

# Radiation Detector Development for Direct Dark Matter Search

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# SUMMARY

- ◆ **Dark Matter: one of the frontiers of astro and particle physics.**
- ◆ **Still a lot of room to use your beautiful detectors for direct detection of DM.**
  - What is required for that? ← **My Talk**

# The History of the Dark started

*Along time ago  
in galaxies far far away*

**not quantitative at all**

VOLUME 86

OCTOBER 1937

NUMBER 3

ON THE MASSES OF NEBULAE AND OF  
CLUSTERS OF NEBULAE

F. ZWICKY

2. We must know how much dark matter is incorporated in nebulae in the form of cool and cold stars, macroscopic and microscopic solid bodies, and gases.

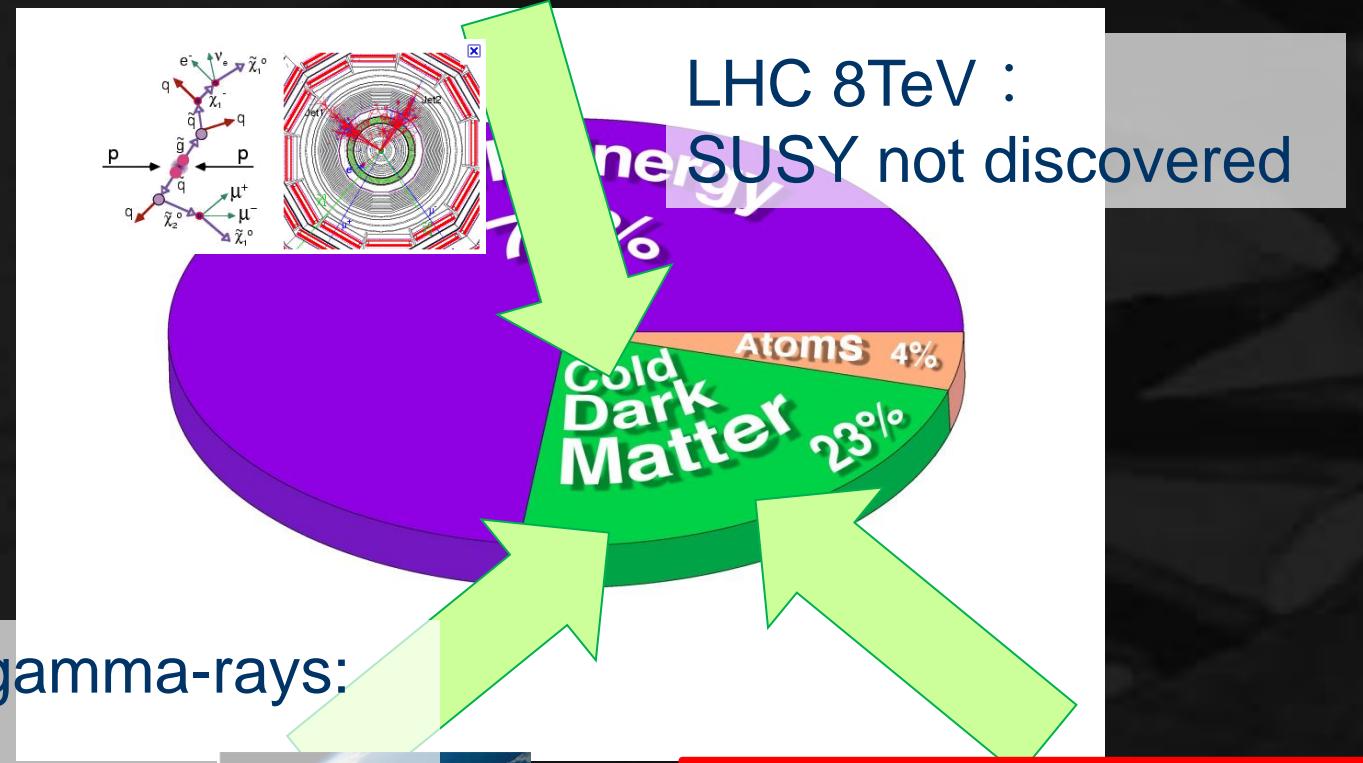
*Along time ago  
in galaxies far far away*

Distance: 300 million light-years

Method iii is based on the *virial theorem* of classical mechanics. The application of this theorem to the Coma cluster leads to a minimum value  $\bar{M} = 4.5 \times 10^{10} M_{\odot}$  for the average mass of its member nebulae.

Year: 1930s

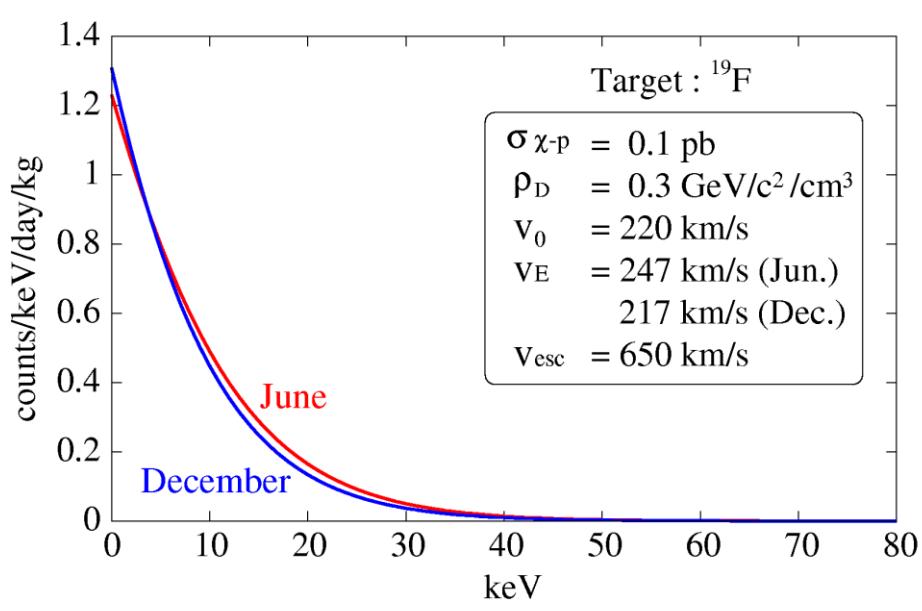
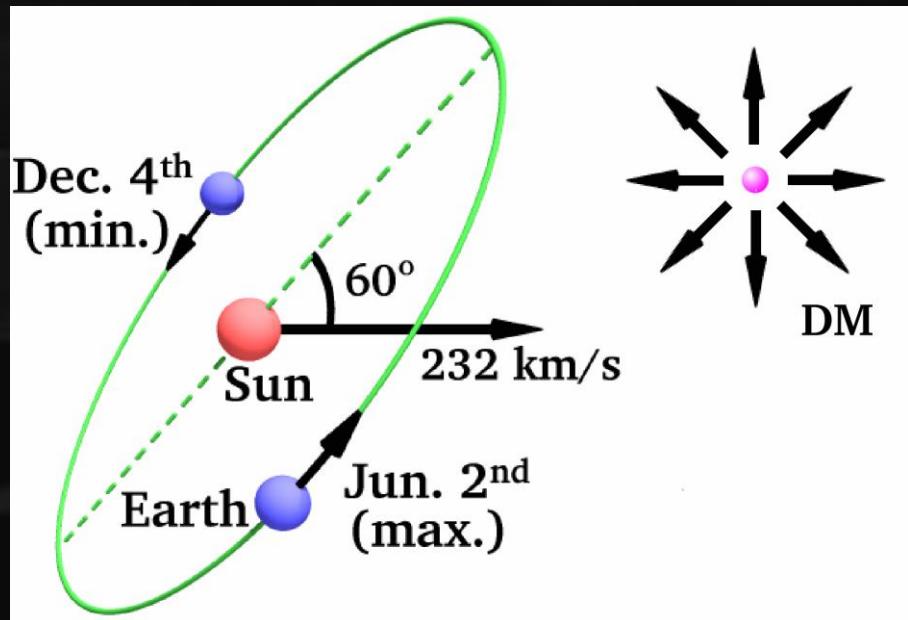
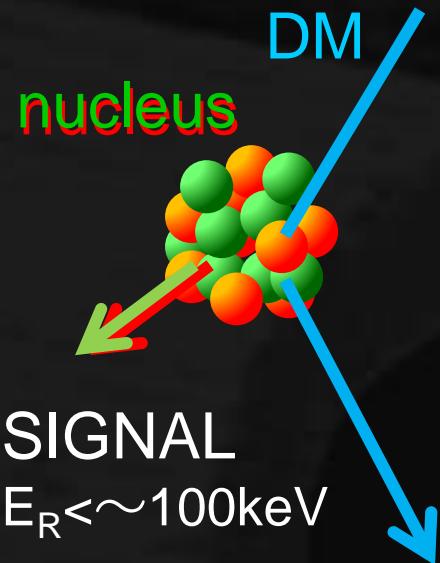
# Dark Matter Accelerator



Indirect  
Detection

Direct  
Detection

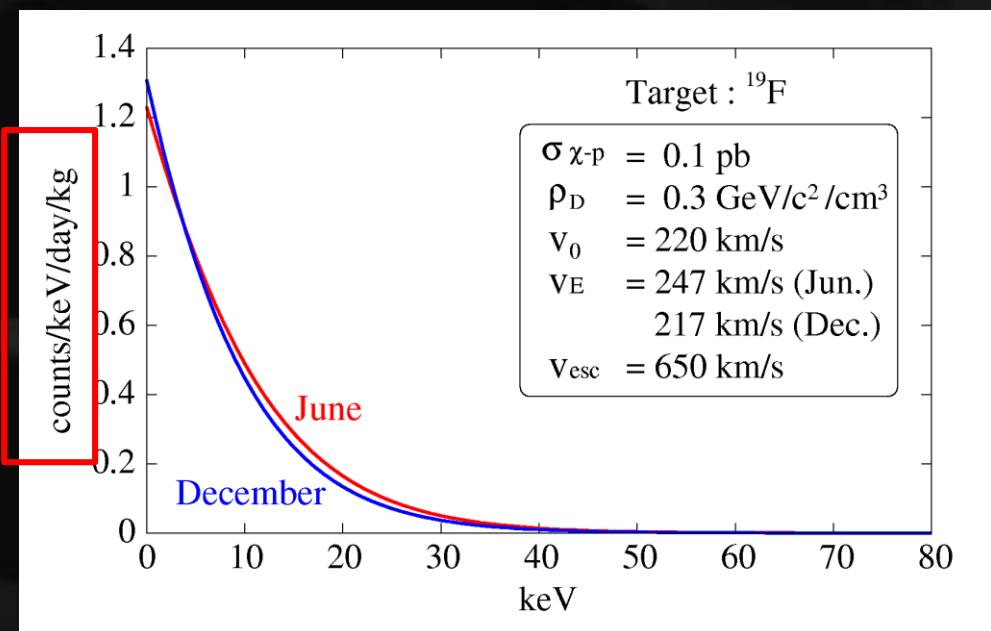
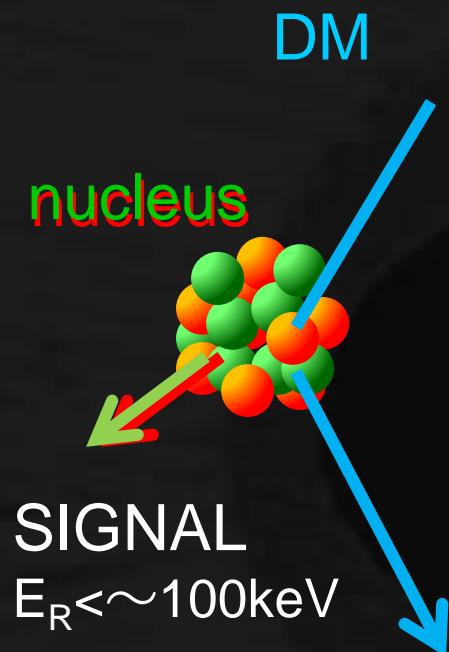
# ◆ DM direct detection



## expected DM signals

- ① observed \* events
- ② energy spectrum
- ③ seasonal modulation
- ④ direction-sensitive

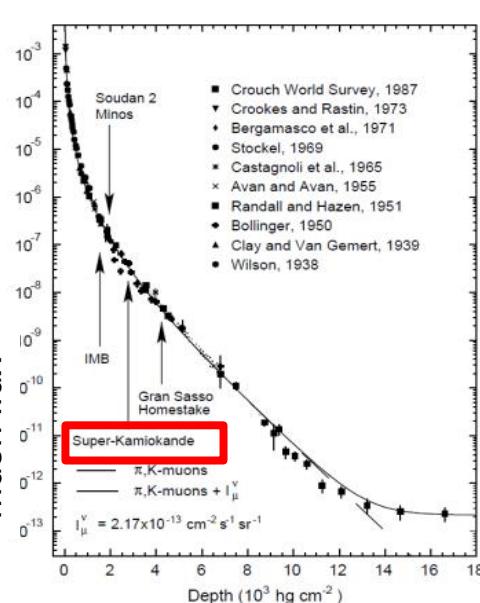
# ◆ DM direct detection



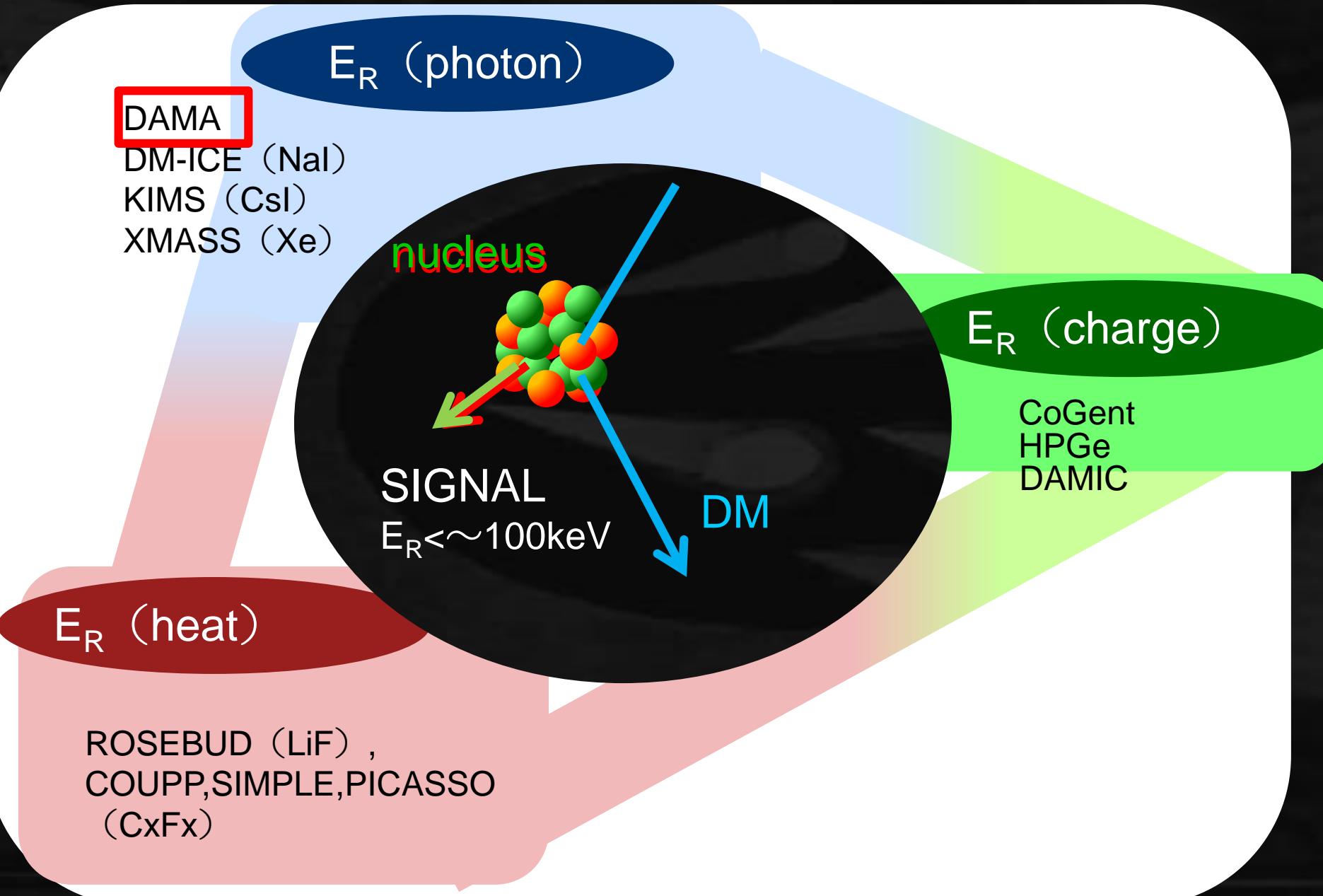
Key feature 1 : Large mass

# world-wide underground laboratories

- To reduce cosmic-ray background



# ◆ Direct Detection Methods



# ◆ What's special with DAMA?

- Large: 250kg
- Pure (clean): low contamination of radioactive background source (Uranium, Thorium, 40K)

NAIAD/DM-Ice17 crystals: (arXiv:1401.4804v1, PLB 616 (2005) 17–24)

- ~30x DAMA's K-40 contamination
- 5 - 10x DAMA's single-hit event rate (no multi-hit cut applied in NAIAD/DM-Ice17)

22" diameter NaI Crystal  
Neil Spooner, Reina Maruyama  
on behalf of the DM-Ice Collaboration

TeVPA/IDM - Astroparticle Physics 2014  
June 26, 2014  
Amsterdam

Manufacturer	Form	Measurement	$^{238}\text{U}$ (ppt)	$^{232}\text{Th}$ (ppt)	$\text{natK}$ (ppb)
Saint Gobain	Powder	DAMA (HPGe)	< 20	< 20	< 100
Saint Gobain	Crystal	DAMA/LIBRA	0.7 - 10	0.5 - 7.5	< 20
Saint Gobain	Crystal	ANALIS-0	7.6	7.7	410
Bicron/Saint Gobain	Crystal	NAIAD/DM-Ice17	55	33	550
Sigma-Aldrich	Powder (standard grade)	DM-Ice (HPGe)	40	89	440
Sigma-Aldrich	Powder (astro grade)	DM-Ice (HPGe)	63	< 95	< 126
Sigma-Aldrich	Powder (astro grade)	A-S (ICPMS)	-	-	~ 4
Alpha-Spectra	Powder	DM-Ice (HPGe)	< 100	< 200	< 120
Alpha-Spectra	Powder	ANALIS-25 (HPGe)	< 55	< 130	< 90

\*DAMA ppt numb  
for other crystals

PICO-LON(Tokushima)

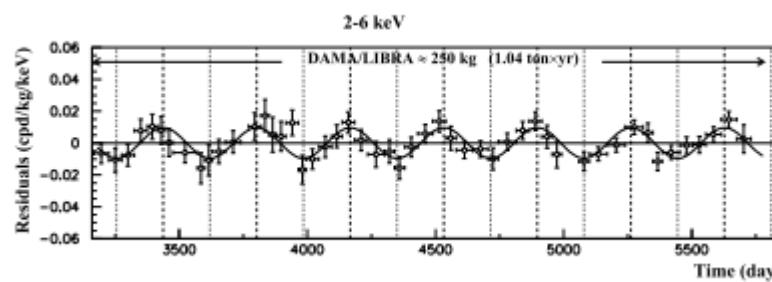
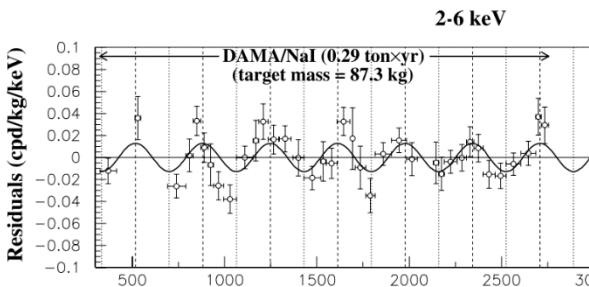
~8ppt

<1ppt

not yet

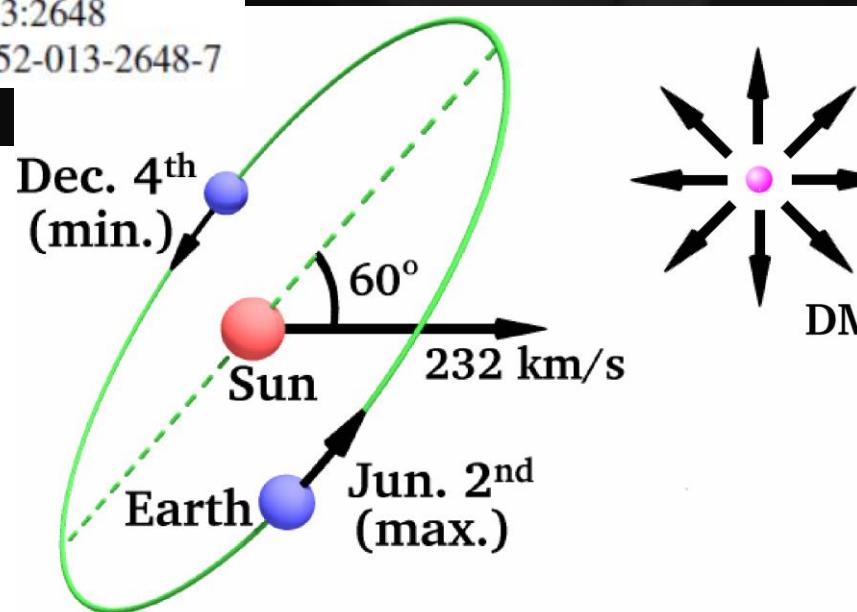
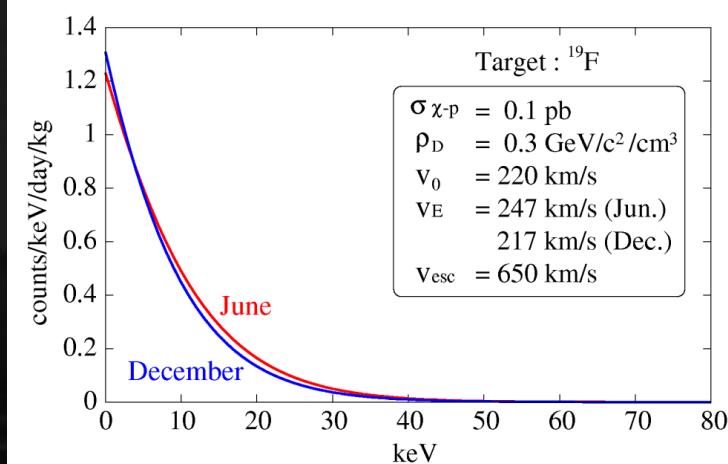
# DAMA/LIBRA

- 250kg NaI scintillators
- Exposure: 1.33ton • years
- 14cycles seasonal modulation (9.3 $\sigma$ )



Eur. Phys. J. C (2008) 56: 333–355  
DOI 10.1140/epjc/s10052-008-0662-y

Eur. Phys. J. C (2013) 73:2648  
DOI 10.1140/epjc/s10052-013-2648-7

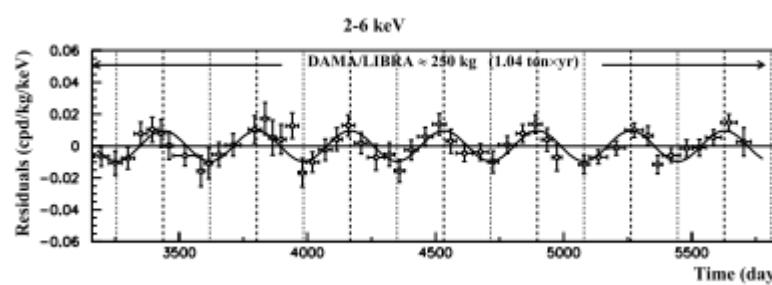
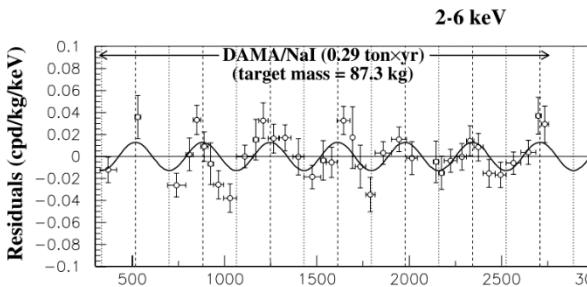


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DAMA page



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Eur. Phys. J. C (2013) 73:2648  
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We have SIGANALS, it's done?

No...

# ◆ Direct Detection Methods

DAMA  
DM-ICE (NaI)  
KIMS (CsI)  
**XMASS (Xe)**

$E_R$  (photon)

(photon + charge)

ZEPILINE II/III  
XENON10/100  
LUX (Xe)  
ArDM • WARP (Ar)

(photo

**Make it even larger!**

CRESST  
(CaWO<sub>4</sub>)

$E_R$  (heat)

ROSEBUD (LiF) ,  
COUPP, SIMPLE, PICASSO  
(CxFx)

SIGNAL  
 $E_R < \sim 100\text{keV}$

DM

$E_R$  (charge)

CoGent  
HPGe  
DAMIC

(charge + heat)

CDMS (Ge/Si)  
EDELWEISS (Ge)

# ◆ Direct Detection Methods

$E_R$  (photon)

DAMA  
DM-ICE (NaI)  
KIMS (CsI)  
**XMASS (Xe)**

nucleus

Make it even larger!

$E_R$  (heat)

ROSEBUD (LiF) ,  
COUPP, SIMPLE, PICASSO  
(CxFx)

$E_R$  (charge)

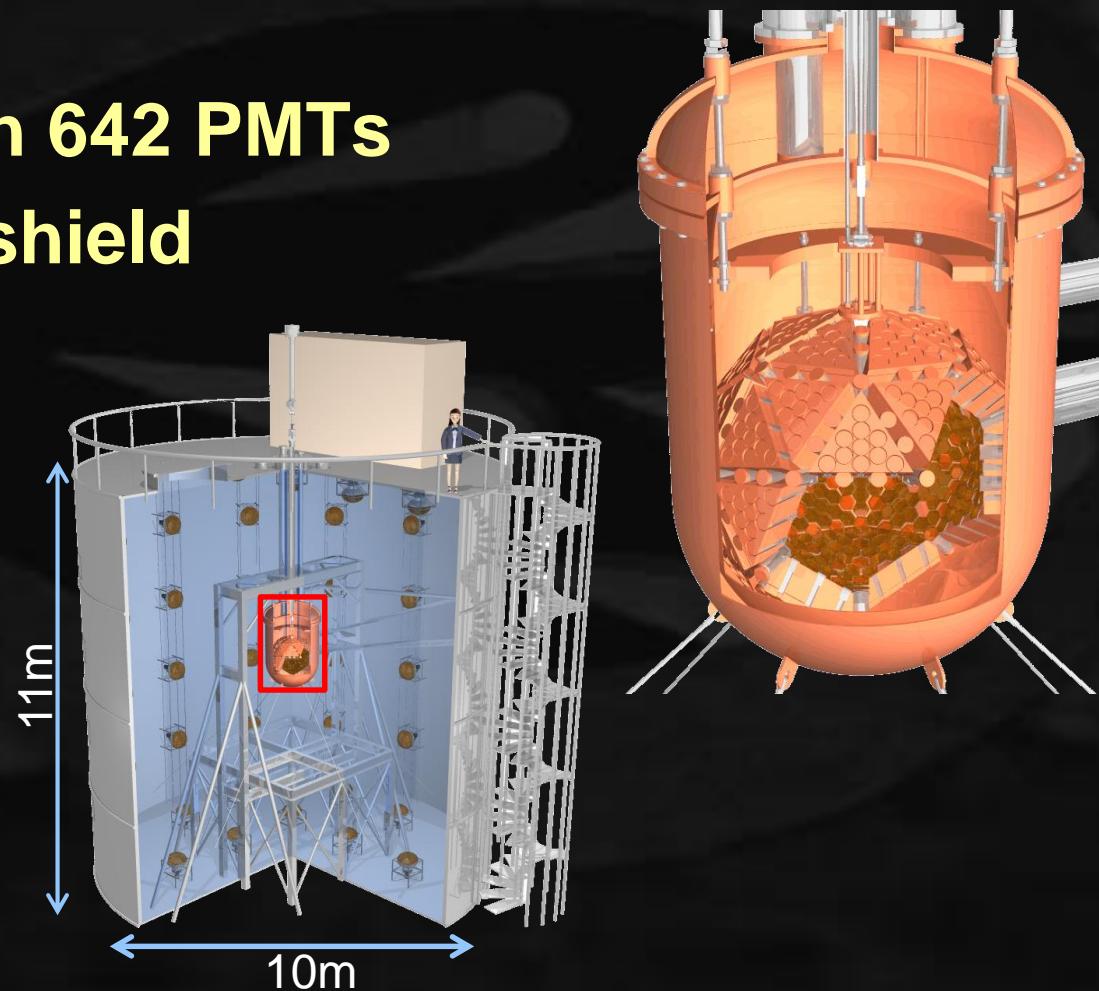
CoGent  
HPGe  
DAMIC

SIGNAL  
 $E_R < \sim 100\text{keV}$

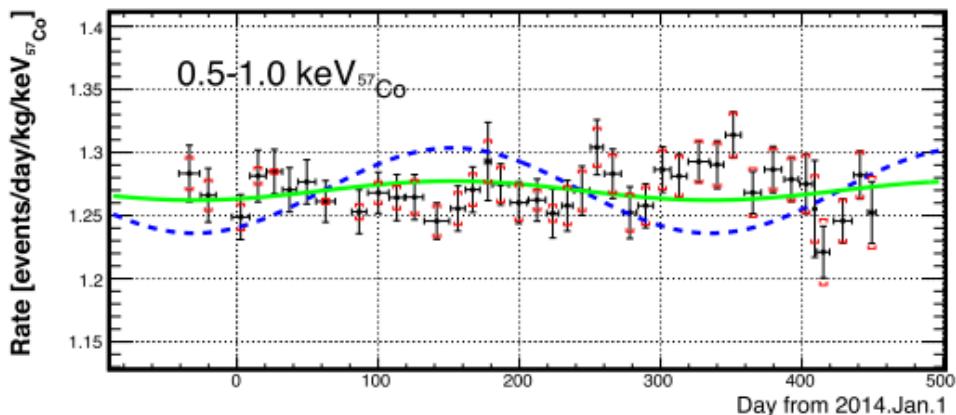
DM

## ◆ XMASS (Japan)

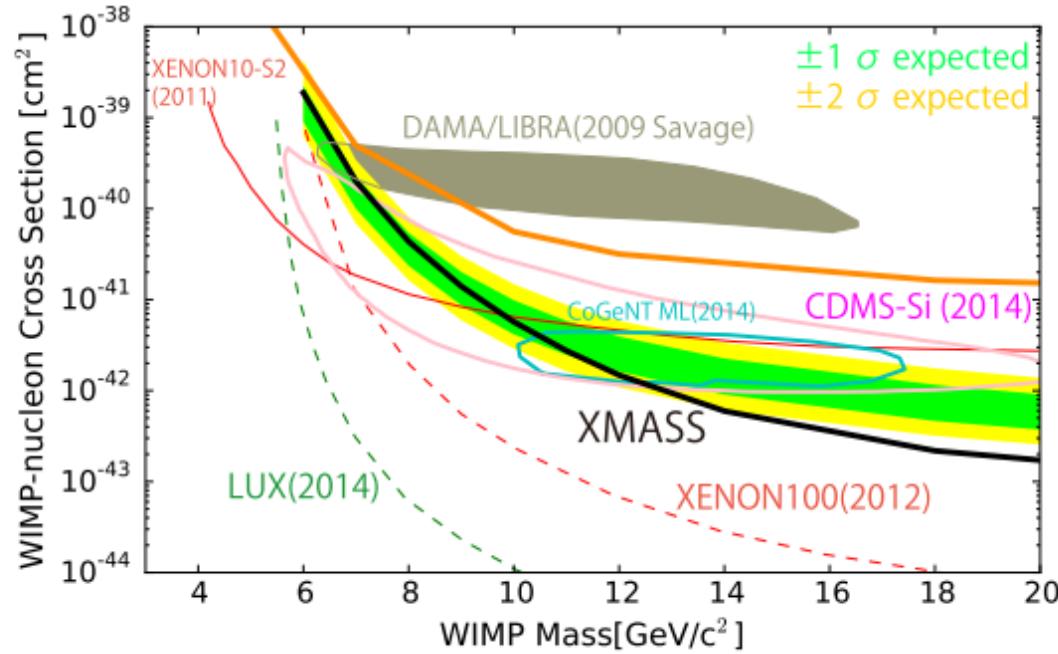
- In Kamioka
- A single-phase detector with ~830kg LXe
- Equipped with 642 PMTs
- Active water shield



- exposure 0.86ton years in only 1.3years

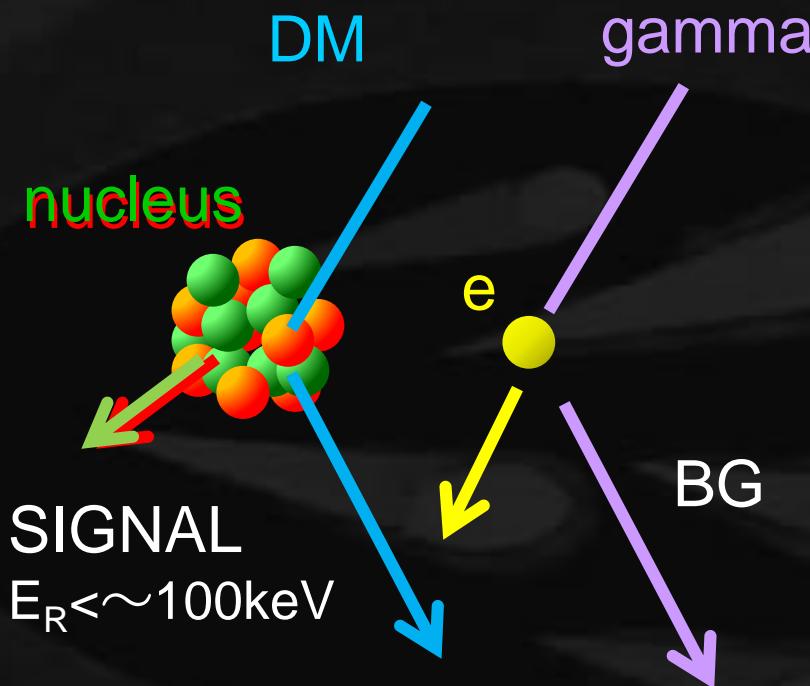


XMASS arXiv1151.04807



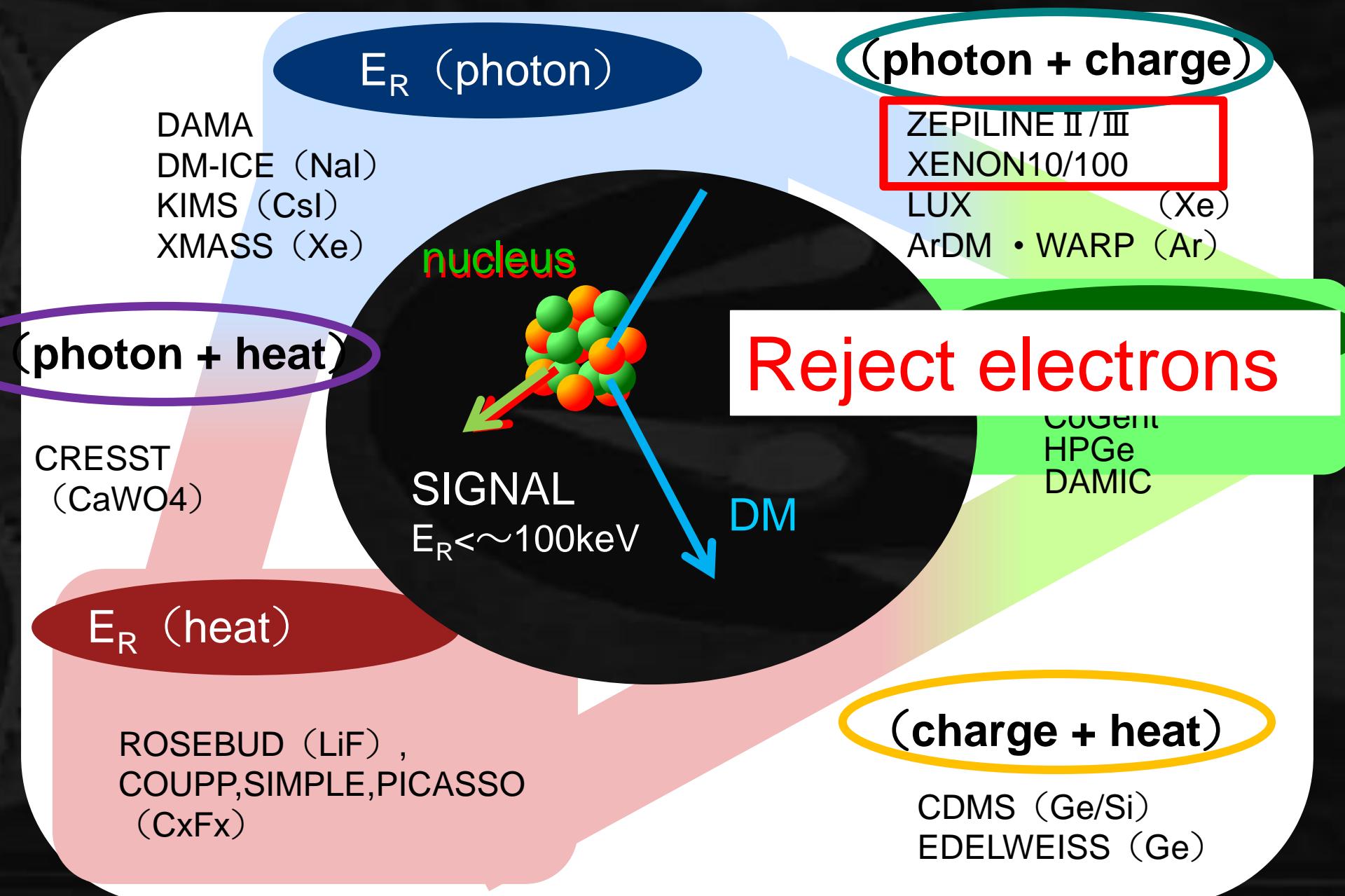
- excluded some part of DAMA region with seasonal modulation analysis

## ◆ DM direct detection



Key feature 2 :  
Particle ID for low background

# ◆ Direct Detection Methods



## ◆ 2-phase Liquid Xenon

- XENON100 : 161kg
- LUX : 370kg

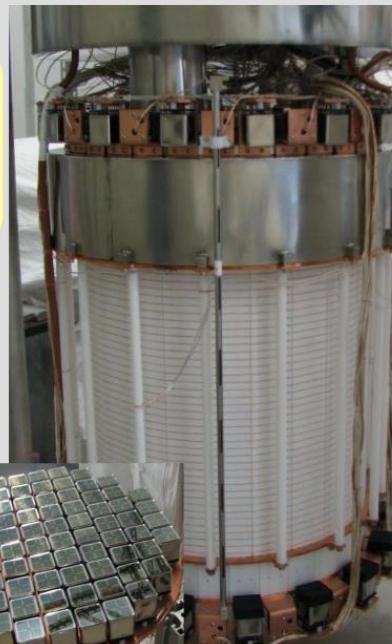
### XENON100

#### Goal (compared to XENON10):

- increase target  $\times 10$
- reduce gamma background  $\times 100$
- material selection & screening
- detector design

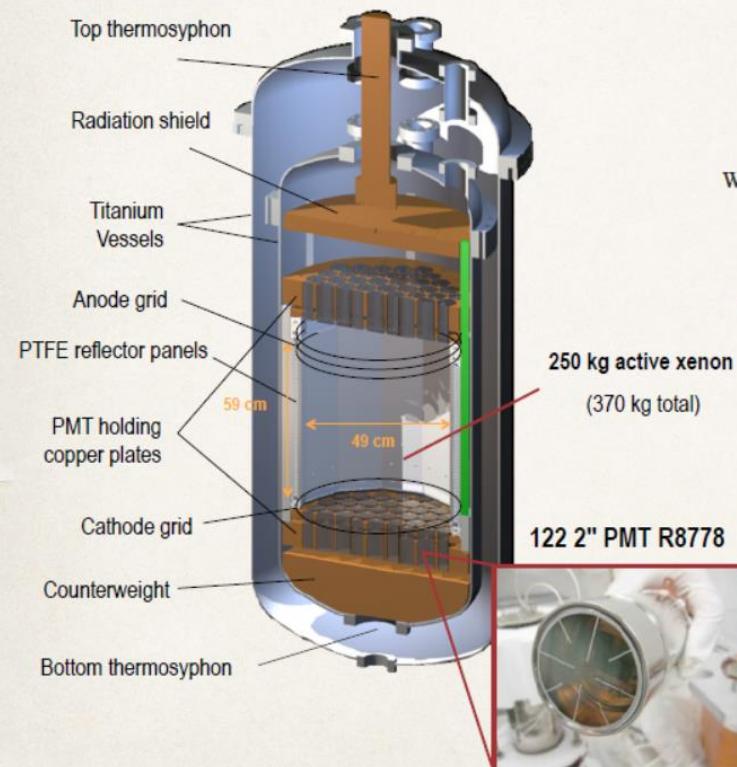
#### Quick Facts:

- 161 kg LXe TPC (mass:  $10 \times \text{Xe10}$ )
- 62 kg in target volume
- active LXe veto ( $\geq 4$  cm)
- 242 PMTs (Hamamatsu R8520)
- improved Xe10 shield (Pb, Poly, Cu, H<sub>2</sub>O, N<sub>2</sub> purge)



Marc Schumann (U Zürich) – XENON100

## The LUX Detector



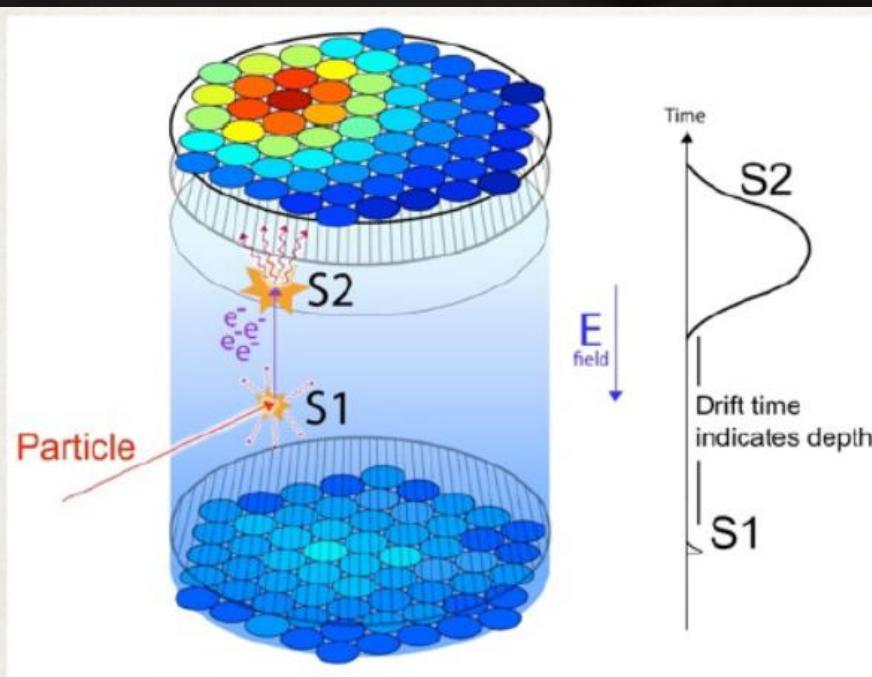
Alexandre Libdote

Astroparticle Physics 2014

LUX  
NIM  
arXiv

# 2-phase Liq. Xenon

- electron rejection

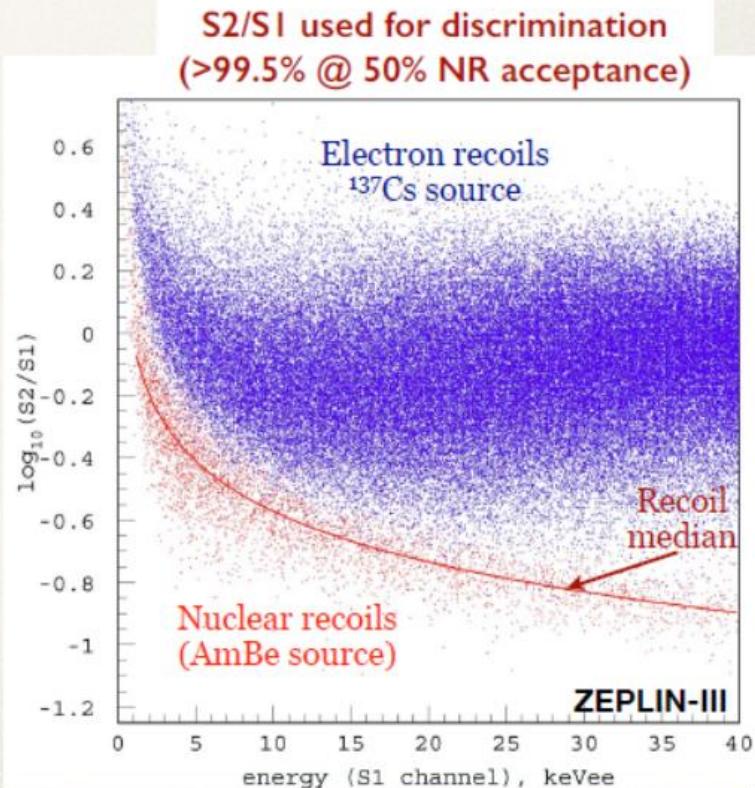


## 3D Position Reconstruction

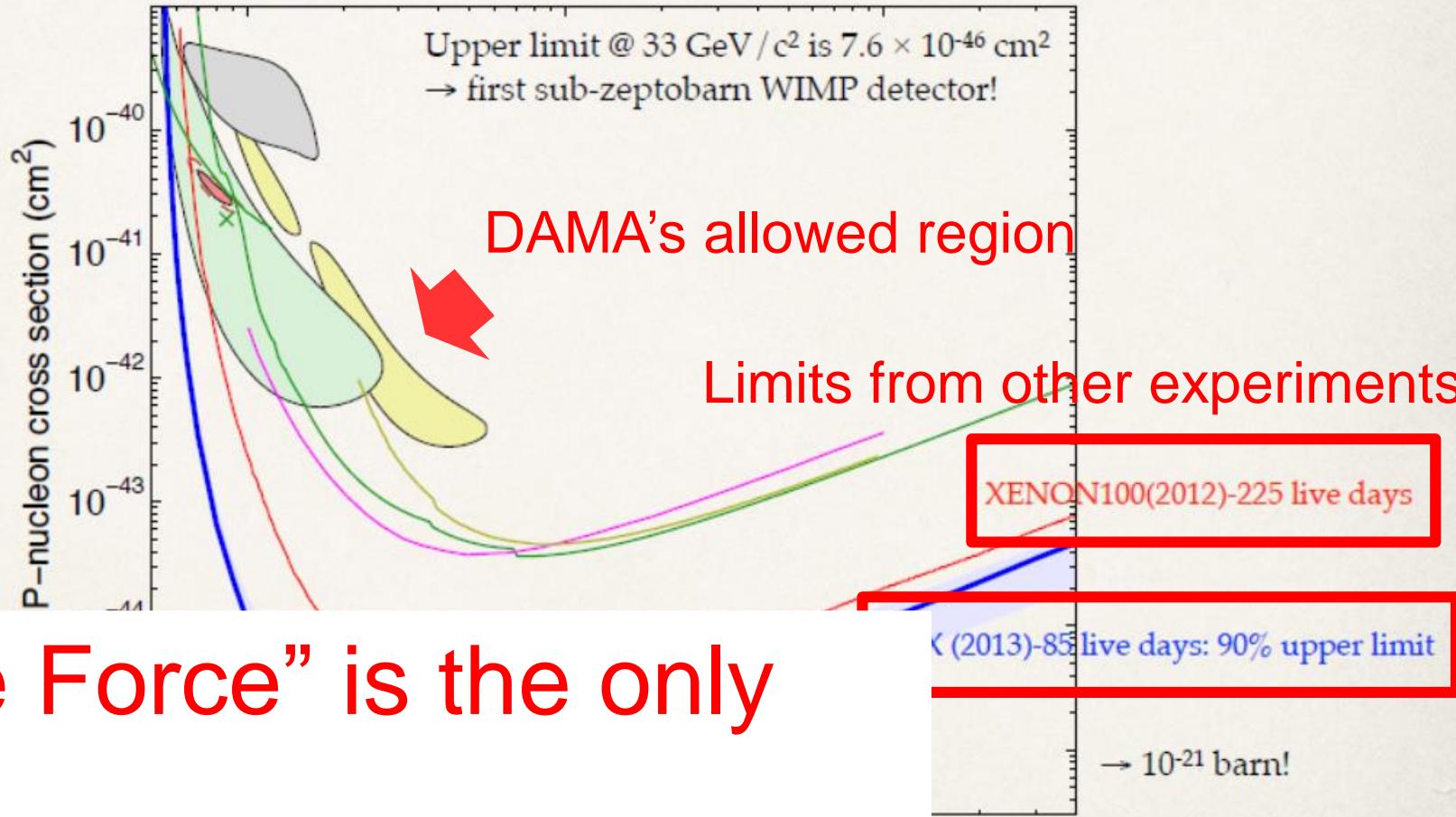
- Z from time difference between S1 and S2 (1.5 mm/ $\mu$ s @ 181 V/cm)
- XY reconstructed from light pattern (resolution of a few mm in WIMP search region)

## Discrimination technique

- WIMPs and neutrons interact with nuclei short, dense tracks
- $\gamma$ s and  $e^-$  interact with atomic electrons longer, less dense tracks



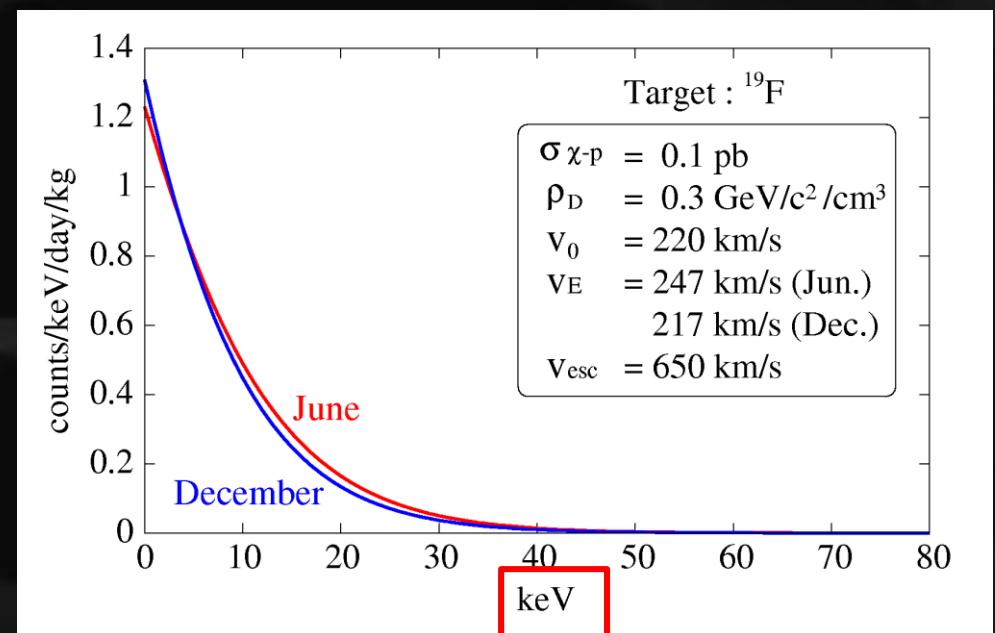
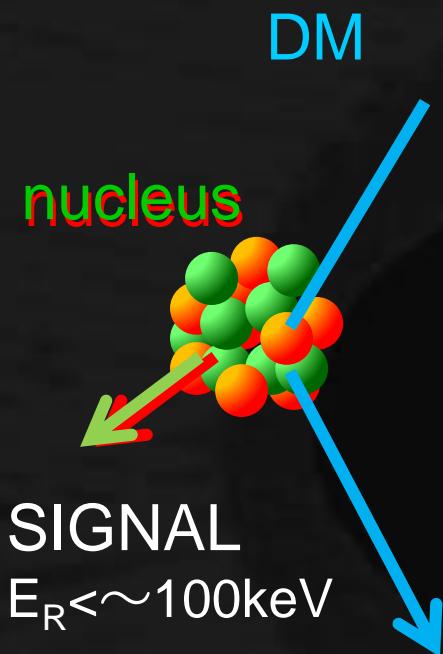
# Spin-independent limit



“Brute Force” is the only way?

again NO!

# ◆ DM direct detection



Key feature 3: Low threshold

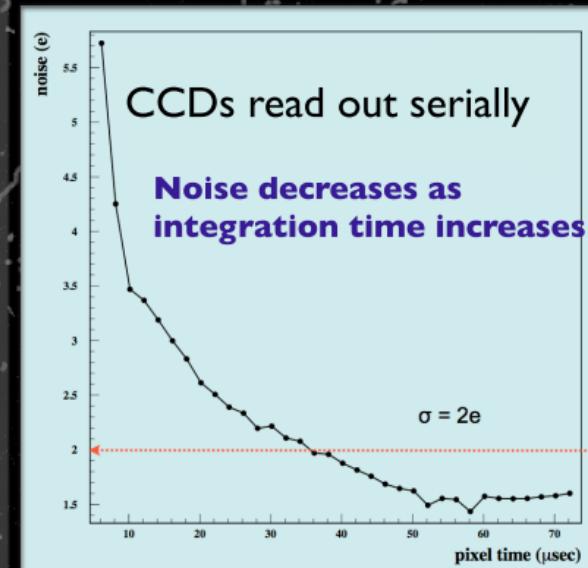
# ◆ Low threshold

J. Barreto et al. / Physics Letters B 711 (2012) 264–269

- DAMIC (CCD 0.5 g)
- Extremely low threshold

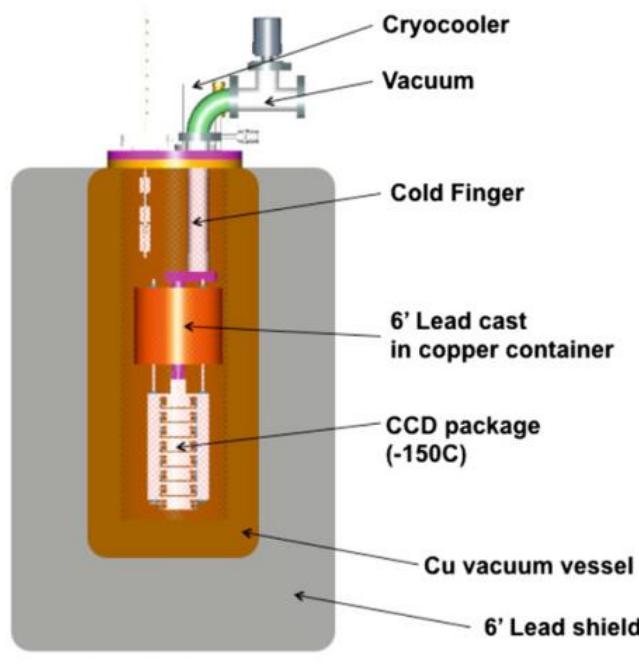
## Energy threshold for DM search

- CCDs cooled to -150 C to reduce noise
- 50  $\mu$ s / pixel
  - RMS of 2 e-
  - 7.2 eV equivalent ionizing in Silicon
- Threshold of 40 eVee
  - Lowest of current DM experiments
- We are pushing energy threshold even further
  - RMS of 0.2 e- may be possible

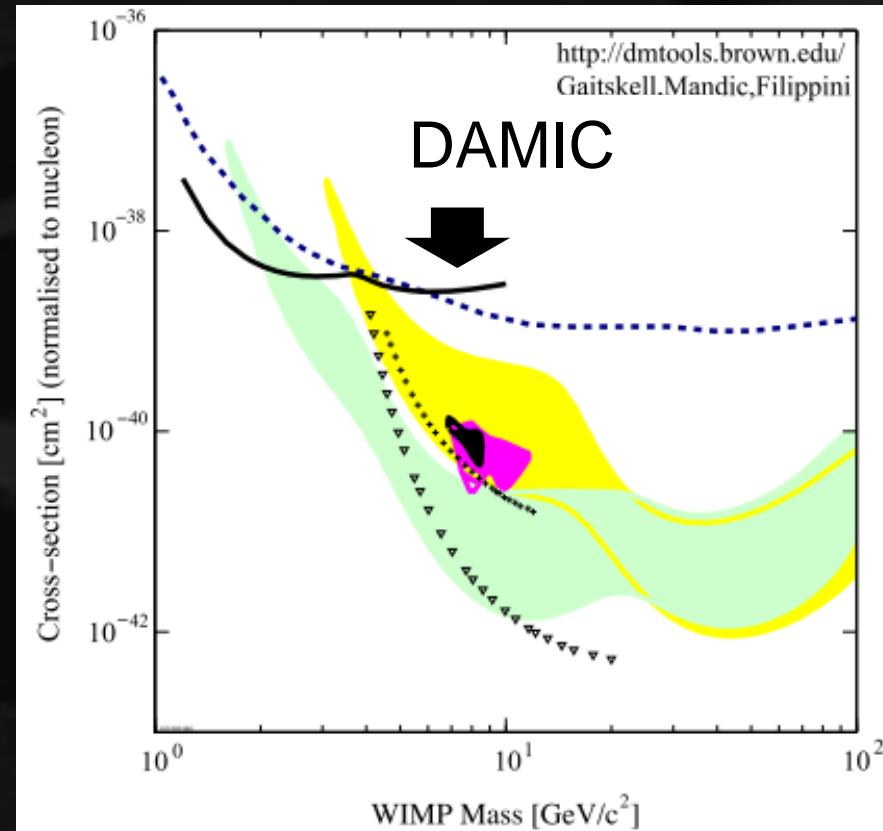


Experiment	Threshold
DAMIC	0.04 keV <sub>ee</sub>
COGENT	0.5 keV <sub>ee</sub>
CDMS II	3 keV <sub>ee</sub>
Xenon 100	8.4 keV <sub>nr</sub>

- exposure 0.5g  $\times$  11month
- comparable to kg-scale detectors



J. Barreto et al. / Physics Letters B 711 (2012) 264–269



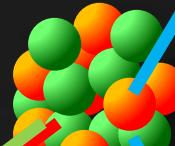
**Fig. 13.** Cross section upper limit at 90% C.L. for the DAMIC results (solid black) compared to CRESST 2001 (dashed blue), XENON10 [40] (triangles) and CDMS [41] (crosses). The shaded areas correspond to the 5-sigma contour consistent with the DAMA/LIBRA annual modulation signal (yellow: no ion channeling, green: ion channeling) [39]. The magenta contour corresponds to the DM interpretation of the CoGent observed excess and the black contour is the region of interest for the CoGent annual modulation signal [4]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

[http://dmtools.brown.edu/  
Gaitskell.Mandic.Filippini](http://dmtools.brown.edu/Gaitskell.Mandic.Filippini)

## ◆ DM direct detection

DM

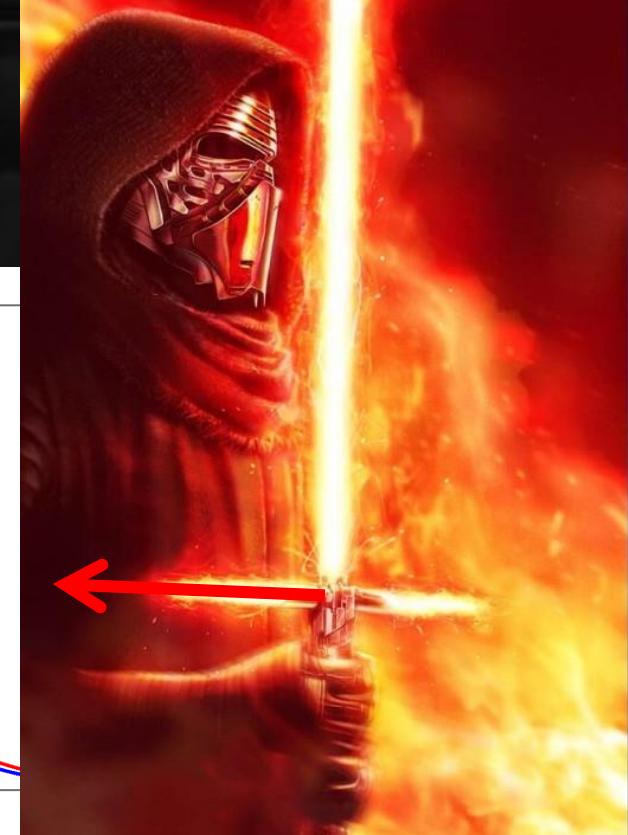
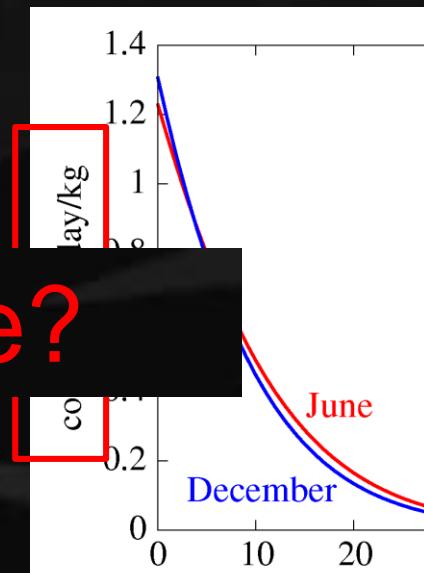
nucleus



ANYTHING else?

SIGNAL

$E_R < \sim 100\text{keV}$



YES, we have another AXIS

Key feature 1 : Large mass

Key feature 2 : Particle ID

Key feature 3: Low threshold

# ◀ another axis : nuclear track

PRL73(1994)1067



FIG. 2. A false color CCD image resulting from a  $^{252}\text{Cf}$  neutron source. The colors black, blue, red, and white represent the order of increasing light intensity levels. The area displayed represents a 25 cm by 25 cm section of the detector plane. See the text for a description of image features.



nuclear tarack +  $E_R$

$E_R$ 検出 (光)

DAMA  
KIMS

(光+温度)

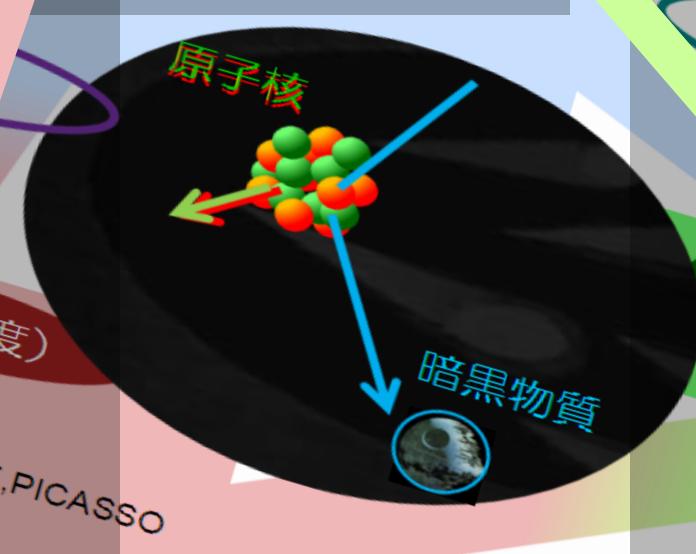
CRESST

$E_R$ 検出 (温度)

ROSE

COUP

SIMPLE, PICASSO



(光+電離)

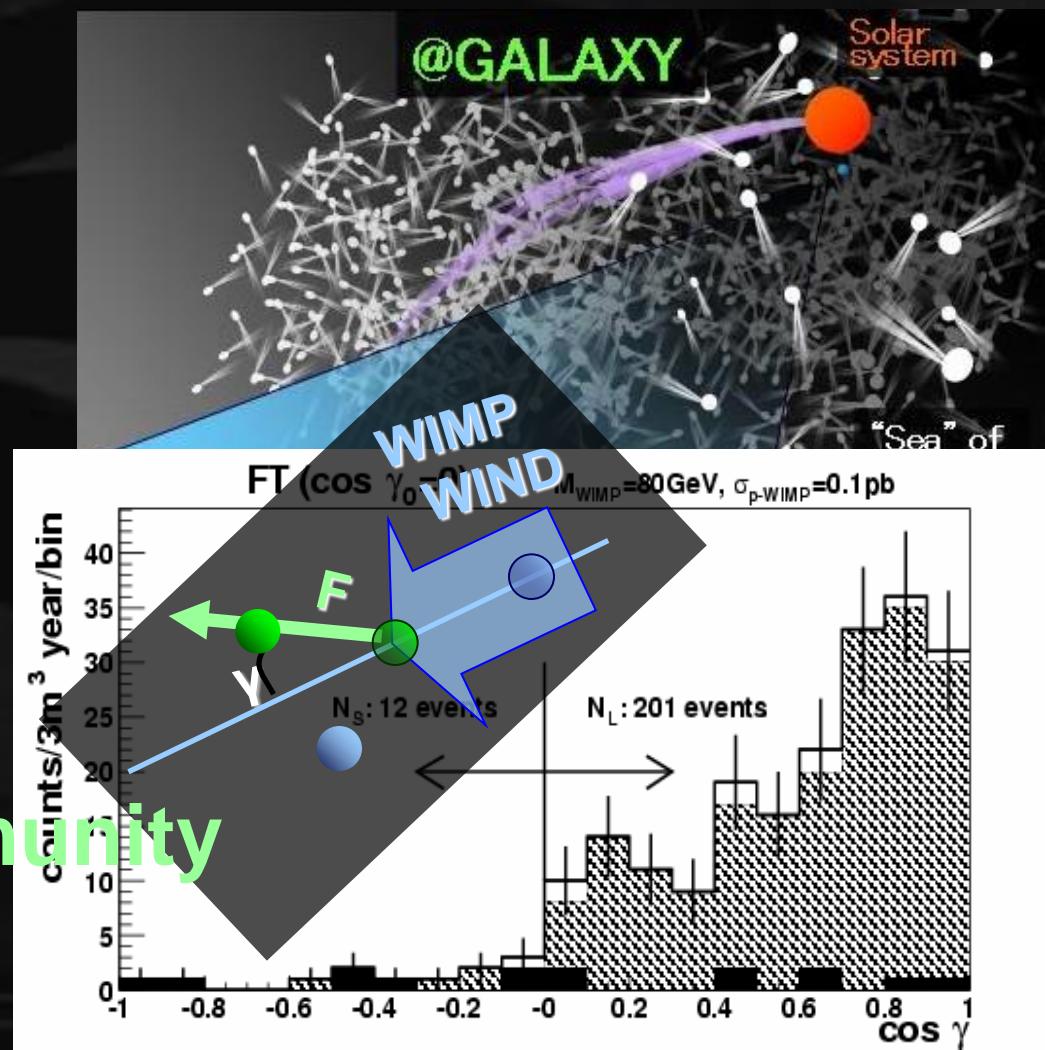
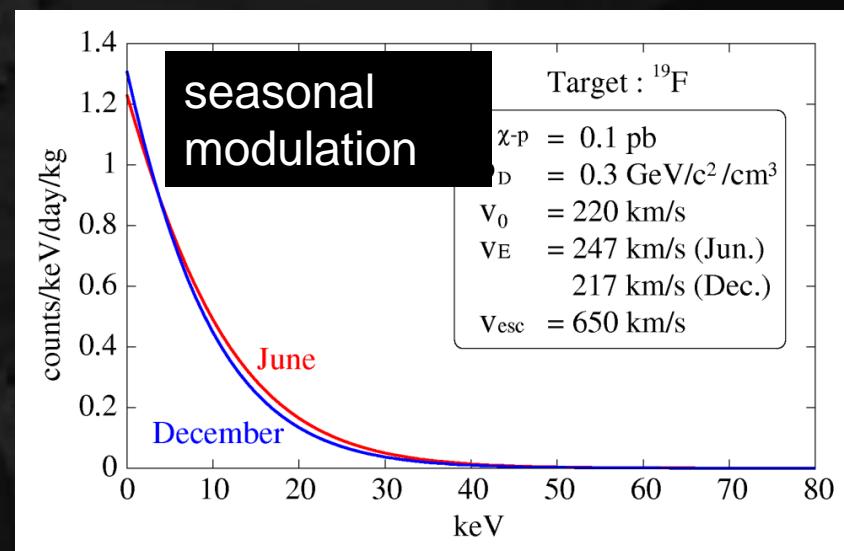
ZEPILINE II/III  
XENON10/100  
ArDM · WARP

$E_R$ 検出 (電離)

HPGe

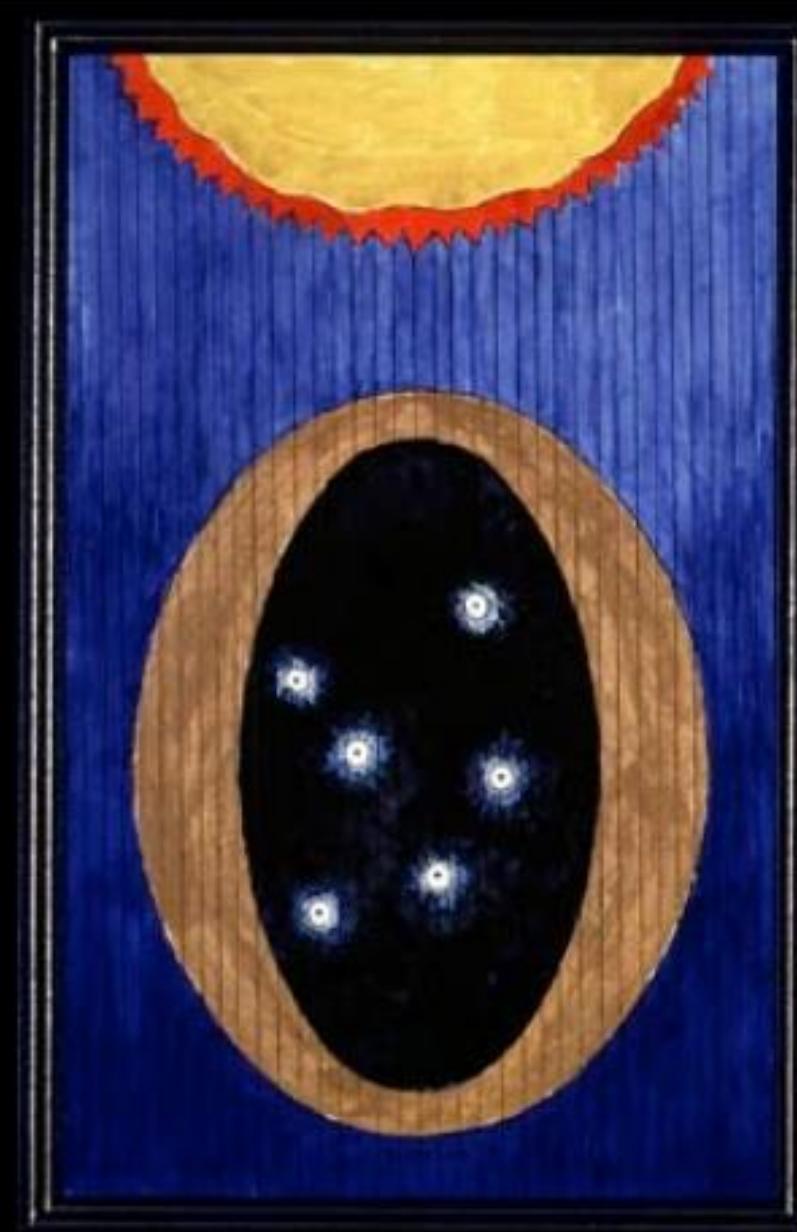
# Recoil nucleus tracks?

- Direction-sensitive to DM
- Large asymmetry due to the solar motion
- DM-WIND



International community  
"CYNGUS"

# ◆ Is direction sensitivity important? YES.



S  
ha  
som  
fysi  
t  
m  
R  
förl  
fij  
-  
jetc

# Cygnus, awaken.

The image is a collage of six panels, each showing a different particle detector setup or component, with a central world map indicating their geographical locations:

- DRIFT [UK]**: Shows a large cylindrical detector with a red vertical dimension arrow labeled "1m".
- NEWAGE [Kobe +]**: Shows a rectangular detector with a red horizontal dimension arrow labeled "30cm".
- HAWAI**: Shows a close-up of a detector component with a red arrow pointing to it from the world map.
- DMTPC [USA]**: Shows a close-up of a detector component with a red arrow pointing to it from the world map.
- MIMAC [France]**: Shows a close-up of a detector component with a red arrow pointing to it from the world map.
- EMULSION [Nagoya +]**: Shows a large green detector component with a red horizontal dimension arrow labeled "10cm".

A central white circle contains a world map with red arrows pointing from the detector labels to specific locations:

- An arrow points from HAWAI to the Hawaiian Islands.
- An arrow points from DMTPC to the USA.
- An arrow points from MIMAC to France.
- An arrow points from NEWAGE to Japan (Kobe).
- An arrow points from EMULSION to Japan (Nagoya).

**DRIFT [UK]**

- MWPC (2mm pitch)
- First started direction-sensitive method
- Underground
- Low background
- Large size ( $1\text{m}^3$ )

**NEWAGE [Kobe +]**

- $\mu$ -PIC (400 $\mu\text{m}$  pitch)
- Only NEWAGE obtained direction-sensitive limit
- Underground

**HAWAI**

**DMTPC [USA]**

**MIMAC [France]**

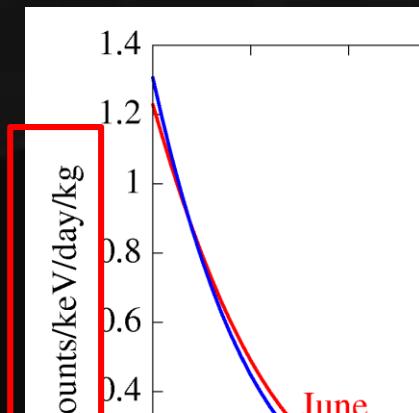
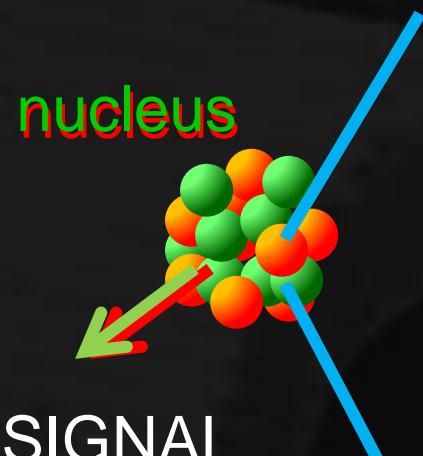
- Micromegas (~400 $\mu\text{m}$  pitch)
- Measured quenching factor in detail
- R&D at surface

**EMULSION [Nagoya +]**

- emulsion (400 $\mu\text{m}$  pitch)
- good position resolution
- large mass
- No time resolution

## ◆ DM direct detection

DM



Special feature : Direction-sensitivity

Key feature 1 : Large mass

Key feature 2 : Particle ID

Key feature 3: Low threshold

Thank you

*May the Dark Matter be with you.*