

# Short Summary of Ongoing Research Activities of the DAMA Collaboration at LNGS

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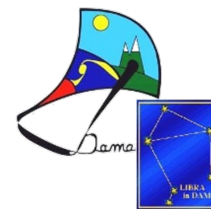
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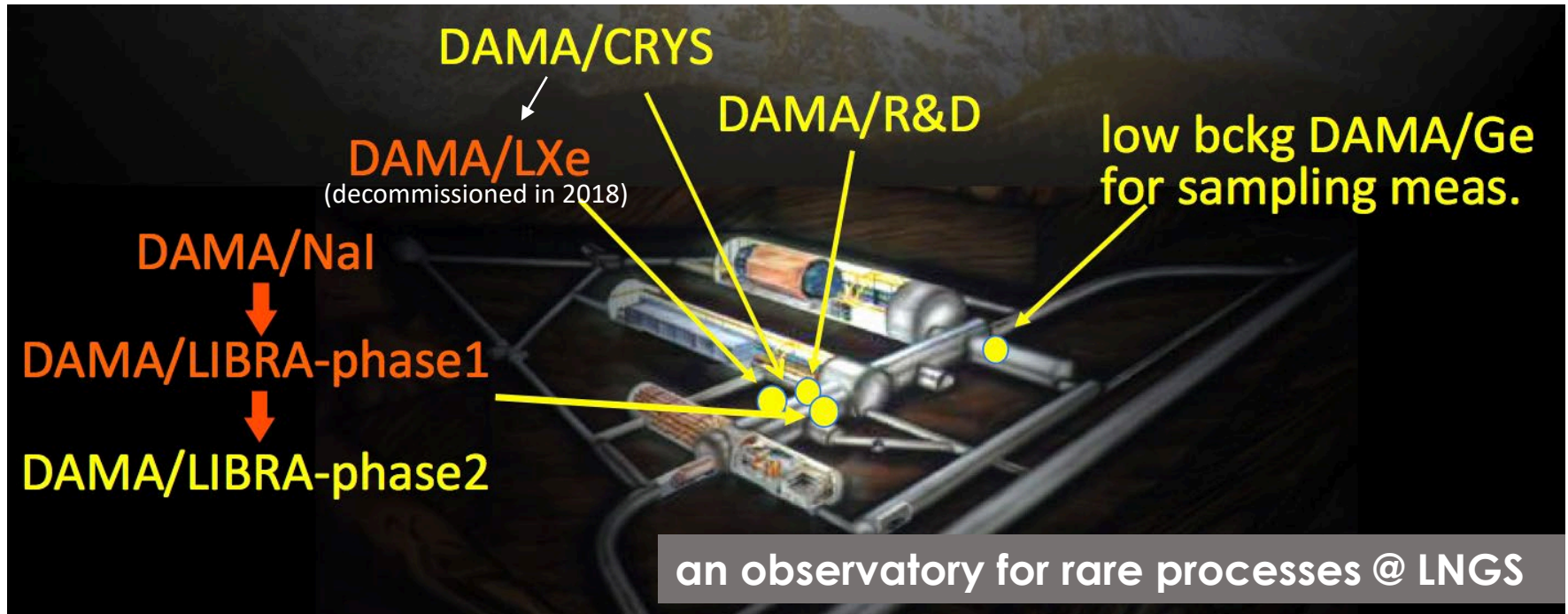
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Istituto Nazionale di Fisica Nucleare



# DAMA Collaboration and Setups



web site: <http://people.roma2.infn.it/dama>

## Collaboration:

Roma Tor Vergata, Roma La Sapienza, LNGS, IHEP/Beijing

+ by-products and small scale expts.: INR-Kiev + some Russian institutions,  
Queen's University – Canada,

+ neutron meas.: ENEA-Frascati, ENEA-Casaccia

+ in some studies on  $\beta\beta$  decays (DST-MAE and Inter-Universities project): IIT Kharagpur  
and Ropar, India

# MAIN RESEARCH ACTIVITIES

Mainly focused on the field of Astroparticle Physics, with particular interest in experimental physics at underground laboratories

Rare nuclear processes

Development/characterization of new detectors

Development Monte Carlo simulation, DAQ system, data analysis software

Testing and monitoring systems of electronic devices

Rare Events Investigations  
using Scintillation or Ionization Detectors  
(e.g. NaI(Tl), CdWO<sub>4</sub>, ZnWO<sub>4</sub>, HP-Ge and many others )

Rare  $\alpha$  and  $\beta$  decays

$\beta\beta$  decay modes in various isotopes

Direct DM investigation with ULB NaI(Tl)

Direct DM investigation by directionality approach with high purity ZnWO<sub>4</sub> (Applied for not all the DMp candidates)

Corollary analyses model-dependent of DAMA results

# SOME OF MOST RECENT STUDIES

- Many competitive limits on lifetimes of  $2\beta^+$ ,  $\epsilon\beta^+$ ,  $2\epsilon$  and  $2\beta^-$  processes
- First searches for many  $\beta\beta$  decay modes in several isotopes

## Double Beta Decay

### Two-neutrino

#### Why?

- Matrix elements
- Axial vector contribution
- Nuclear model
- Information for the  $0\nu\beta\beta$  search
- Knowledge of the spectral shapes can use to mitigate the background for  $0\nu\beta\beta$  studies

EPJ A55 (2019) 201  
 NP A990 (2019) 64  
 AIPC 2165 (2019) 020014  
 JP G45 (2018) 095101  
 UNI 4 (2018) 147

Recent research mainly focused on the study of positive  $\beta\beta$  decay modes

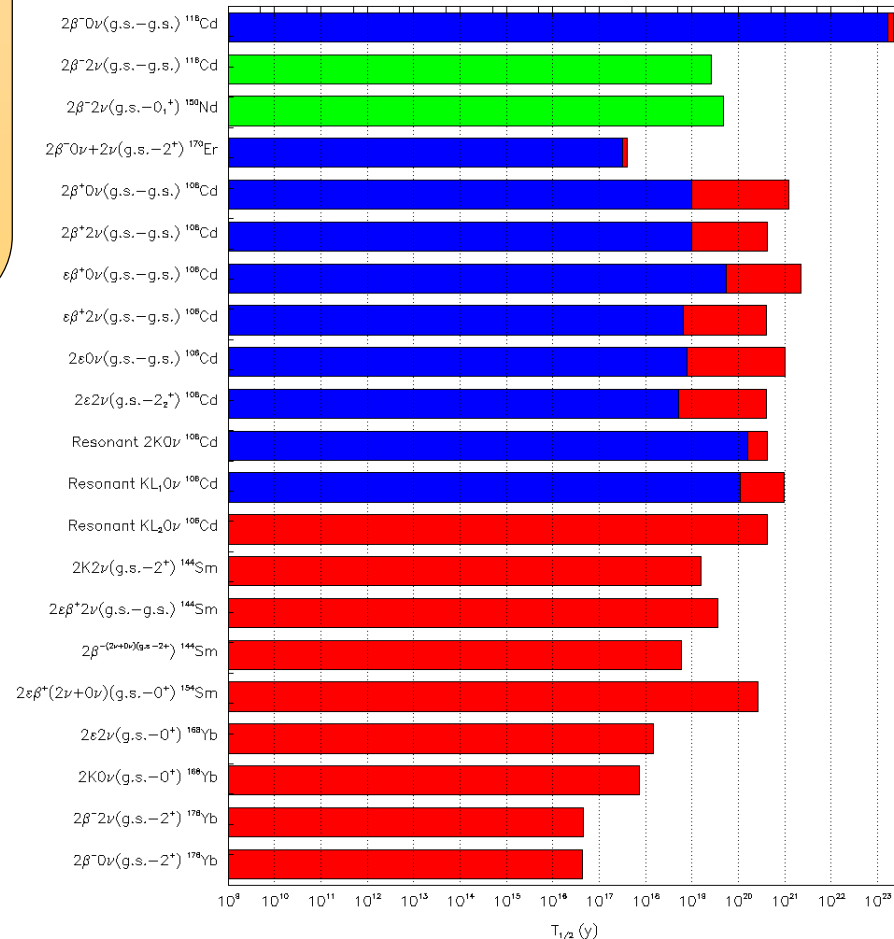
### Neutrino-less

#### Why?

Violate the full lepton number and therefore provides a unique window into physics beyond the Standard Model

### Partial List

Legend:   
█ DAMA observed   
█ DAMA limits   
█ Previous limits



# SOME OF MOST RECENT STUDIES

## AURORA experiment ...

Enrichment & radiopurity allow to reach very high sensitivity even with relatively "small" crystals

### $^{116}\text{CdWO}_4$

- ✓ Data taking with two  $^{116}\text{CdWO}_4$  (1.162 kg) detectors enriched in  $^{116}\text{Cd}$  at 82%
- ✓ Background: **0.1 counts/year/kg/keV at 2.7-2.9 MeV**

The best up-to-date accuracy for the  $2\beta^-2\nu$  decay mode:

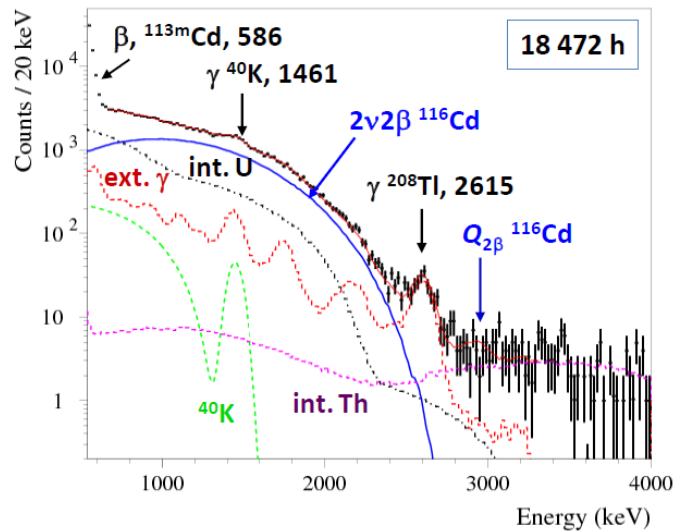
$$T_{1/2} = [2.630 \pm 0.011(\text{stat})_{-0.123}^{+0.113}(\text{sys})] \times 10^{19} \text{ yr}$$

and one of the more sensitive limit for the  $2\beta^-0\nu$ :

$$T_{1/2} \geq 2.2 \times 10^{23} \text{ yr} \longrightarrow \langle m_\nu \rangle \leq (1.0 - 1.7) \text{ eV}$$

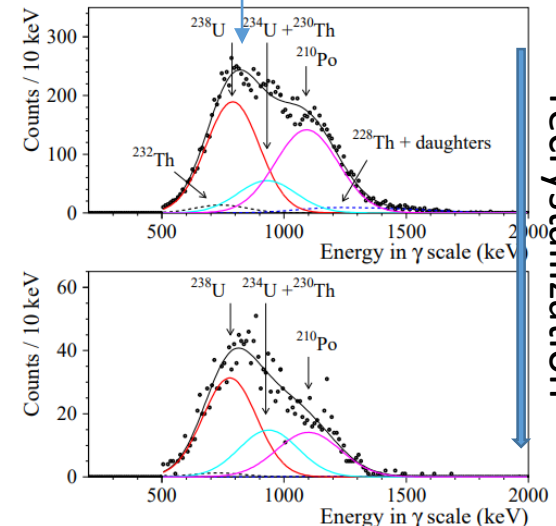
PRD 98 (2018), 092007

Studies to improve radiopurity of enriched crystals in progress



e.g.:  
Developing Ba-based crystal scintillators to study  $\beta\beta$  decay of  $^{130}\text{Ba}$  and  $^{132}\text{Ba}$  isotopes with the "source=detector" approach

preliminary results published, investigation in progress with Queen's University colleagues



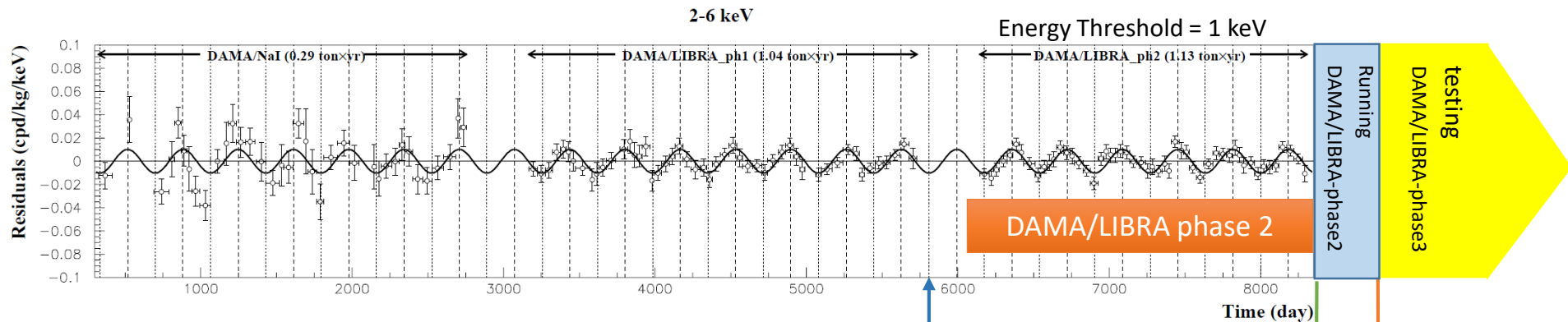
NIM A935 (2019)  
NIM A833 (2016)

# SOME OF MOST RECENT STUDIES

## Dark Matter Model Independent Annual Modulation

Main publications: <http://people.roma2.infn.it/~dama/web/publ.html>

Data analysed with many different procedures → always consistent results



DAMA/LIBRA upgrade optimized for the phase2 (fall 2010): replacement of all the PMTs with higher Q.E. ones from dedicated R&D (+new preamp in fall 2012 and other developments)

Data released:  
Model-independent analyses

Universe 4 (2018) 147  
Nucl. Phys. At. En. 19 (2018) 307  
arXiv:1907.06405 in press  
...

Many corollary model dependent-analyses in press

DAMA/LIBRA-phase2 favors the presence of a modulated behavior with proper features at  $9.5 \sigma$  C.L over 6 annual cycles, confirming the results of previous DAMA/NaI and DAMA/LIBRA-phase1 expts.

DAMA/NaI & DAMA/LIBRA-phase1 & DAMA/LIBRA-phase2 favor the presence of a modulated behavior with proper features at  $12.8 \sigma$  C.L over 20 independent annual cycles



No modulation above 6 keV

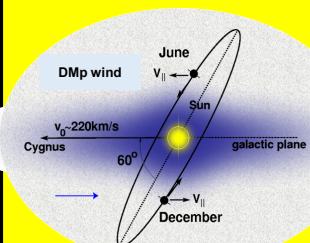
No modulation in the whole energy spectrum

No modulation in the multiple-hits events

No systematics/side-reactions able to mimic the observed effect (i.e. able to account for the whole observed modulation amplitude and simultaneously satisfy the many specific requirements of the exploited signature)

Developments towards directionality with anisotropic scintillators (seminal papers by DAMA colleagues):

Studying the response of the  $ZnWO_4$  in keV region



Measurements of the Quenching Factor of Oxygen Nucleus

Angle	Axis	$E_{peak}$ (keV $_{eq}$ )	$E_{recal,0}$ (keV)	$Q$	$Q_{in}/Q_e$
80°	3	99.2±2.5	1387	0.0715±0.0018	1.189 ± 0.047
80°	1	83.4±2.5	1387	0.0601±0.0018	
70°	3	87.0±2.1	1116	0.0780±0.0019	1.227 ± 0.063
70°	1	78.9±3.2	1116		
60°	3	to be completed	856		In press on EPJA
60°	1	to be completed	856		

Only for DMP candidates able to induce nuclear recoils

ADAMO project

# SOME OF THE PLANNED ACTIVITIES IN NEXT FUTURE

- **Direct Dark Matter investigation:**
  - Running DAMA/LIBRA-phase2
  - 4 crystal are in testing for the possible phase3 with new pre-amplifiers and metallic-PMTs
  - New phenomenological studies
  - Further developments for the ADAMO project
- **New investigations of several rare processes**
- **Double beta decay studies in various isotopes, in particular:**
  - on  $^{116}\text{Cd}$  and  $^{106}\text{Cd}$  with increased sensitivities
  - on Barium isotopes
  - on  $^{150}\text{Nd}$
  - on Sm, Er, Yb isotopes

**R&D developments of (new) crystal scintillators**

**Performances for low-radioactivity experiments**

**Purification techniques of oxide of rare earths**

**...and more**