The scintillation crystals of tungstate and molybdate for high sensitivity 2β and dark matter experiments

B.Grinyov , L.Nagornaya, I.Tupitsyna

Institute for Scintillation Materials

ISMA

Outline

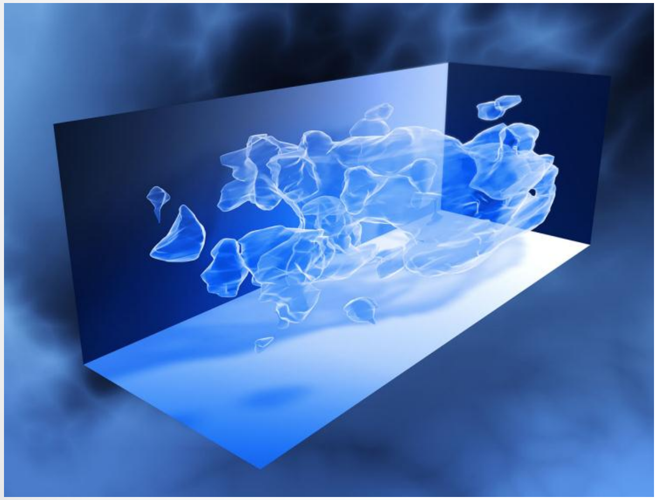
- **Motivation**
  - new kind of matter
  - experiments of Dark Matter searching
  - scintillation method
  - scintillation-phonon method
- **Scintillators for DM and 2β searching**
  - radioactive contamination
  - spectrometric characteristics
  - cryogenic scintillators
- **Conclusions**

Motivation

Dark Matter

We cannot explain the nature of 95% of *the Universe* mass

new kind of matter (new particles)



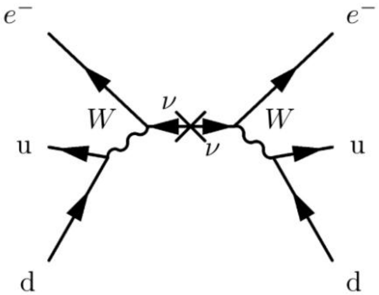
3D map of the large-scale distribution of dark matter, reconstructed from measurements of weak gravitational lensing with the Hubble Space Telescope.

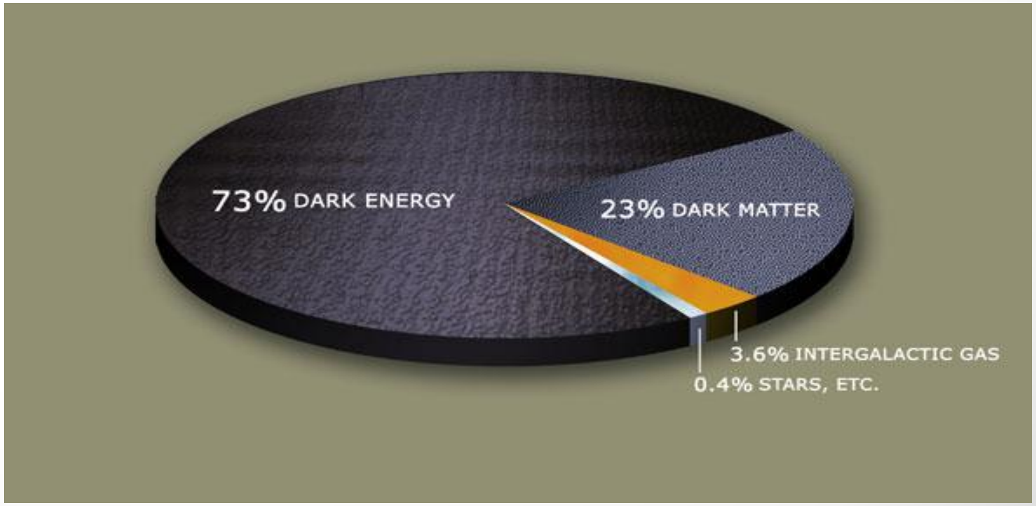
Popular candidates for DM particles

- **Weakly Interacting Massive Particles (WIMPs)**
- **Neutrinos**

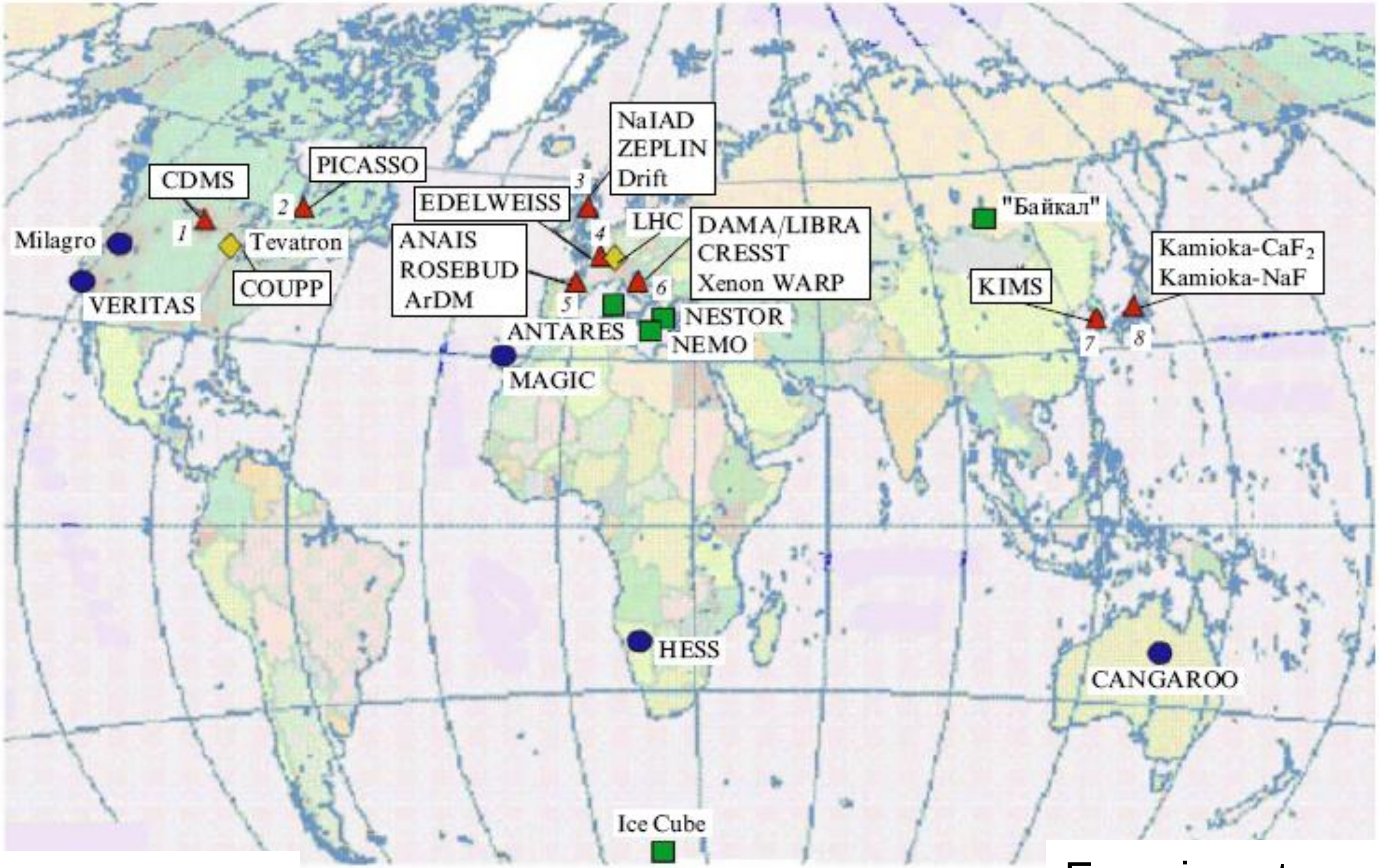
Double beta decay

- **Nature of neutrino**
- **Neutrino mass**
- **Lepton number conservation**





Experiments of DM searching



🟩 neutrino telescopes
● gamma-ray telescopes
◆ accelerators
▲ underground laboratory

Experiments on satellites


PAMELA


GLAST

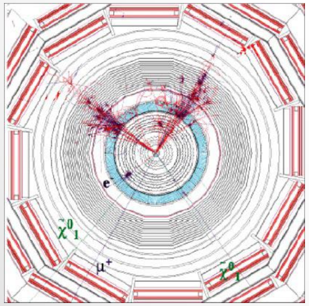

AMS

The search methods of DM particles

Collider

LHC

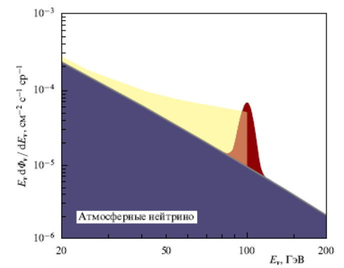
WIMP -100 GeV at E>2000 GeV Impossible to determine what contribution the new formed particles make to the DM in the Universe



Indirect methods

(WIMP annihilation product registration)

- ❑ Neutrinos in neutrino telescopes
- ❑ Photons by ground gamma-ray telescopes
- ❑ Photons by cosmic gamma-ray telescopes
- ❑ Cosmic positrons and antiprotons



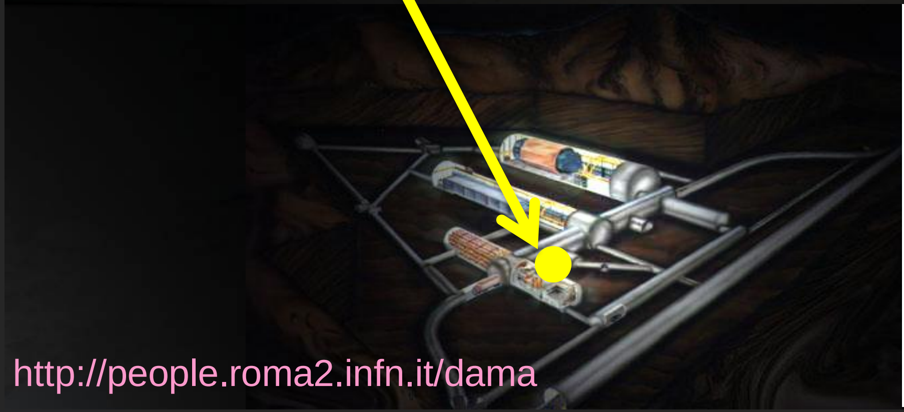
Direct methods

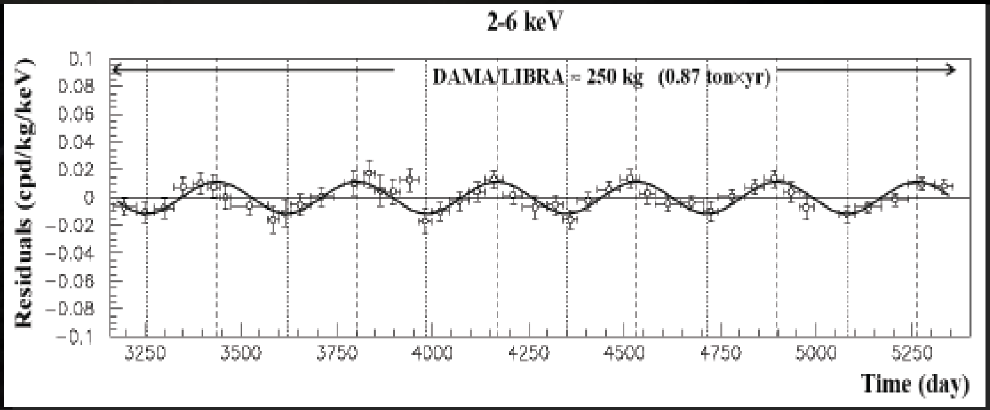
- Detectors of ionization
- Scintillation detectors
- Detectors of heat
- Combination detectors

Scintillation method

- DAMA, DAMA/LIBRA - NaI(Tl), Gran-Sasso

Independent Annual Modulation Result


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



- NaIAD – NaI , Bowlby
- KIMS-CsI(Tl),Yangyang

Deviations from the background count of events not found

Scintillation-phonon method

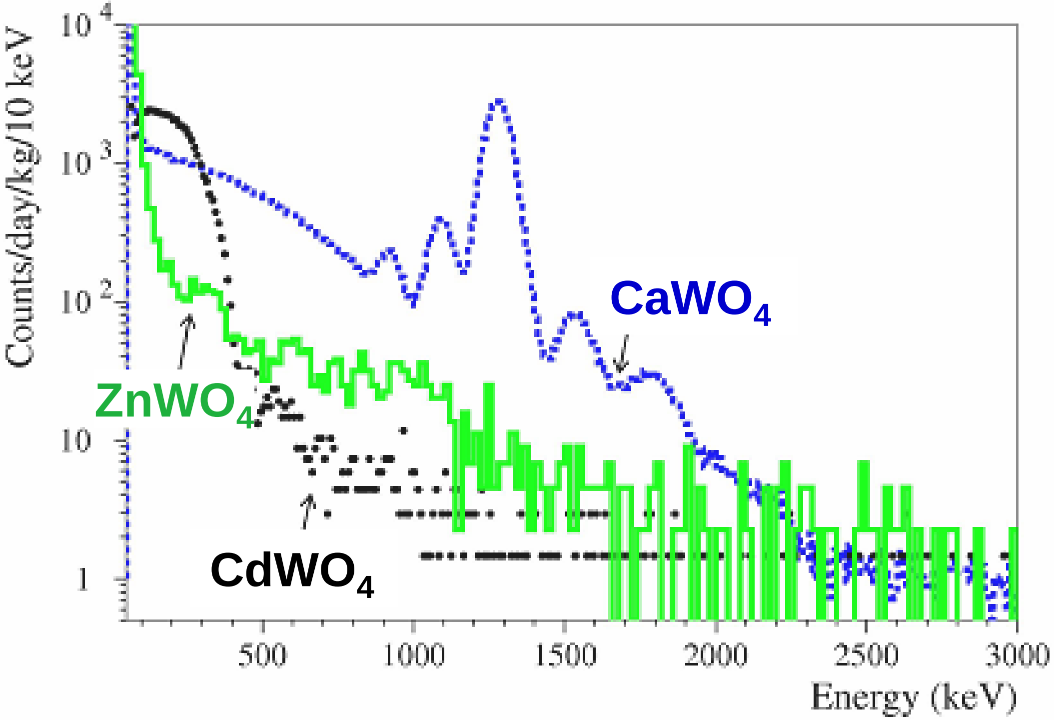
- The energy threshold of the recoil energy -10 keV
- High energy resolution, comparable with germanium detectors.
- Effective separation of events from the γ-rays (β–, α-particles) and the recoil nucleus

Scintillators for DM and 2β searching

Requirements to scintillators

- a high light output at milli-Kelvin temperature
- an extremely low level of radioactive contamination (<0.01 mBk/kg)
- presence of specific nuclei (2β decay) (for example ^{64,70}Zn, ^{180,186}W, ^{92,98,100}Mo)
- a variety of elements in scintillation targets (Dark matter)

$ZnWO_4$ - an excellent radiopure



The measurements carried out at Solotvina Underground Laboratory (Ukraine) and Gran Sasso National Laboratories (Italy).

	$ZnWO_4$ (1)	$CaWO_4$ (2)
^{232}Th	0.0015	0.7
^{235}U	≤ 0.003	1.6
^{238}U	0.002	300
Total α	≤ 0.2	400
^{40}K	≤ 0.4	
^{65}Zn	0.5	
^{90}Sr-^{90}Y	≤ 0.4	

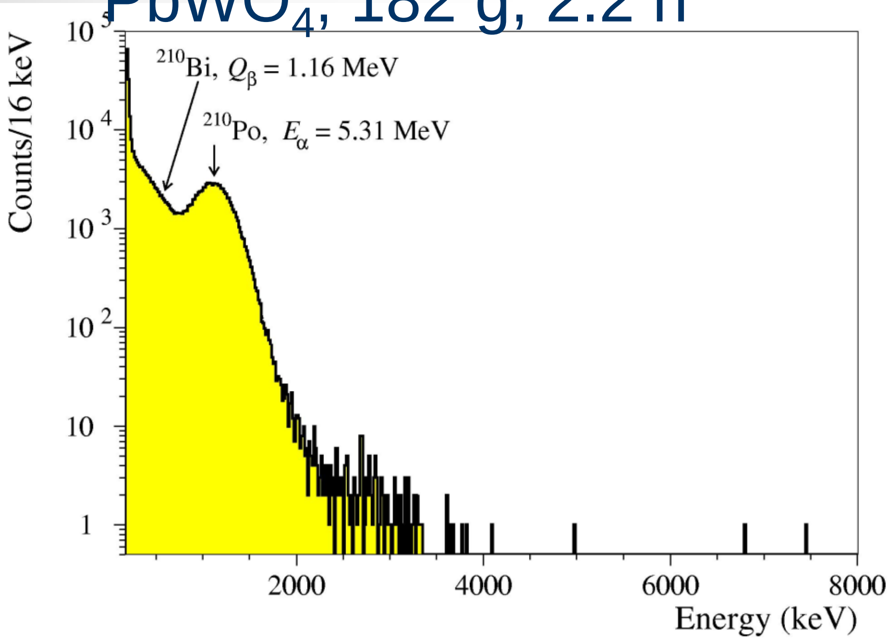
1)P.Belli et al., Nuclear Physics A826 (2009) 256

2)NIMA 538 (2004) 657; APP 23 (2005) 249

$ZnWO_4$ is promising to search for **2β $^{64,70}Zn$, ^{180}W, ^{186}W; DM**

$PbWO_4$, $PbMoO_4$

$PbWO_4$, 182 g, 2.2 h



Chain	***Nuclide***	***Activity (mBq/kg)***
^{232}Th	**^{228}Th**	**≤13**
^{238}U	**^{226}Ra**	**≤10**
	^{210}Po	**$(53\text{-}79)\times10^3$**

The radioactive background level of these crystals is rather high and is determined by the presence of ^{210}Po. ISMA carries out works on purification of archaeological lead and growing of lead tungstate crystals with low radioactive background. **Possible applications of this crystal include studies of double beta-decay, searches for dark matter and its usage as protection against photomultiplier cathode radiation and active light-guide**

DM searching scintillators: where we are?

Our goal: the total activity < 0.01 mBq/kg

$CaWO_4$	~10^4
$ZnWO_4$	~20
$CaMoO_4$	~500
$PbWO_4$	~5×10^6 ~400 (Arch)
$PbMoO_4$	
BGO	~10^3 - 10^4

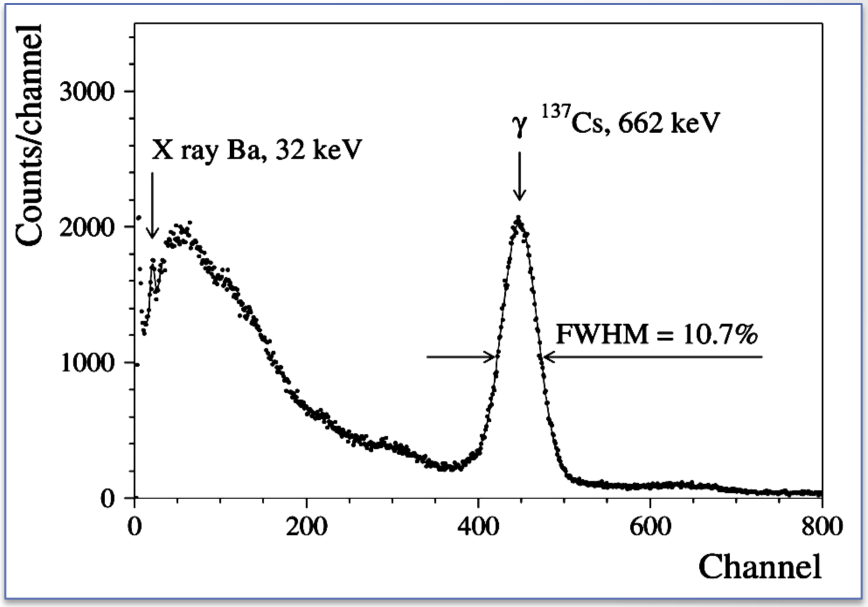
- $CdWO_4$ ~50
- $CdMoO_4$

$\Big\}$ depleted in ^{113}Cd

- $MgWO_4$
- $ZnMoO_4$
- …

$ZnWO_4$ for 2β and DM

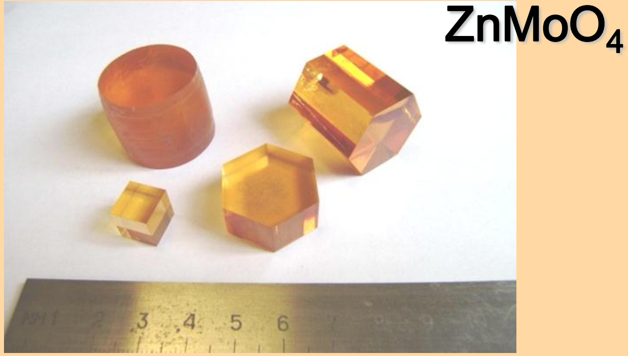
Large volume $ZnWO_4$ crystal scintillators up to ∅50 ×100 mm

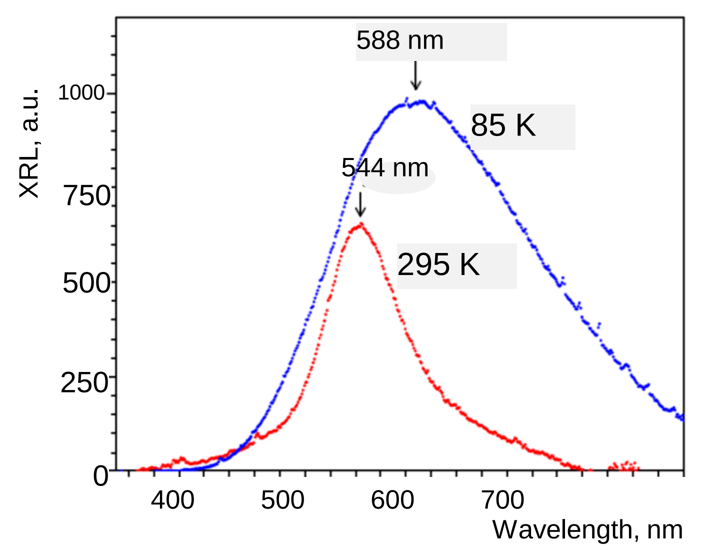


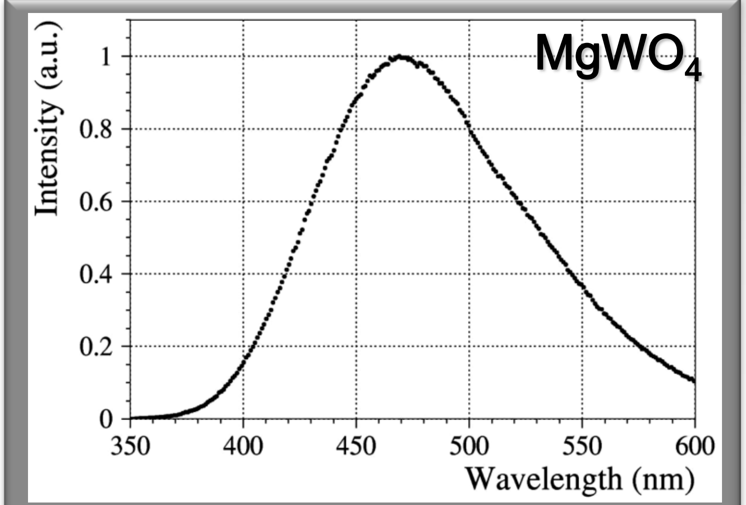
The energy resolution of $ZnWO_4$ scintillation elements was 8.5 % with 1 cm^3 sample and 10.7 % with a hexagonal scintillation element 40 × 40 mm for 662 keV γ line of ^{137}Cs

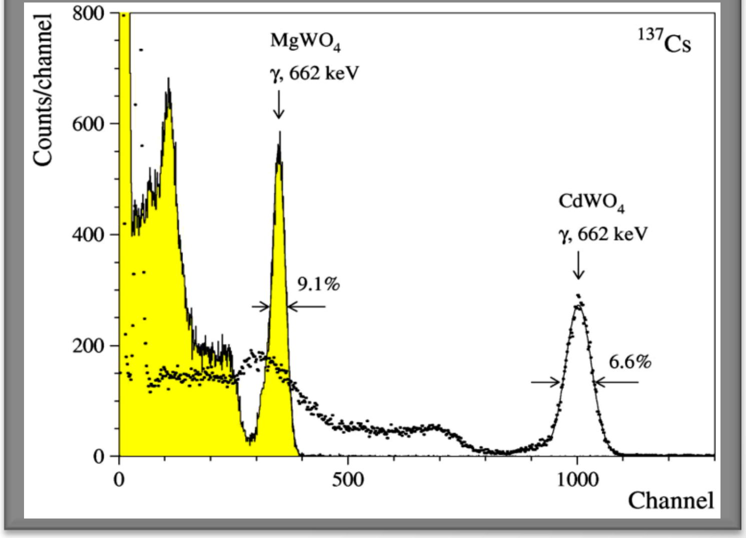
$ZnWO_4$ is one of the best candidates as a detector for cryogenic 2β decay and Dark Matter experiments !

XRL and energy spectra of ^{137}Cs γ-rays measured for $MgWO_4$, $ZnMoO_4$









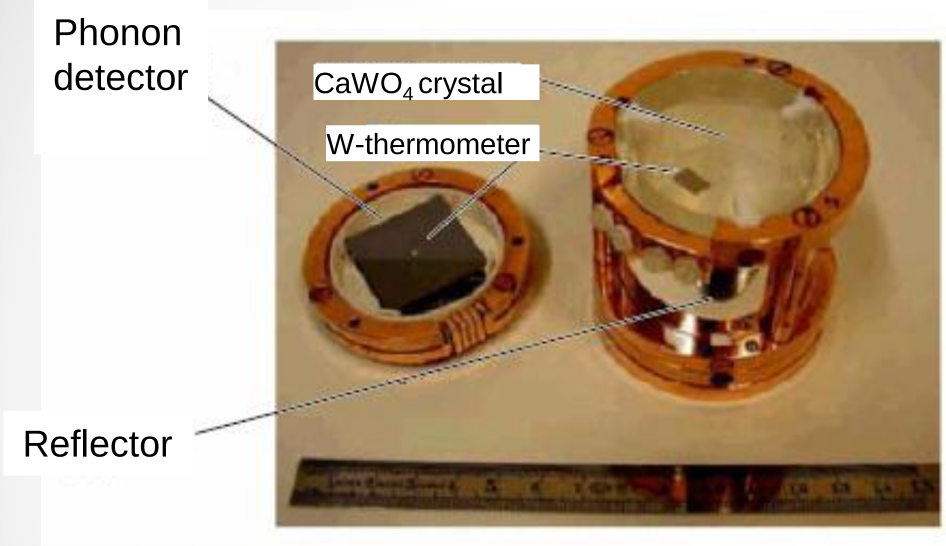
The crystals show intense luminescence under X-ray excitation.

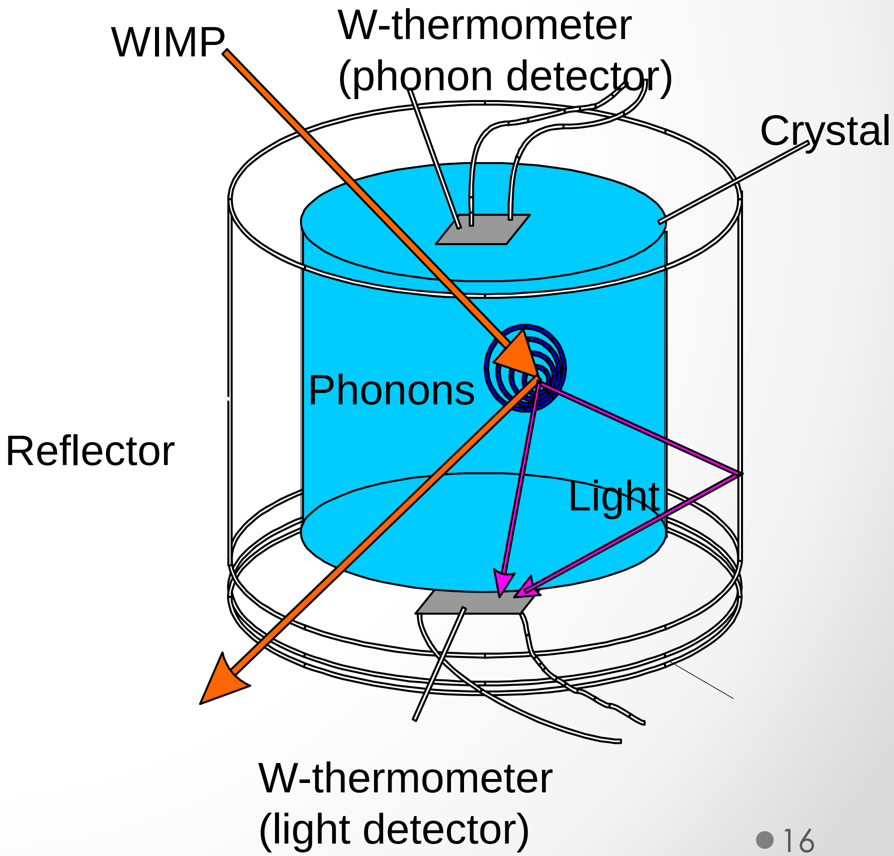
The relative photoelectron yield of $MgWO_4$ is about 35% to $CdWO_4$.

The energy resolution of a $MgWO_4$ small sample gives 9.1 % for the 662 keV γ-quanta of Cs

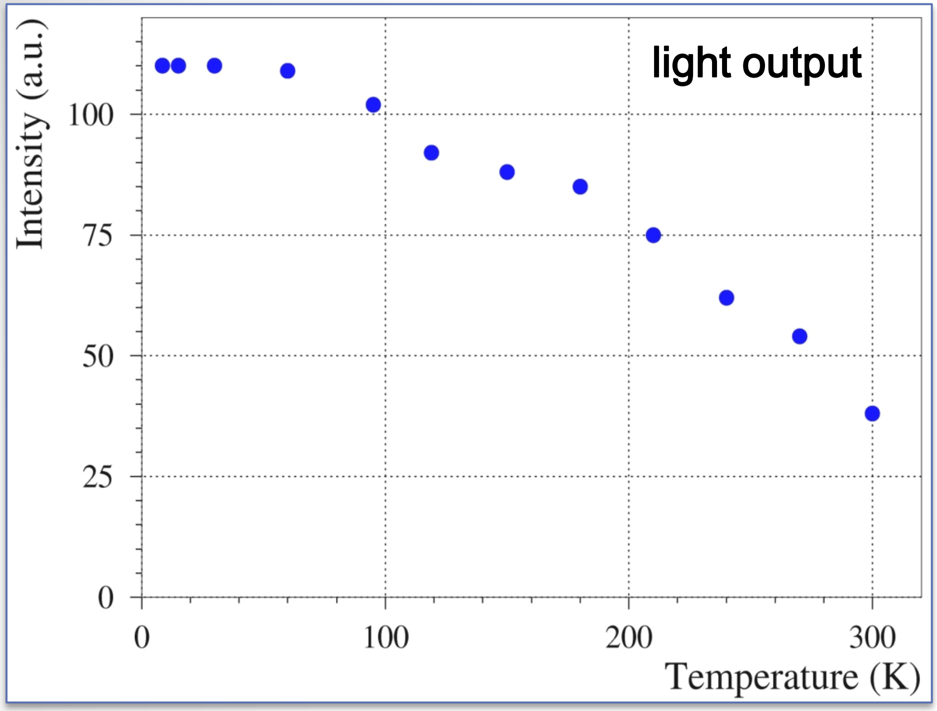
Combined cryogenic detectors

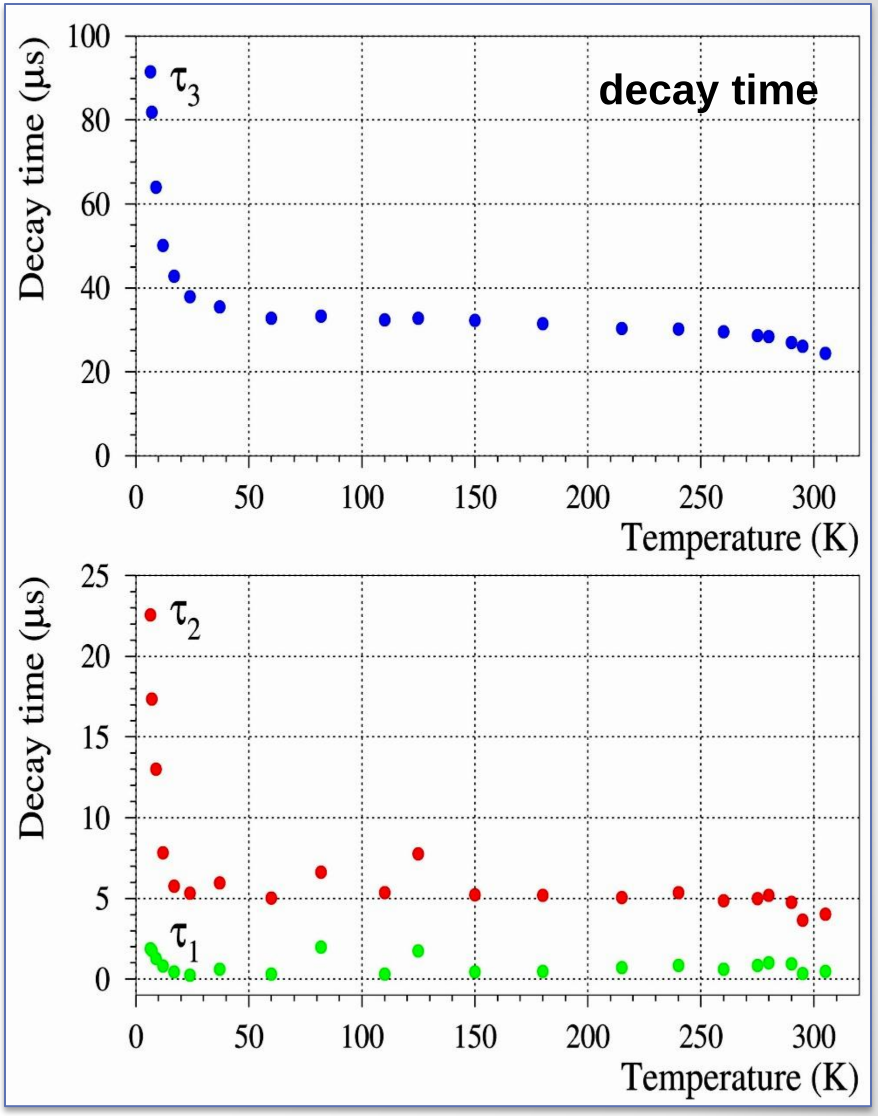
CRESST-II detector





$ZnWO_4$ temperature dependence of light output and decay time

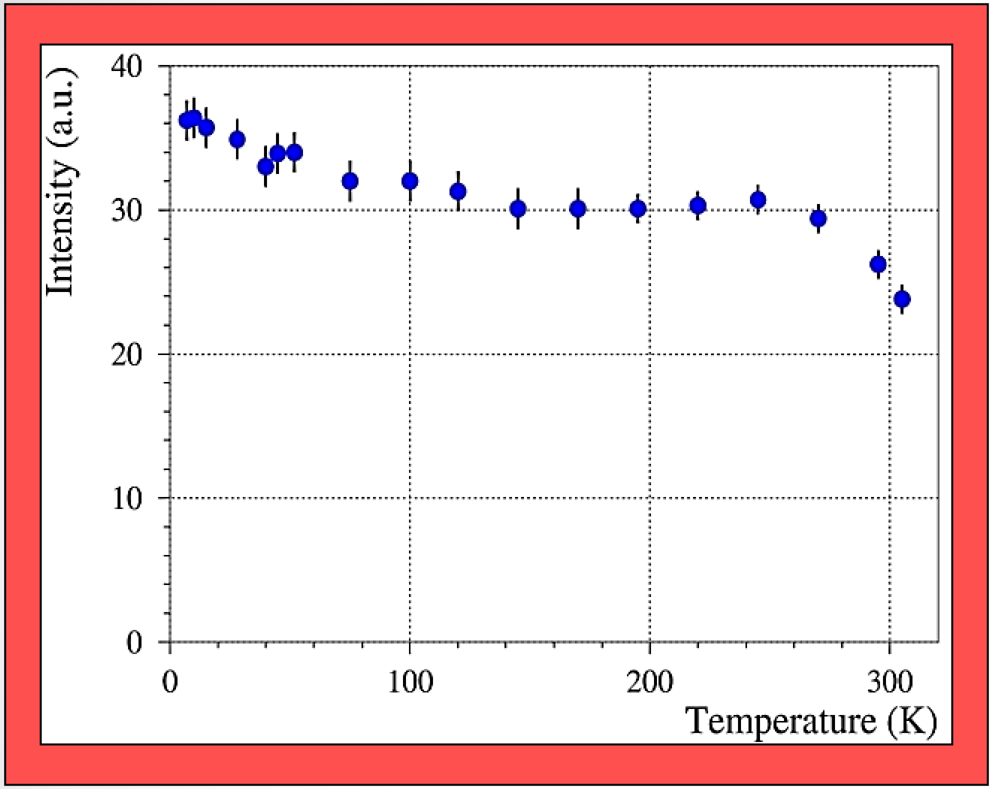


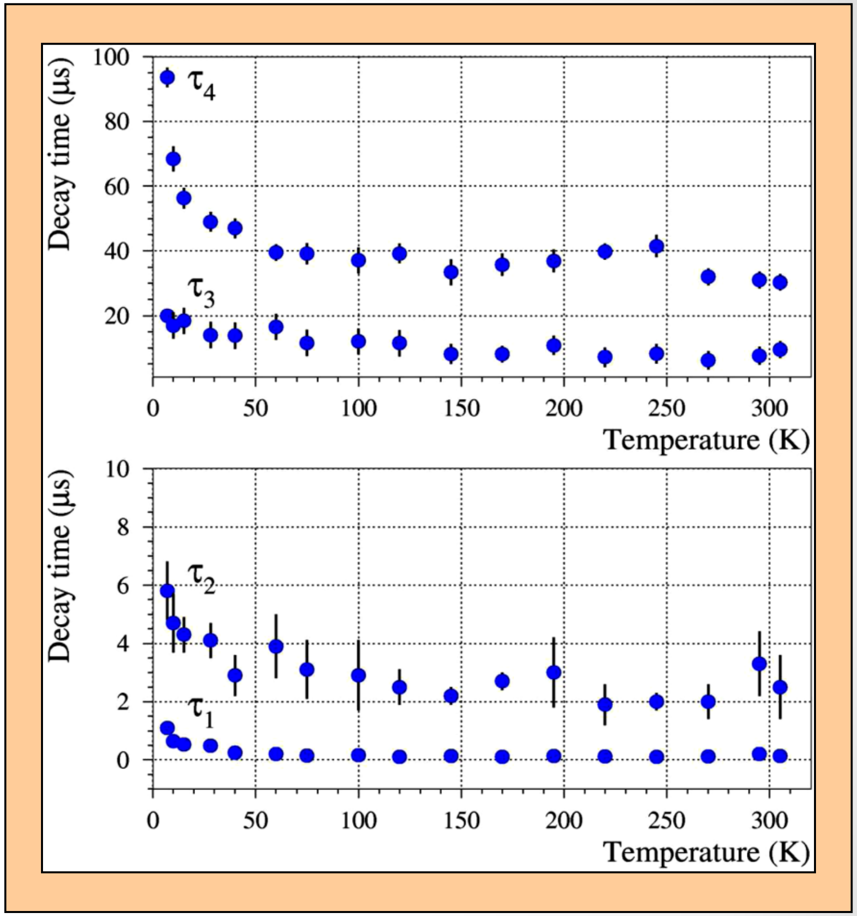


The light output of $ZnWO_4$ demonstrates about three-fold increases and decay time becomes about three times longer with decrease of temperature from 300 K to 7 K.

The relative light output of $ZnWO_4$ at 10 K is 110-115 % that of $CaWO_4$

Temperature dependence of $MgWO_4$ light output and decay time

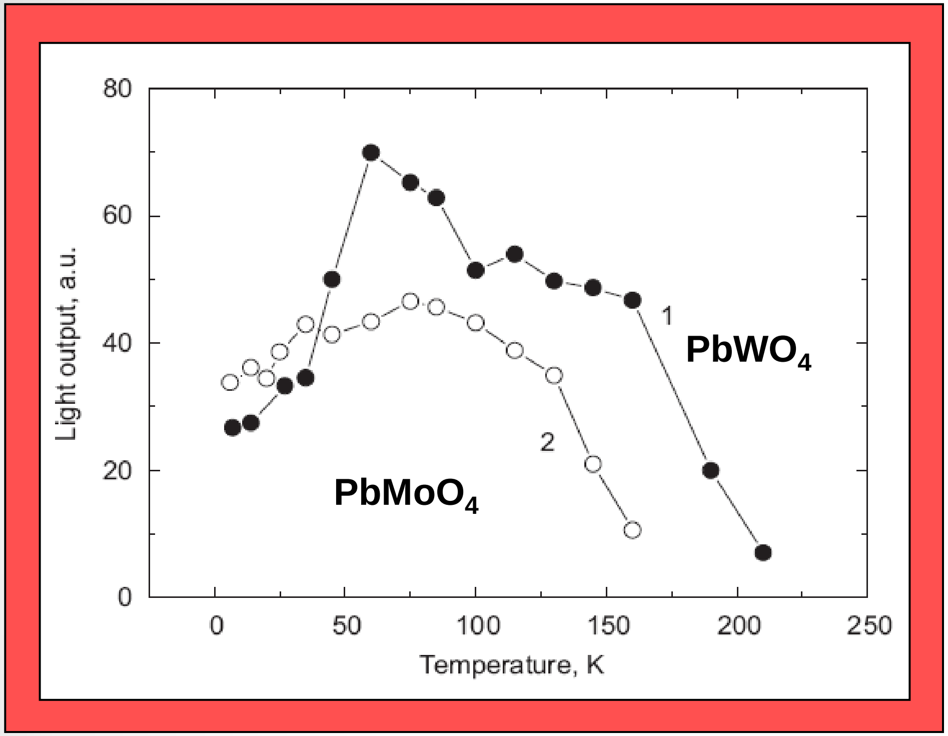




The light output of $MgWO_4$ increases and decay time becomes longer with decrease of temperature not as much.

The relative photoelectron yield is 33% that of $ZnWO_4$ at T = 7 K

$PbWO_4$ and $PbMoO_4$ temperature dependence of light output



Light output of $PbWO_4$ and $PbMoO_4$ crystal at 7and 77K relative to $CaWO_4$

Crystal	T, K	Light output, %
$PbWO_4$	77 7	66 27
$PbMoO_4$	77 7	46 34

It is known - the scintillation in both materials is thermally quenched at RT
Then the light yield increases steeply with cooling.
When cooling is below 50K the light output drops significantly

Why is that? How can we influence these processes?

Conclusions

- Tungstate and molybdate crystal scintillators are promising materials for search of DM and 2β decay

- Cryogenic scintillation-phonon detector is the detector of new generation with high resolution and accurate identification of events

- **For the production of scintillators for cryogenic detectors it is necessary to study them at cryogenic temperatures in detail**

Thank you!

Acknowledgments

Thanks to H.Kraus , V.Mikhailik, V.Degoda, et al.

Special Thanks to Fedor Danevich