with preferred inelastic scattering
- Mirror Dark Matter
- Light Dark Matter
- Self interacting Dark Matter
- Dark Matter (including some scenarios for WIMP) electron-interacting
- Sterile neutrino
- heavy exotic canditates, as "4th family atoms", ...
- Elementary Black holes such as the Daemons
- Kaluza Klein particles
- … and more

Possible model dependent positive hints from indirect searches (but interpretation, evidence itself, derived mass and cross sections depend e.g. on bckg modeling, on DM spatial velocity distribution in the galactic halo, etc.) **not in conflict with DAMA results;**

Available results from direct searches using different target materials and approaches do not give any robust conflict & compatibility with positive excesses



About interpretation

See e.g.: Riv.N.Cim.26 n.1(2003)1, IJMPD13(2004)2127, EPJC47(2006)263, IJMPA21(2006)1445, EPJC56(2008)333, PRD84(2011)055014, IJMPA28(2013)1330022

…models…

- Which particle?
- Which interaction coupling?
- Which Form Factors for each target-material?
- Which Spin Factor?
- Which nuclear model framework?
- Which scaling law?
- Which halo model, profile and related parameters?
- Streams?
- ...

…and experimental aspects…

- Exposures
- Energy threshold
- Detector response (phe/keV)
- Energy scale and energy resolution
- Calibrations
- Stability of all the operating conditions.
- Selections of detectors and of data.
- Subtraction/rejection procedures and stability in time of all the selected windows and related quantities
- Efficiencies
- Definition of fiducial volume and non-uniformity
- Quenching factors, channeling, …
- …

Uncertainty in experimental parameters, as well as necessary assumptions on various related astrophysical, nuclear and particle-physics aspects, affect all the results at various extent, both in terms of exclusion plots and in terms of allowed regions/volumes. Thus comparisons with a fixed set of assumptions and parameters' values are intrinsically strongly uncertain.

No experiment can be directly compared in model independent way with DAMA

Signal rate in a given scenario

Eur. Phys. J. C 73 (2013) 2276

As a consequence of the ***light response***, recoil nuclei induced by the considered DM candidates could be discriminated from the background thanks to the expected variation of their low energy distribution along the year (or day)

The expected signal counting rate in the energy window (E1,E2) is a function of the time *t*

(i.e. of Type equation here. $v_d(t)$ the **detector velocity in the galactic rest frame**)

$$R(E_1,E_2,t)=\int d^3\vec{v}\int d\Omega_{cm}\frac{\xi\rho_0 N_n}{m_{DM}}\left|\vec{v}\right| f[\vec{v}+\vec{v}_d(t)]\frac{d\sigma_n}{d\Omega_{cm}}\frac{1}{2}\left[erf\left(\frac{q_n(\Omega_{out})E_n-E_1}{\sqrt{2}\Delta}\right)-erf\left(\frac{q_n(\Omega_{out})E_n-E_2}{\sqrt{2}\Delta}\right)\right]$$

DM particle velocity in the laboratory frame

local DM halo density

number of target-nuclei (n) per mass unit

differential cross section in the c.m. frame

quenching factor, it depends on Ω_{out} the output direction of the nuclear recoil in the lab frame

recoiling nucleus kinetic energy in the laboratory frame

nuclear recoil direction in the center of mass frame

DM particle mass

DM velocity distribution in the galactic rest frame

detector energy resolution

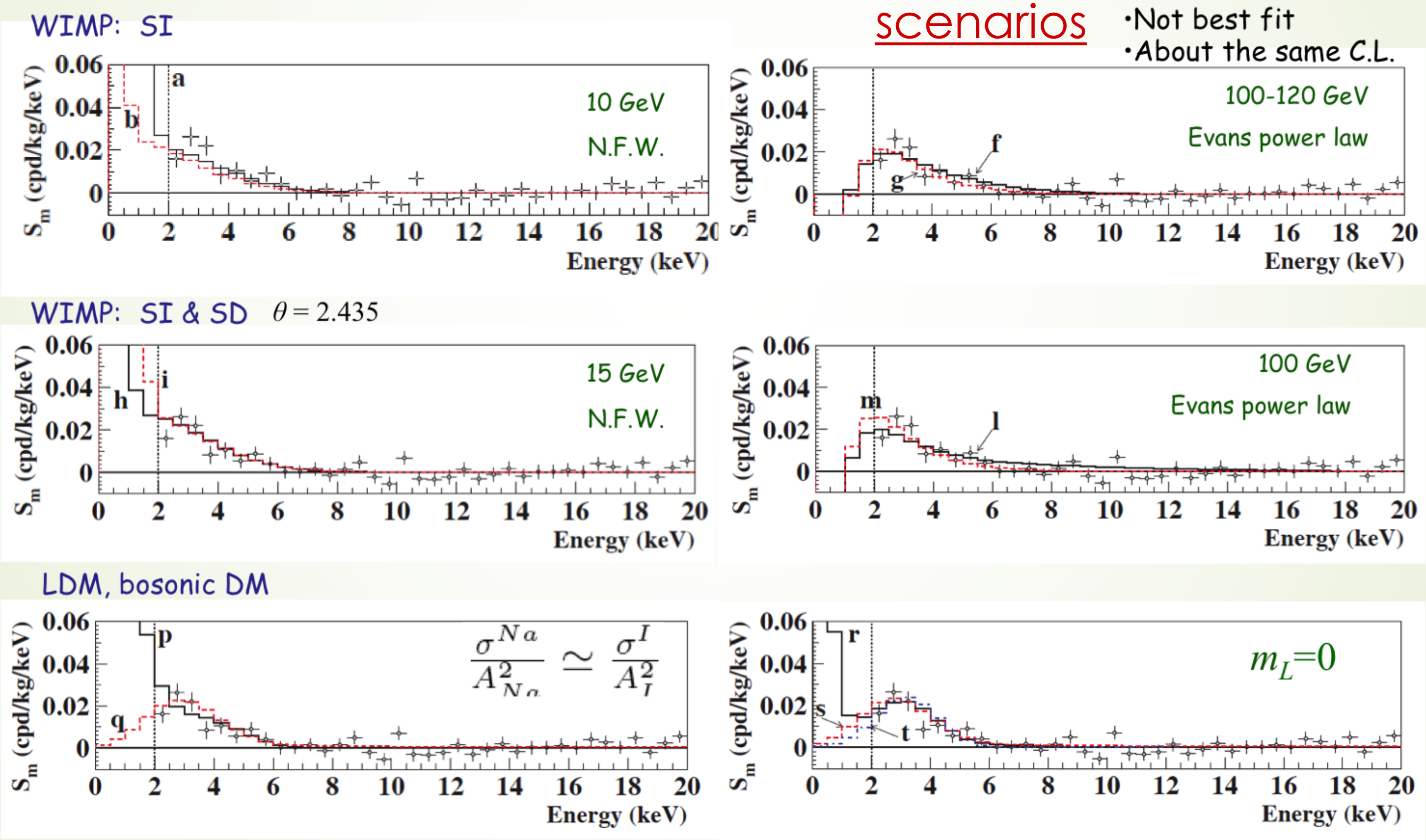
NB: Many quantities are model dependent and a model framework has to be fixed
In this example, for simplicity, a set of assumptions and of values have been fixed, without considering the effect of the existing uncertainties on each one of them

Model-independent evidence by DAMA/NaI and DAMA/LIBRA

well compatible with several candidates in many astrophysical, nuclear and particle physics scenarios

Just few <u>examples</u> of interpretation of the annual modulation in terms of candidate particles in <u>some</u> <u>scenarios</u>

- Not best fit
- About the same C.L.



Compatibility with several candidates; other ones are open

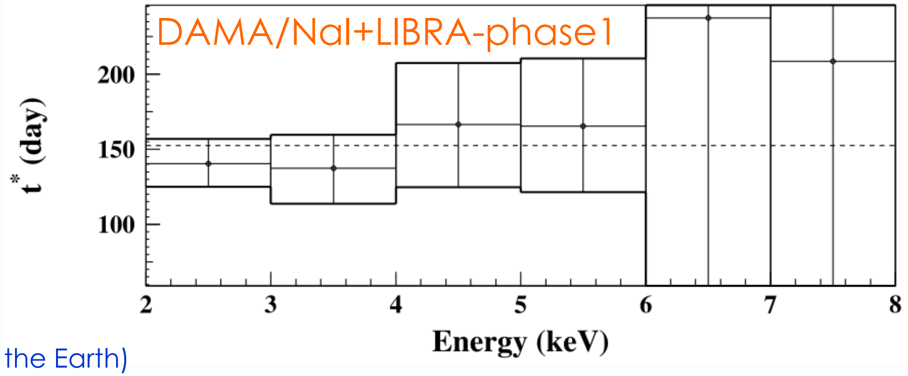
EPJC56(2008)333
IJMPA28(2013)1330022

The second orders effects to be investigated by DAMA/LIBRA-phase2

The importance of studying second order effects and the annual modulation phase

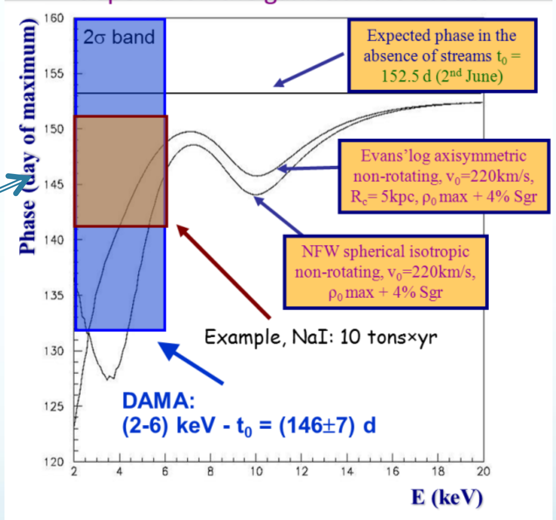
High exposure and lower energy threshold can allow further investigation on:

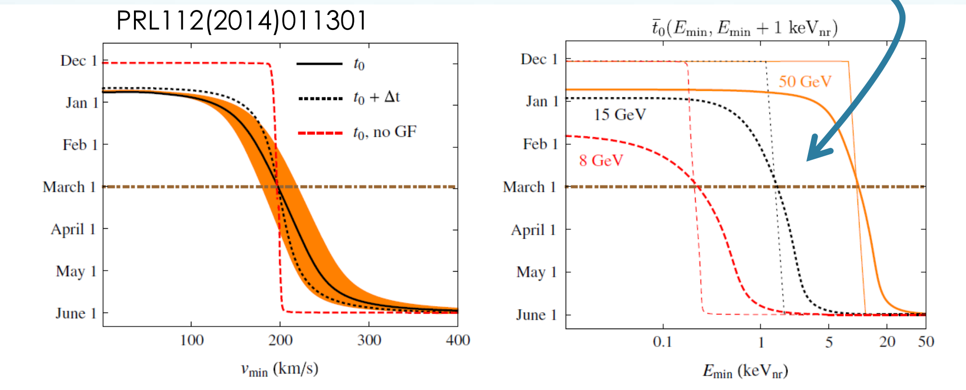
- the nature of the DM candidates
  - ✓ to disentangle among the different astrophysical, nuclear and particle physics models (nature of the candidate, couplings, inelastic interaction, form factors, spin-factors …)
  - ✓ scaling laws and cross sections
  - ✓ multi-component DM particles halo?
- possible diurnal effects on the sidereal time
  - ✓ expected in case of high cross section DM candidates (shadow of the Earth)
  - ✓ due to the Earth rotation velocity contribution (it holds for a wide range of DM candidates)
  - ✓ due to the channeling in case of DM candidates inducing nuclear recoils.
- astrophysical models
  - ✓ velocity and position distribution of DM particles in the galactic halo, possibly due to:
    - satellite galaxies (as Sagittarius and Canis Major Dwarves) tidal “streams”;
    - caustics in the halo;
    - gravitational focusing effect of the Sun enhancing the DM flow (“spike“ and “skirt”);
    - possible structures as clumpiness with small scale size
    - Effects of gravitational focusing of the Sun



The annual modulation phase depends on :
- Presence of streams (as SagDEG and Canis Major) in the Galaxy
- Presence of caustics
- Effects of gravitational focusing of the Sun

The effect of the streams on the phase depends on the galactic halo model





A step towards such investigations:

➔**DAMA/LIBRA-phase2**

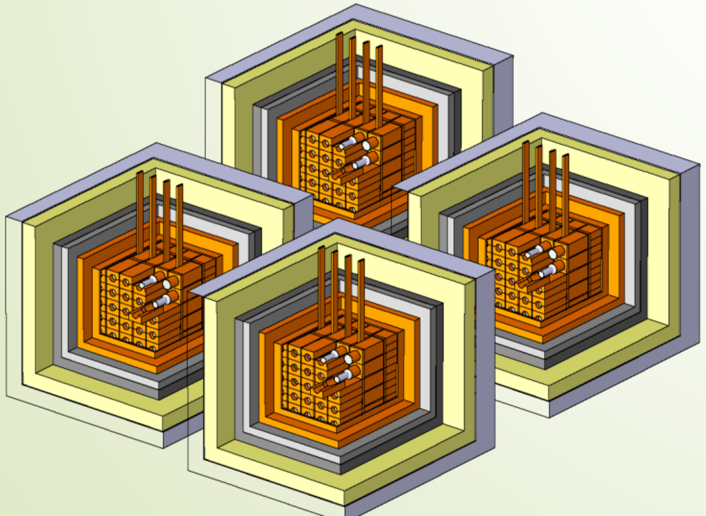
with lower energy threshold and larger exposure

Further developments for DAMA/LIBRA: The strong interest in the low energy range suggests the possibility of a new development of high Q.E. PMTs with increased radiopurity to directly couple them to the DAMA/LIBRA crystals (possible phase3), removing the special quartz light guides which act also as optical window obtaining an ultimate number of ph.e./keV.

The possible multi-purpose full sensitive mass DAMA/1ton

1) Proposed since 1996 (DAMA/NaI and DAMA/LIBRA intermediate steps+some R&D and POR fellowships)
2) Technology largely at hand and still room for further improvements in the low-background characteristics of the set-up (NaI(Tl) crystals, PMTs, shields, etc.)
3) 1 ton detector: the cheapest, the highest duty cycle, the clear signature, fast realization in few years

Design: DAMA/1 ton can be realized by adding 3 replicas of DAMA/LIBRA:

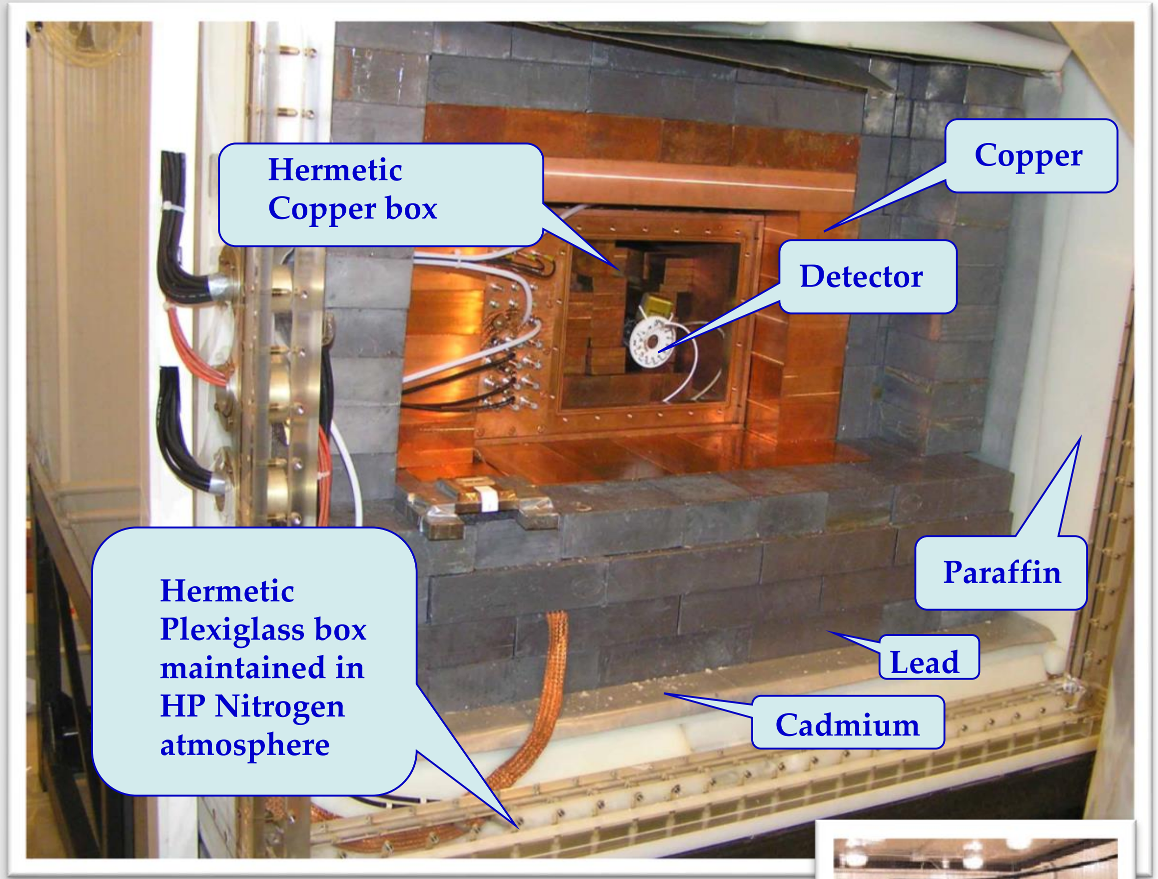


- the detectors of similar size than those already used
- the features of low-radioactivity of the set-up and of all the used materials would be assured by many years of experience in the field
- electronic chain and controls would profit by the previous experience and by the use of compact devices already developped, tested and used.
- new digitizers will offer high expandibility and high performances
- the daq can be a replica of that of DAMA/LIBRA

- **Some R&Ds carried out**

DAMA/Ge and STELLA

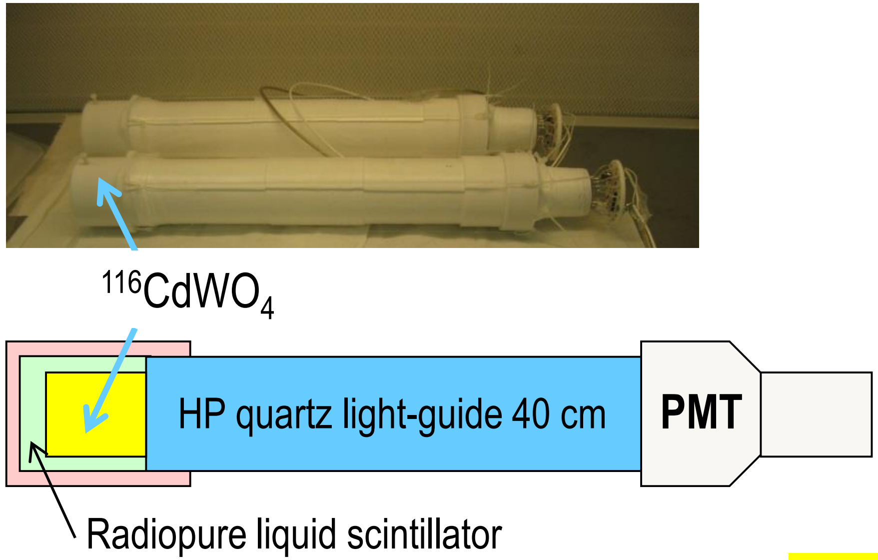
DAMA/R&D

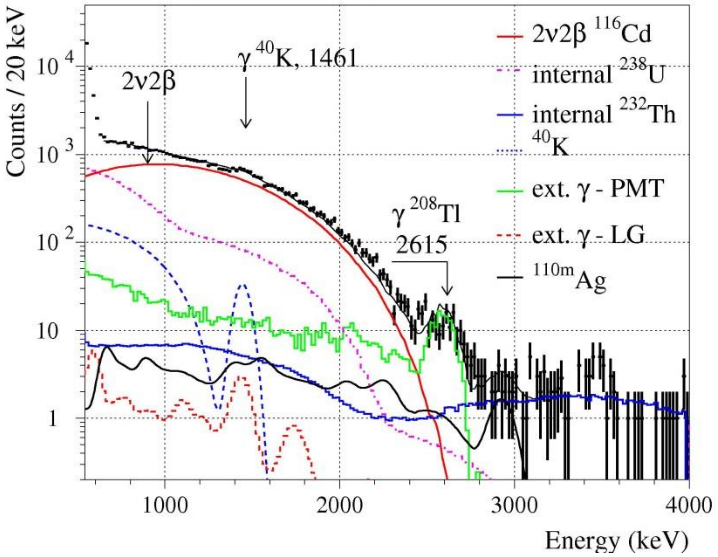


Materiale	^{238}U (ppb)	^{232}Th (ppb)	^{nat}K (ppm)
Cu	< 0.5	< 1	< 0.6
Pb boliden	< 8	< 0.03	< 0.06
Pb boliden2	< 3.6	< 0.027	< 0.06
Polish Pb	< 7.4	< 0.042	< 0.03
Polietilene	< 0.3	< 0.7	< 2
Plexiglass	< 0.64	< 27.2	< 3.3

AURORA: Investigation of double β decay of ^{116}Cd

Experiment is going with two radiopure high quality $^{116}CdWO_4$ (1.176 kg) enriched in ^{116}Cd to 82%. After a few improvement of the set-up the FWHM (at $Q_{2\beta}$ of ^{116}Cd) = 5.2%, background in the ROI ≈ 0.1 cnt/(keV yr kg) (we have 17656 h of data with the background level).

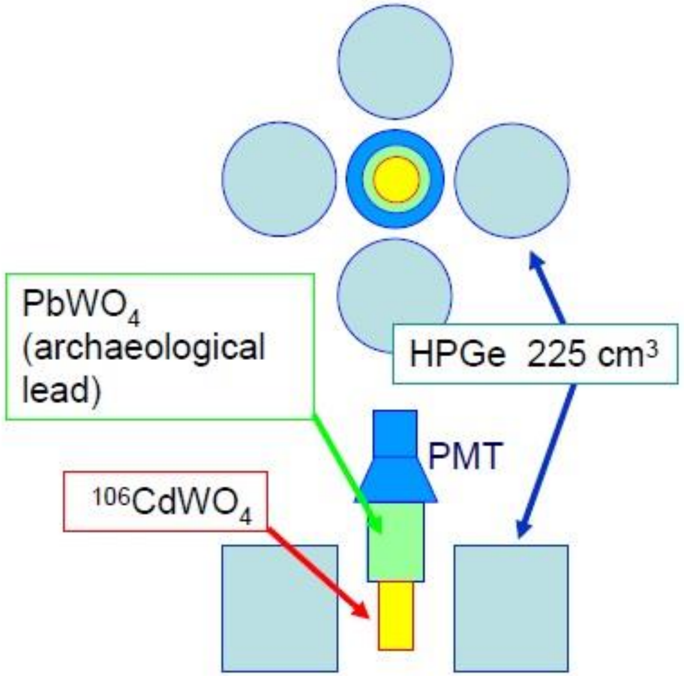




Energy spectrum accumulated over 8397 h after the last upgrade of the detector. The two neutrino decay of ^{116}Cd with the half-life ≈2.6×10^{19} y dominates in the background

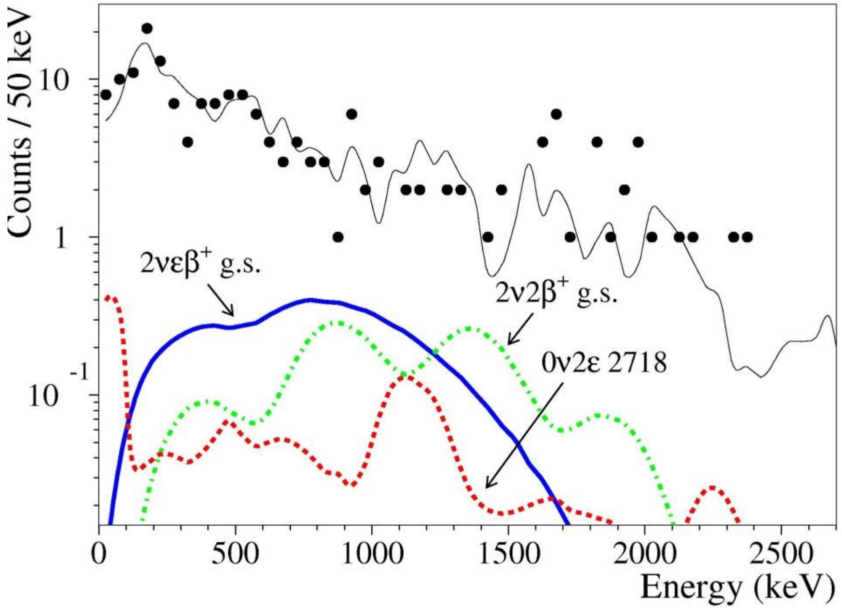
Our goals are to measure the $T_{1/2}^{2\nu 2\beta}$ with high (10-20%) accuracy and set new limits on different channels. Modes with majorons, transitions to the excited levels will be improved too. The experiment is in progress.

Search for double β processes in ^{106}Cd



Scheme of the experimental set-up

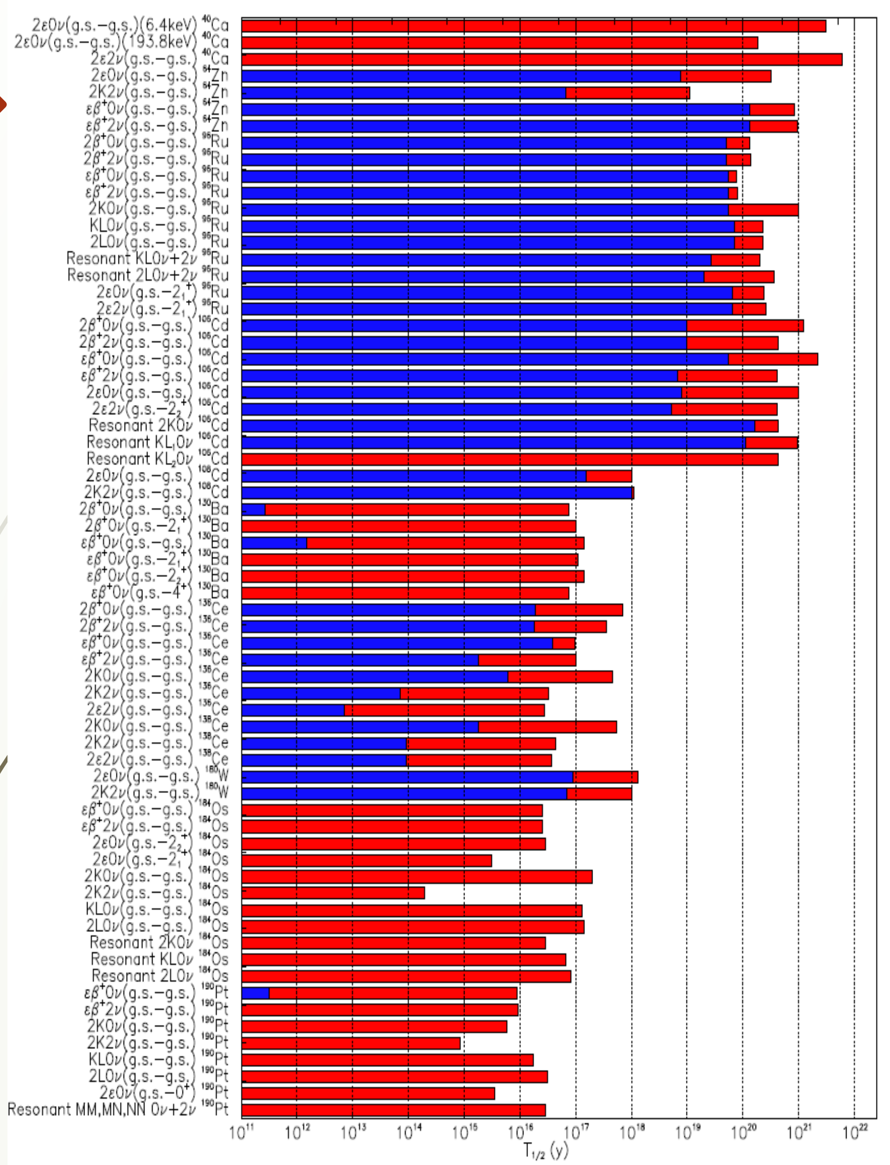
Experiment is finished 05 Feb 2015
Total statistic is 13085 h ≈1.49 yr

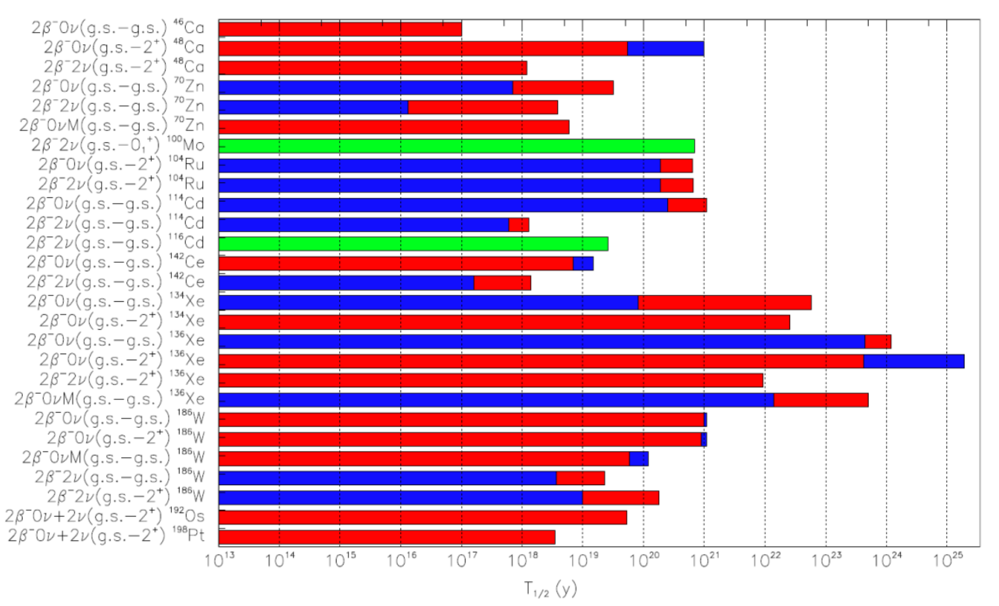


The energy spectrum of the $^{106}CdWO_4$ detector accumulated over 13085 h in coincidence with 511 keV annihilation γ quanta in the HPGe detectors (circles). The model of background is shown by solid line. The Monte Carlo simulated distributions of the $2\nu\varepsilon\beta^+$ and $2\nu2\beta^+$ decays, and the $0\nu2\varepsilon$ transition of ^{106}Cd to the 2718 keV excited level of ^{106}Pd excluded at 90% C.L. are shown.

Data analysis and paper preparation are in progress

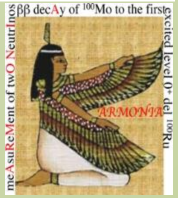
Summary of searches for ββ decay modes (partial list)





ARMONIA: New observation (green) of $2\nu2\beta^-$ $^{100}Mo \rightarrow {}^{100}Ru$ (g.s.$\rightarrow 0_1^+$) decay
NPA846 (2010)143

AURORA: New observation of $2\nu2\beta^-$ ^{116}Cd decay
NPAE2012



- Many competitive limits obtained on lifetime of $2\beta^+$, $\varepsilon\beta^+$ and 2ε processes (^{40}Ca, ^{64}Zn, ^{96}Ru, ^{106}Cd, ^{108}Cd, ^{130}Ba, ^{136}Ce, ^{138}Ce, ^{180}W, ^{190}Pt, ^{136}Xe…).
- Some limits on $2\beta^-$ modes in ^{136}Xe are the presently best ones for this isotope
- First searches for resonant ββ decays in some isotopes

$T_{1/2}$ experimental limits by DAMA (in red) and previous ones (in blue). All the limits are at 90% C.L. except for $0\nu2\beta^+$ in ^{136}Ce and $2\beta^-0\nu$ in ^{142}Ce at 68% C.L.. In green observed!

Many publications on detectors developments and results
Many future measurements in preparation

DAMA/CRYS new small scale facility mainly dedicated to the characterization of new prototype detectors

1) At beginning of 2015 the measurement of a $ZnWO_4$ crystal produced by re-crystallization of the already tested $ZnWO_4$ crystal (aiming to estimate possible reduction in the trace contaminants) concluded.
2) The mechanical opening/closure system improved.
3) The cryogenic part (to allow measurements of the responses of variours scintillators as function of temperature) will be soon installed.
4) A new data taking with $CdWO_4$ crystal scintillator in progress, aiming the investigation of the decay schema of ^{113m}Cd.
5) Investigation of radioactive elements segregation in crystals to develop ultra-radio-pure scintillators for rare events experiments is continuing.

Investigation of ^{113m}Cd decay scheme

Experiments to study beta decay of ^{113m}Cd with the help of the $^{106}CdWO_4$ crystal scintillator (activity of ^{113m}Cd is ≈20 Bq) half-life and beta spectrum shape) started in DAMA/Crys

$^{106}CdWO_4$ crystal scintillator inside plastic light-guide filled by silicon oil viewed by two PMT through quartz guides in the DAMA/Crys shield

The goals of the experiment are measurements:

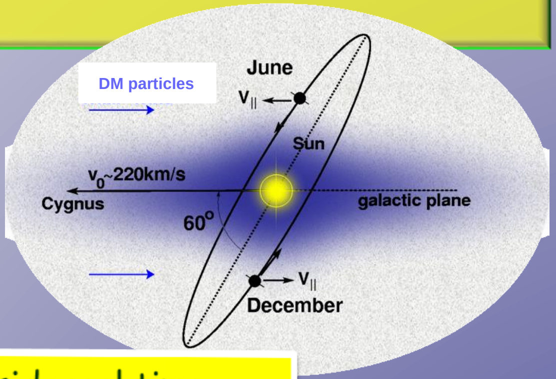
- the ^{113m}Cd half-life
- the beta spectra shape of ^{113m}Cd

By product: the background in the set-up will be estimated (for the future ^{106}Cd experiment)

Development of detectors with anisotropic response

Eur. Phys. J. C 73 (2013) 2276

Anisotropic detectors are of great interest for many applicative fields, e.g.:
⇒ they can offer a unique way to study directionality for Dark Matter candidates that induce nuclear recoils



Taking into account:
- the correlation between the direction of the nuclear recoils and the Earth motion in the galactic rest frame;
- the peculiar features of anisotropic detectors;

The detector response is expected to vary as a function of the sidereal time

Two strategies

Development of $ZnWO_4$ scintillators

- ✓ Both light output and pulse shape have anisotropic behavior and can provide two independent ways to study directionality
- ✓ Very high reachable radio-purity;
- ✓ Threshold at keV feasible;

Development of Carbon Nano Tubes (CNT) detectors

The detection principle is based on variation of the transport properties due to the particle irradiation

The intrinsic 1-D nature of CNTs makes them very promising for the study of directionality

- ➢ Spin-off and patents
- ➢ 3D detectors multi-wire chamber-like with nanotechnology
- ➢ Possible other applications:
  - ▪Particle Physics;
  - ▪Health Physics;
  - ▪etc..

THANKS FOR ATTENTION