DARWIN (XLZD)

(Dark matter Wimp search with liquid xenoN)

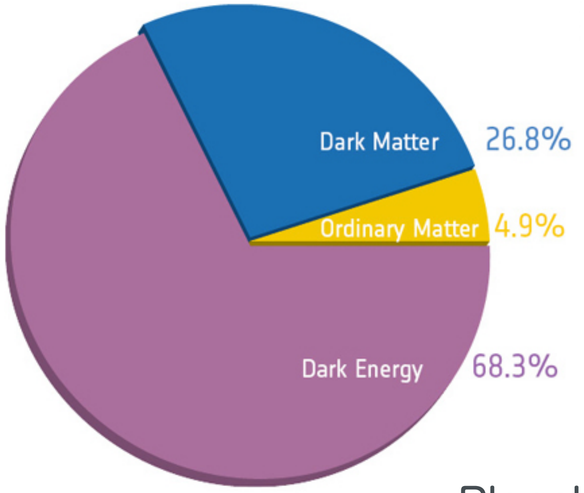
Direct Dark Matter Search

Kavli IPMU, The University of Tokyo
Masaki Yamashita

Dark Matter

DARWIN

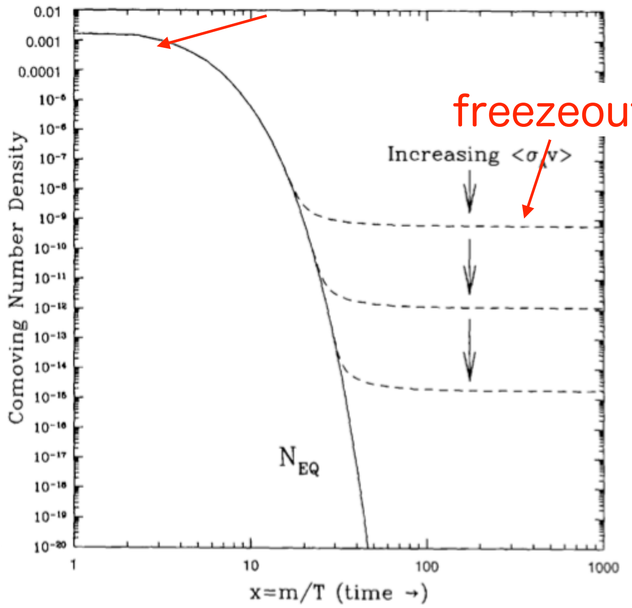
- **Composition of the Universe**
  - Dark Energy/Matter　95% unknown
    - Dark Energy(68%), Dar Matter(27%)



Planck(2013)

- **What is Dark Matter?**
  - WIMP, Axion, Primordial Black Hole …
  - Weakly Interacting Massive Particle (WIMP)
    - **WIMP appears in many beyond the standard models, such as SUSY.**
    - **WIMP is not excluded by the experiments but is detectable near future.**
    - **WIMP is a relic from the simple mechanism of the thermal freeze-out process.**
      - e.g., successful scenario CMB, Big Bang Nucleosynthesis (H, He,..)

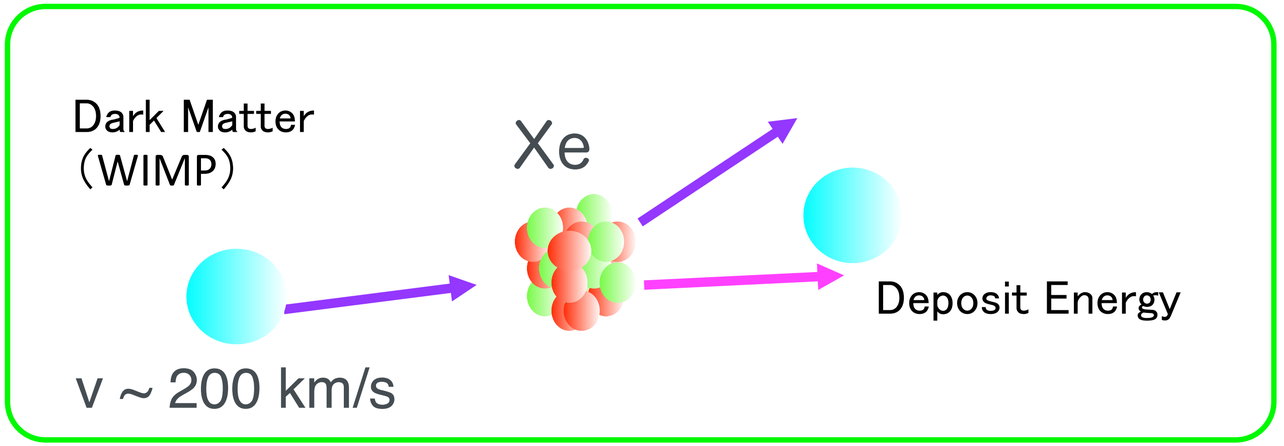
production/annihilation



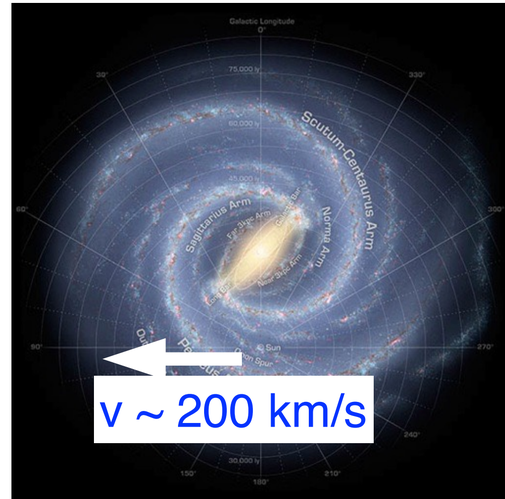
motivated particle theory, particle experiment, and cosmology

=> WIMP miracle

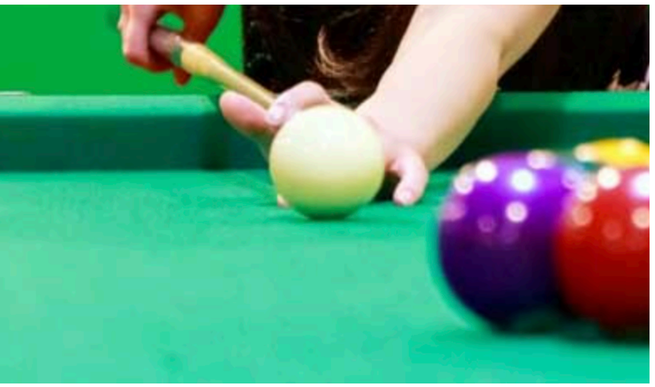
Direct Dark Matter Search

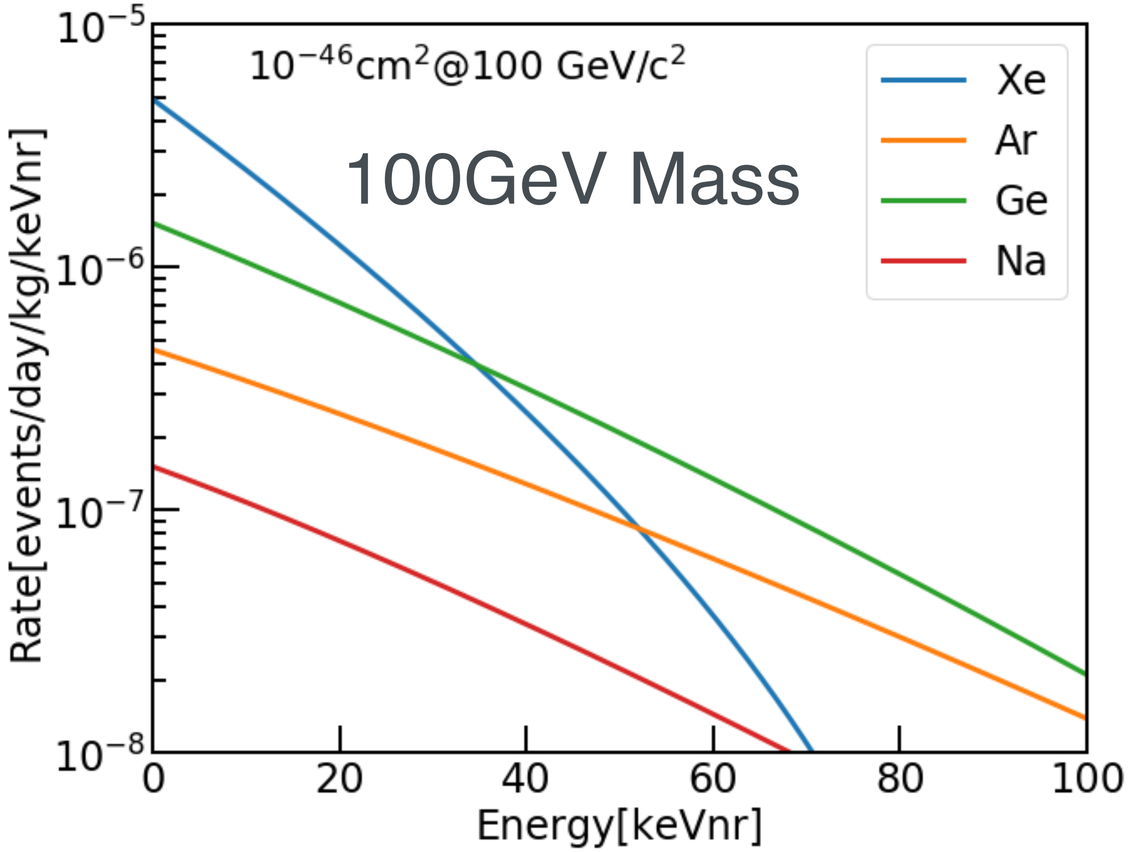


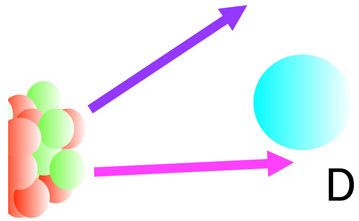
- WIMP mean velocity is about 230 km/s at the location of our solar system.
- WIMPs interact with ordinary matter through elastic scattering on nuclei.
- Typical nuclear recoil energies are of order of 1 to 100 keV.



Direct Dark Matter Search







- WIMP mean ve ur solar system.
- WIMPs interac ring on nuclei.
- Typical nuclear

event rate Form Factor Motion dynamics

$$\frac{dR}{dE_R} = \frac{R_0 F^2(E_R)}{E_0 r} \frac{k_0}{k} \frac{1}{2\pi v_0} \int_{v_{min}}^{v_{max}} \frac{1}{v} f(\mathbf{v}, \mathbf{v_E}) d^3\mathbf{v}$$

What we get from Direct Detection?

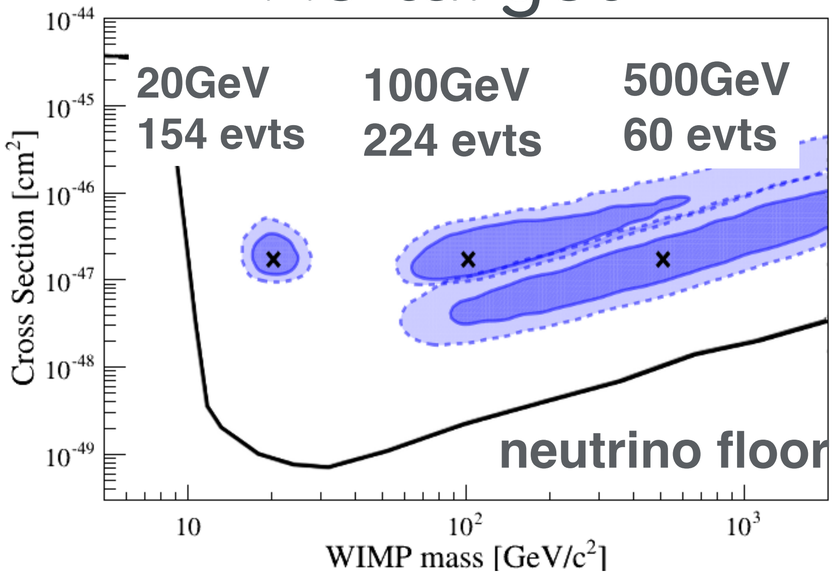
once we detect dark matter….

- **DM particles are traveling around us.**
- **Mass of DM particles**
- **DM-nucleus scattering cross-section**

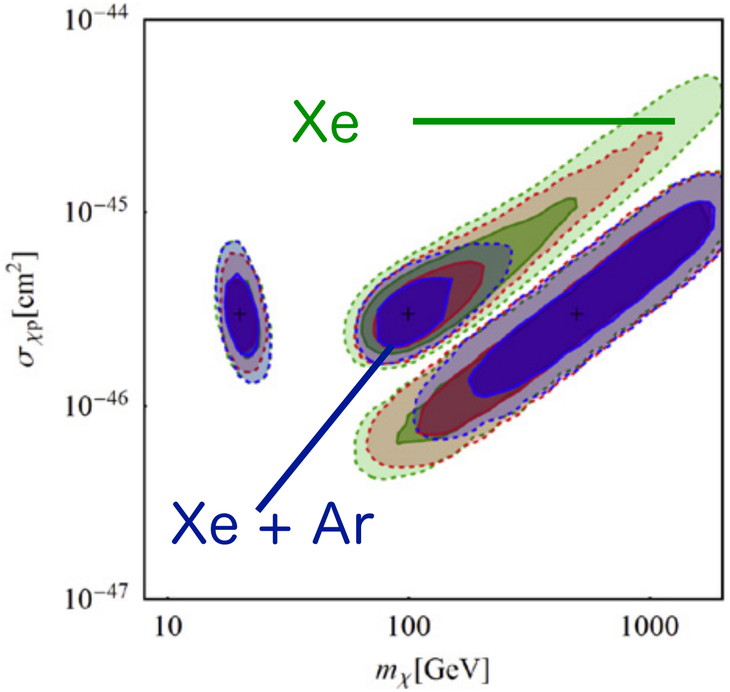
Complementarity of targets

- **It will rely on ρ_{dm} (= 0.3 GeV/cm^3), Velocity distribution (= > Maxwellian, DM stream?)**

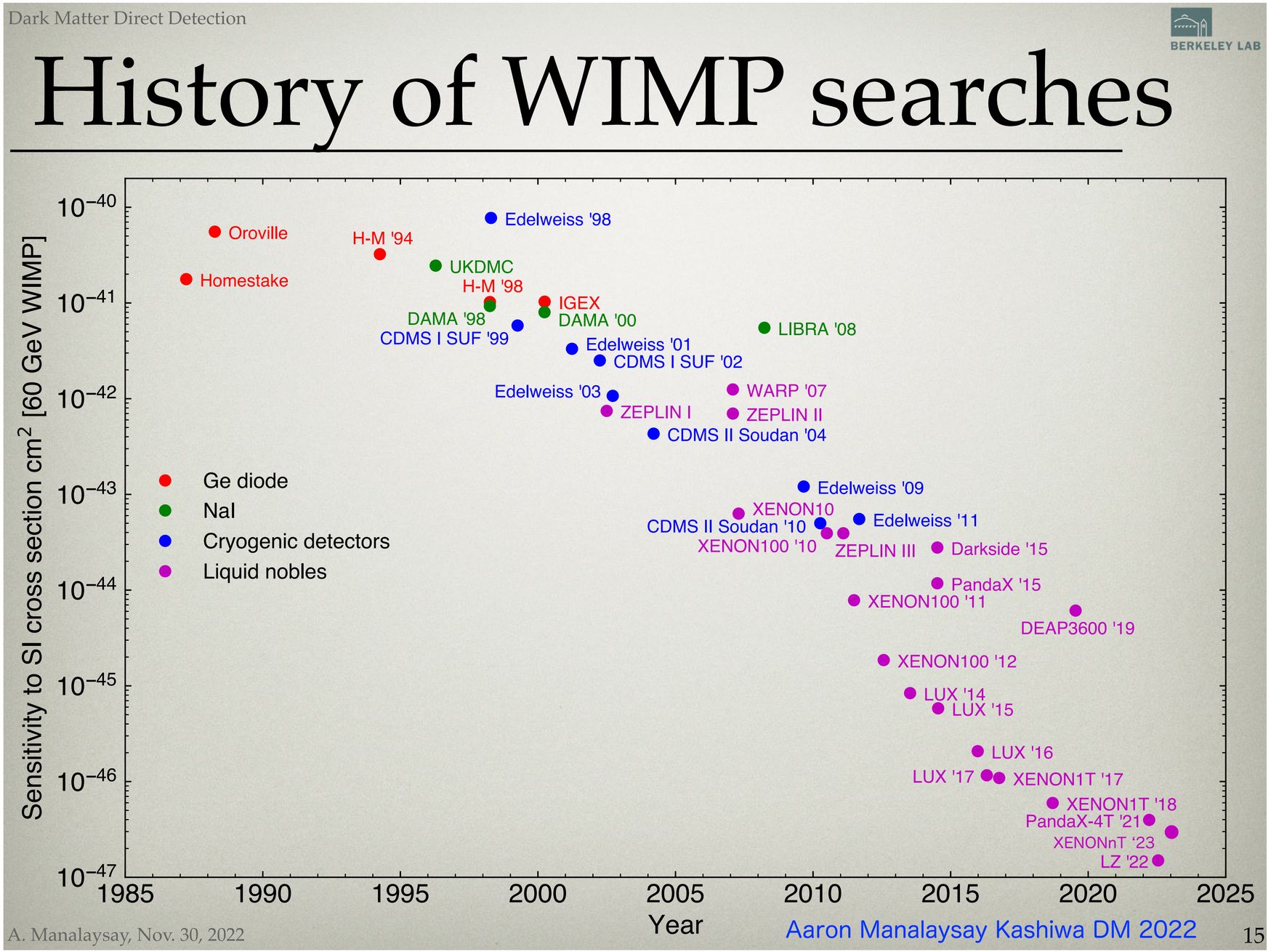
Xe target



J. Aalbers *et al* JCAP11(2016)017



J. Newstead et al , PRD 88, 076011 (2013)



-Semiconductor (Ge, Si)

-Cryogenics (Ge, Si)

- Photon + Charge

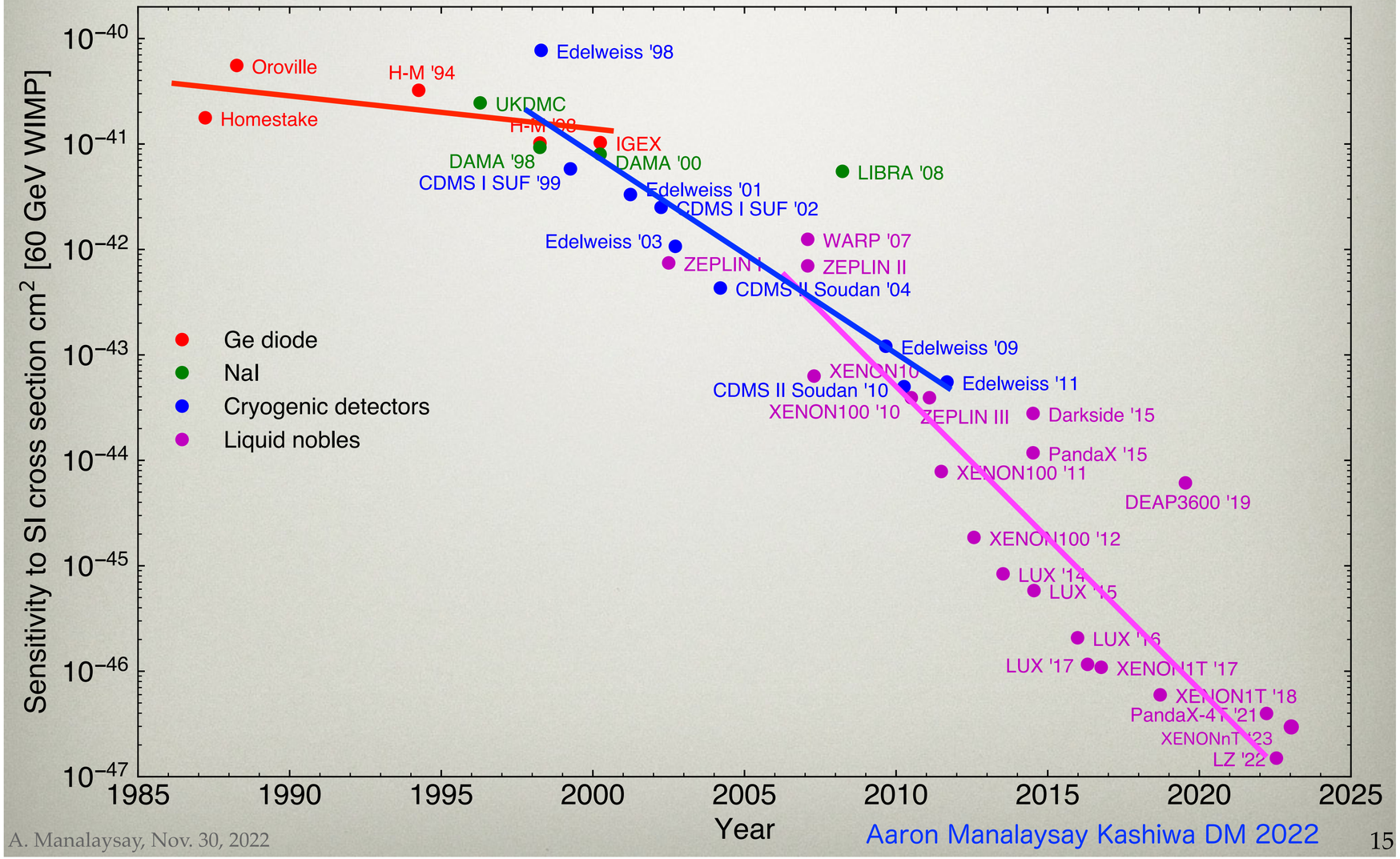
-Liquid Noble Gas (Xe,Ar..)

-Scintillation + Charge

Dark Matter Direct Detection

BERKELEY LAB

History of WIMP searches



A. Manalaysay, Nov. 30, 2022

15

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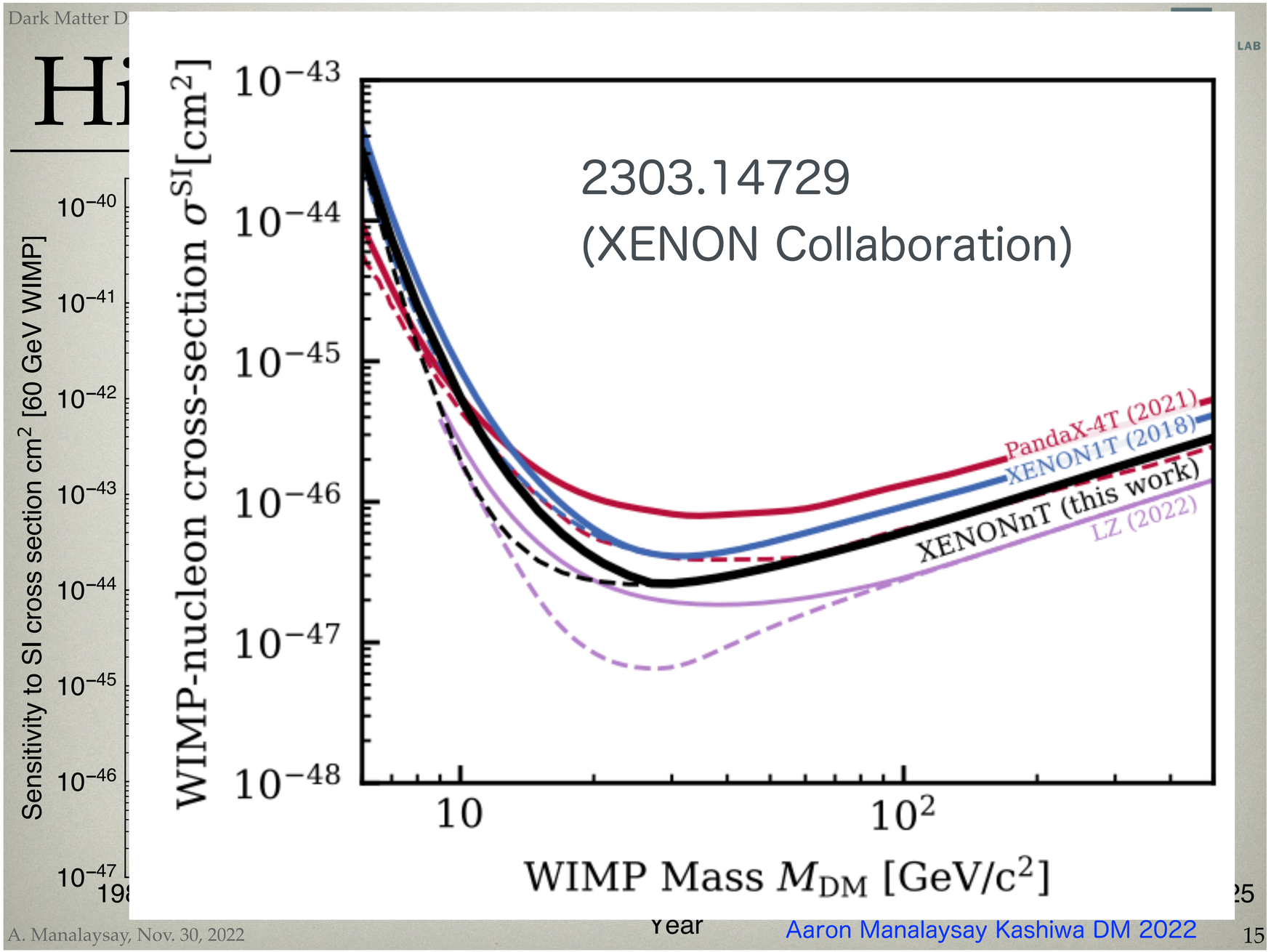


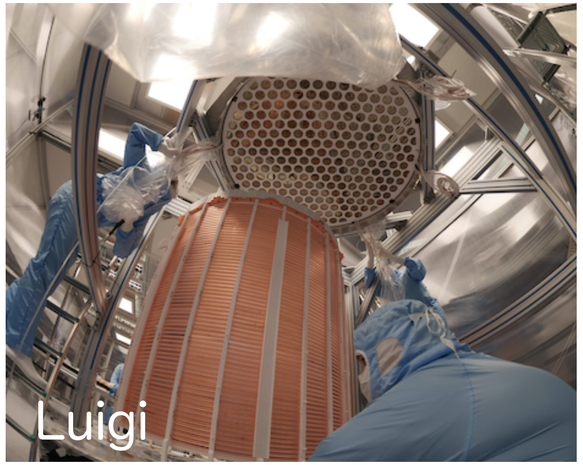
DARWIN

-Semiconductor (Ge, Si)

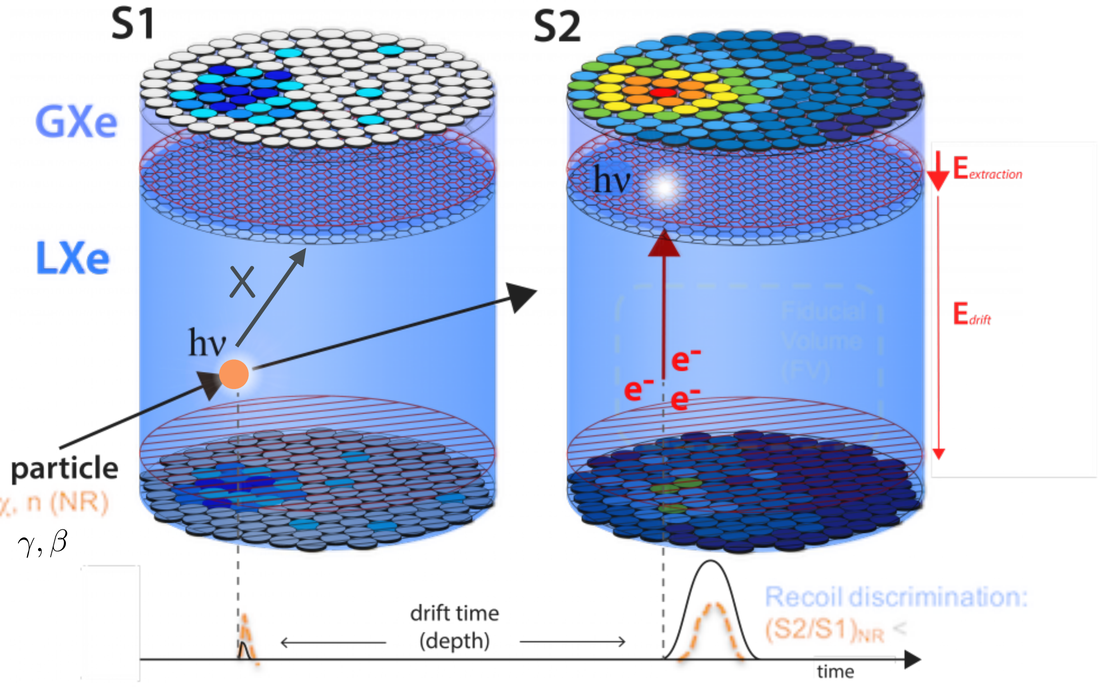
-Cryogenics (Ge, Si)
- Photon + Charge

-Liquid Noble Gas (Xe,Ar..)
-Scintillation + Charge

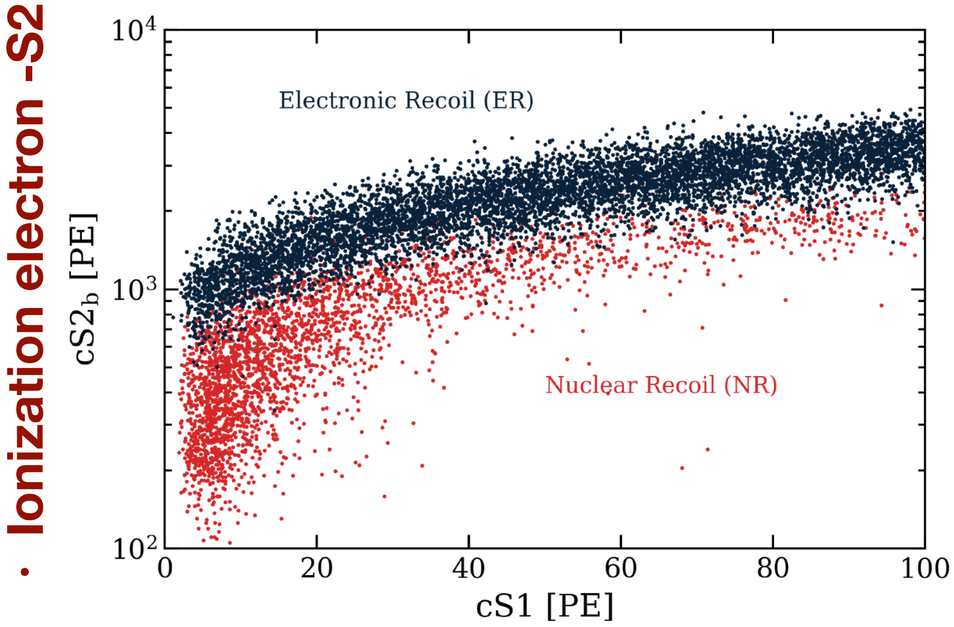
Gas-Liquid Two-phase Xe Time Projection Chamber



- Signal from Scintillation Light(S1) and Charge (S2)
  - 3D Position Reconstruction: x-y (S2) and z (drift time)
  - Xe: Z(=54), Powerful Self-shielding of external radiations such as gamma rays.
  - Identify multiple sites events: Compton Scattering, Neutron
- Particle identification: the nuclear recoil signal (WIMP) from electronic recoil (γ, β rays) with S2/S1 ratio (> 99%)



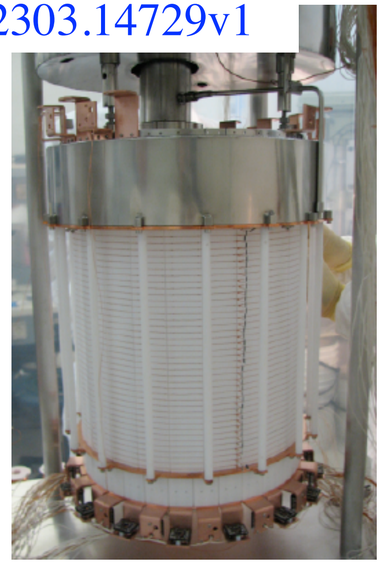
- S1: Scintillation light
- S2: Ionization (Proportional Light)

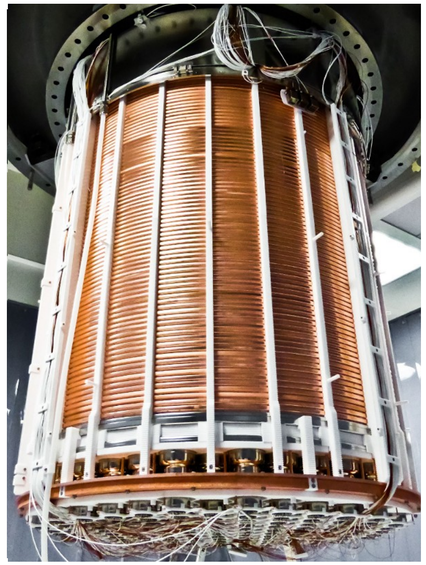


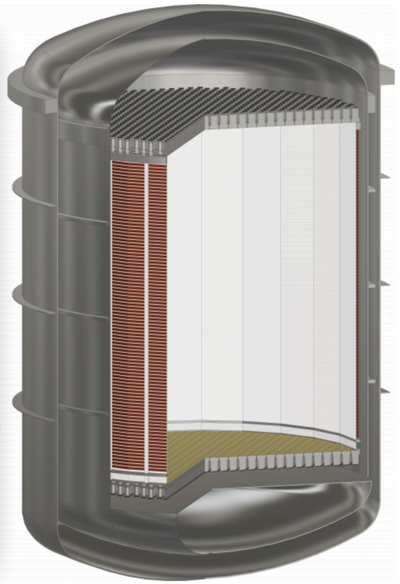
- **Scintillation light - S1**

History of XENON

XENON10	XENON100	XENON1T	XENONnT	DARWIN
2005-2007	2008-2016	2012-2018	2020-	2027–
15 kg	161 kg	3200 kg	8400 kg	50 tonnes
15 cm	30 cm	96 cm	150 cm	260 cm
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2	~10^{-49} cm^2

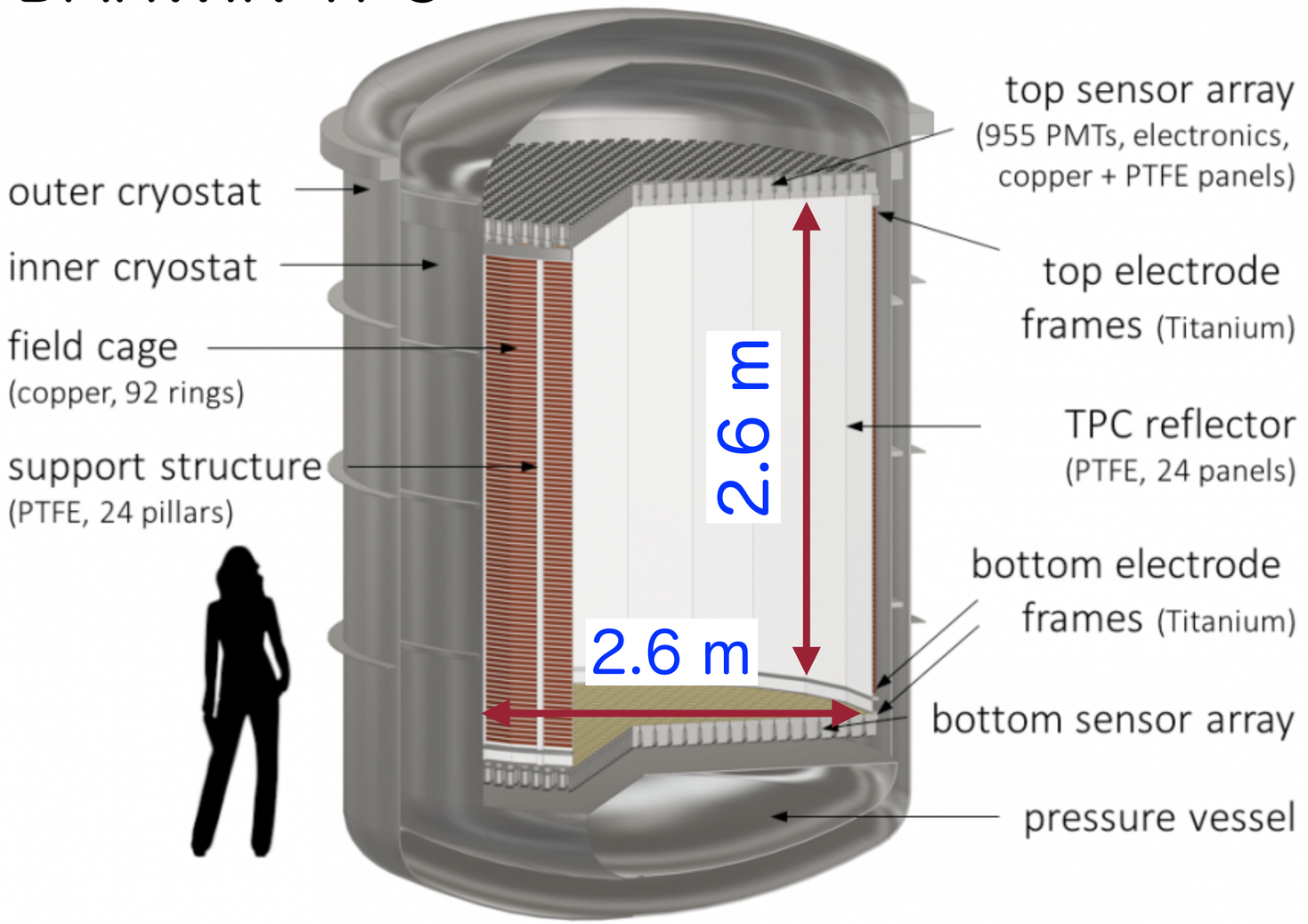






DARWIN Detector

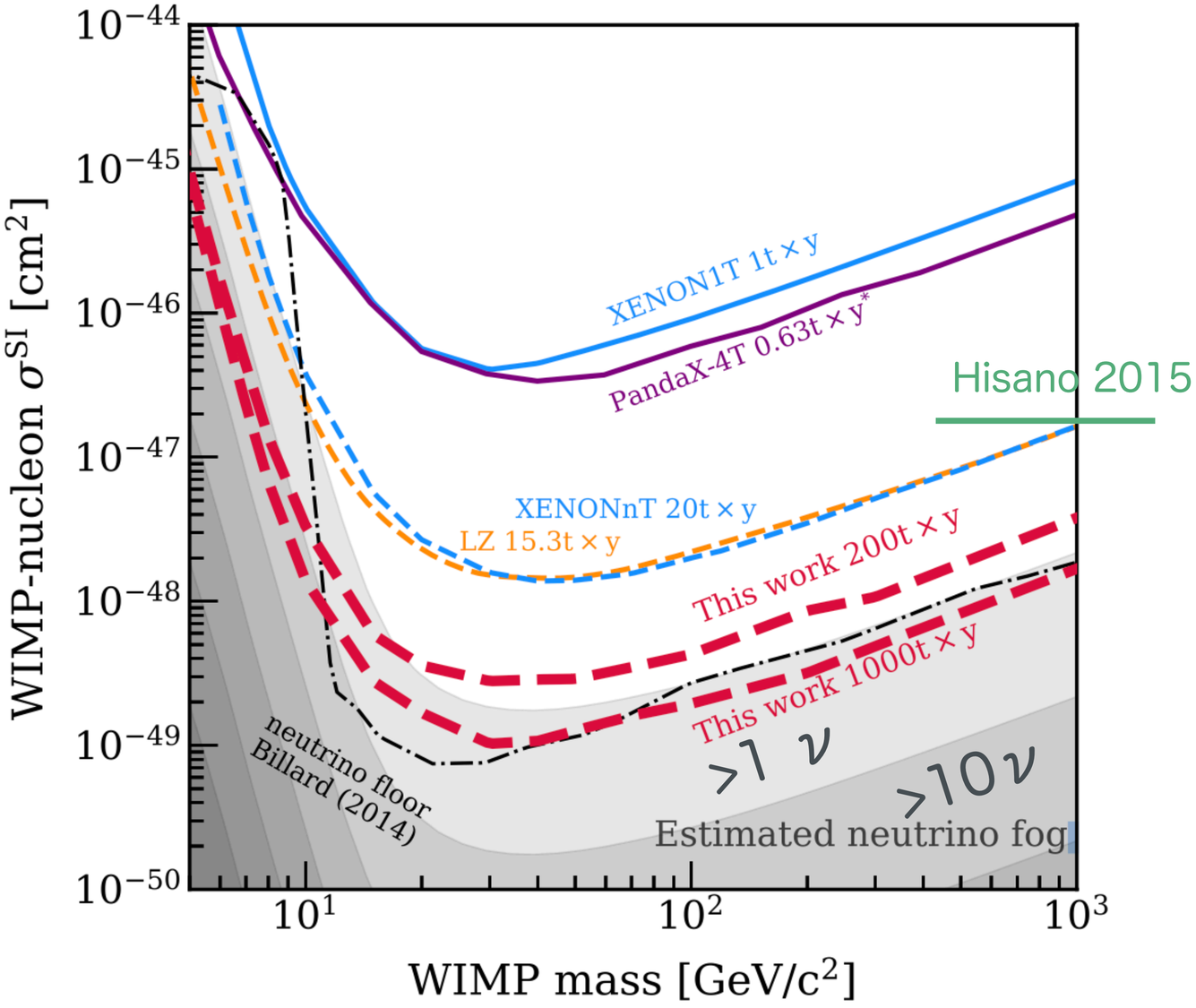
DARWIN TPC



- Total: 50-tonne LXe
  40-tonne Fiducial volume
  (X 10 XENONnT)

- Total: ~2000 3'' PMTs
  (Top + Bottom)
  PTFE reflector

DARWIN (XLZD) Sensitivity



Hisano 2015

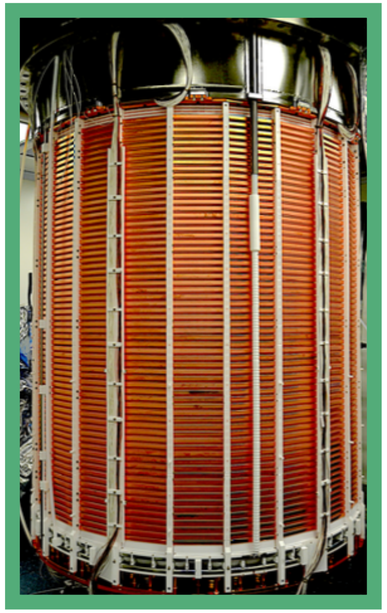
- X 10 higher sensitivity than goal of current ongoing experiments(XENONnT, LZ, PandaX-4
- Exploring WIMP cross sections into the 'neutrino fog' (coherent elastic neutrino-nucleus scattering).
- Ultimate Direct Detection detector

Realization of DARWIN

XENONnT Background

arXiv:2303.14729v1	Nominal	Best Fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	$0.86^{+0.08}_{-0.07}$
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4	0.42 ± 0.17
CEνNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.011
AC	4.3 ± 0.2	4.32 ± 0.15	0.366 ± 0.013
Surface	14 ± 3	12^{+0}_{-4}	$0.35^{+0.01}_{-0.11}$
Total Background	154	152 ± 12	2.0 ± 0.2
WIMP	-	2.6	1.3
Observed	-	152	3

Realization of DARWIN (XENONnT Technology)



TPC

XENONnT
8.5 tonne

LXe

purification

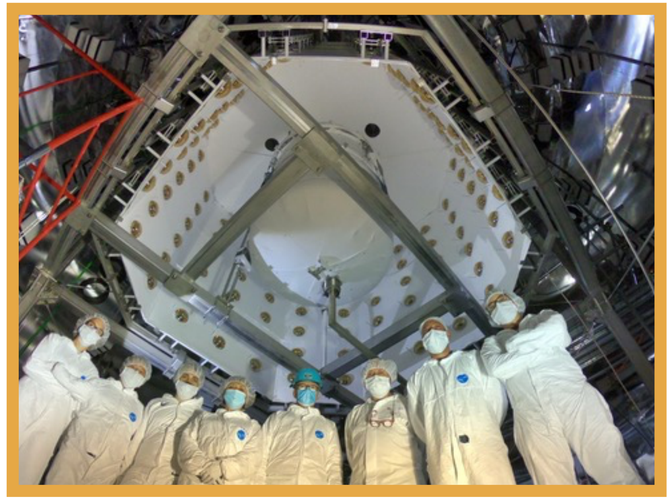
- Faster xenon cleaning
- 2L/min LXe

↑Sensitivity

^{222}Rn distillation

- Reduce Rn (^{214}Pb) from pipes, cables, cryogenic system

↓ BG (ER)

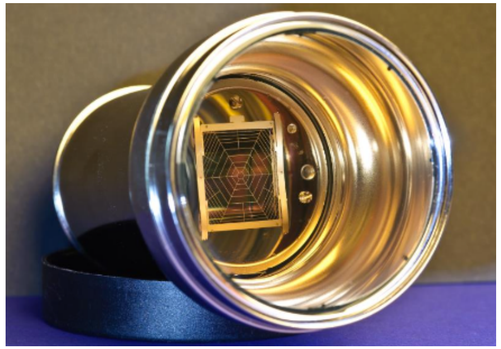


nVeto

- Inner region of existing muon veto
- optically separate
- Gd in the water tank
- 0.5 % $Gd_2(SO_4)_3$

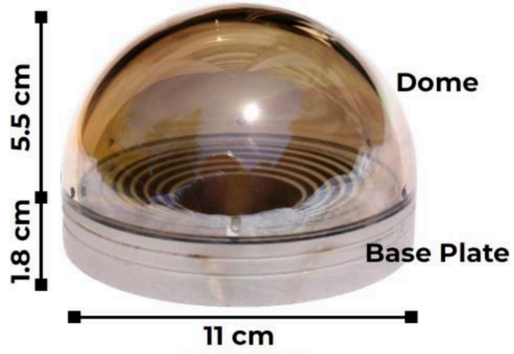
↓ BG (NR)

DARWIN: R&D Photosensor

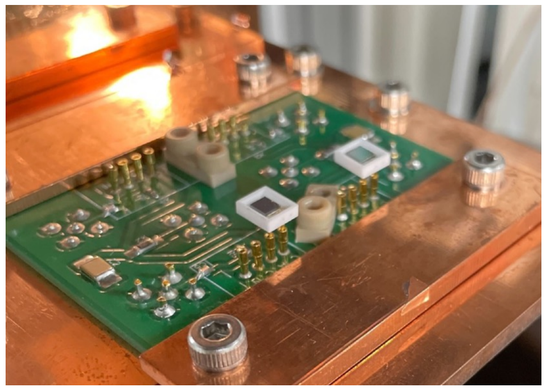


R11410 (LZ, XENONnT, PandaX)

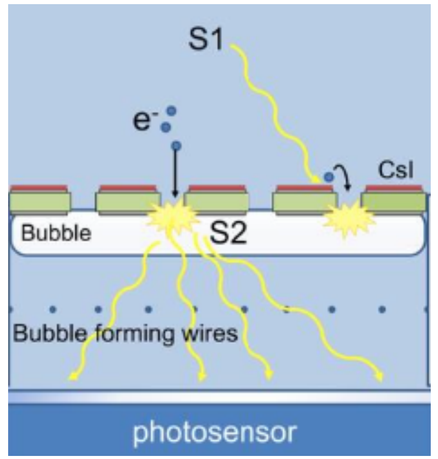
R13111 (XMASS)
Lowest radioactivity



Hybrid sensors
e.g. Abalone



Low Dark Current SiPM (See Kobayashi talk)

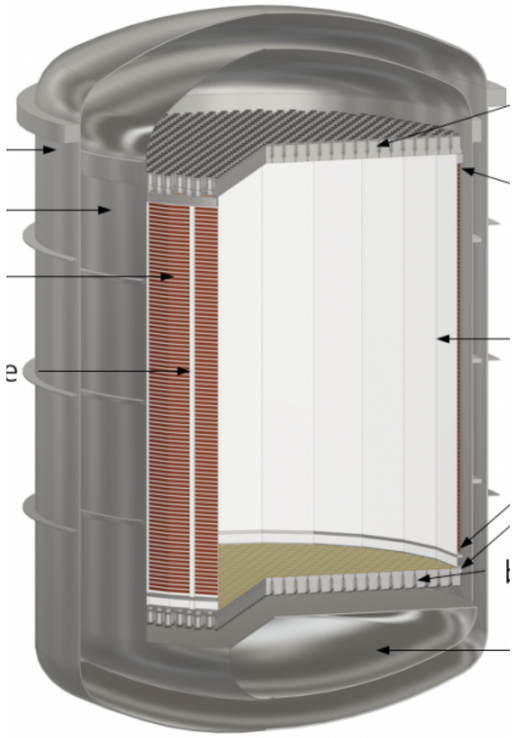


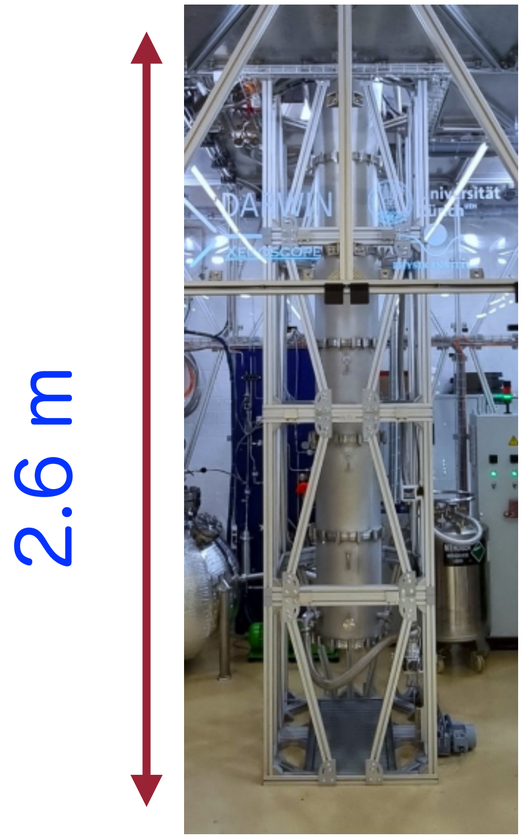
Liquid hole multiplier

DARWIN: R&D Detector

Full height and diameter test facility for DARWIN

Baudis et al. JINST 16 P08052(2021)





High voltage, Purity …

Electrode and other detector components

s

XENON-LZ-DARWIN (XLZD) Consortium

Liquid Xenon Time Projection Chambers => A World leading Technology

The consortium is aiming to build a unique 50-100 tonne ultimate detector XENON-LZ-DARWIN

-> XLZD Consortium

2021/4/26,27 XENON/DARWIN, LUX-ZEPLIN meeting
https://indico.cern.ch/event/1028794/

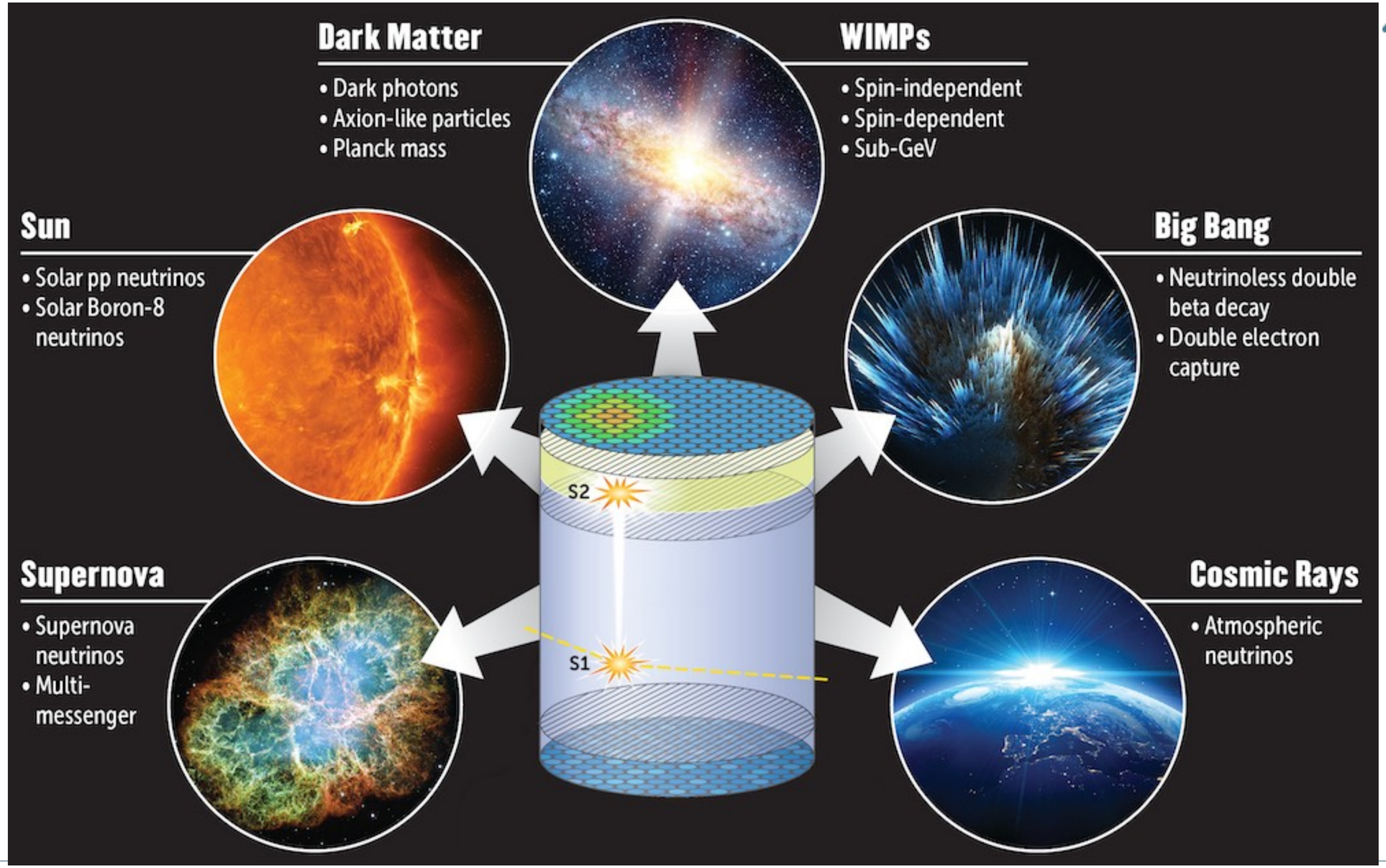
2021/7/6 : **MOU**: XENON, DARWIN, LUX-ZEPLIN
16 countries,104 scientists

2022/6/27-29 1st Summer Meeting at KIT in Germany
Japan： Kavli IPMU UTokyo, Kobe U, Nagoya U,

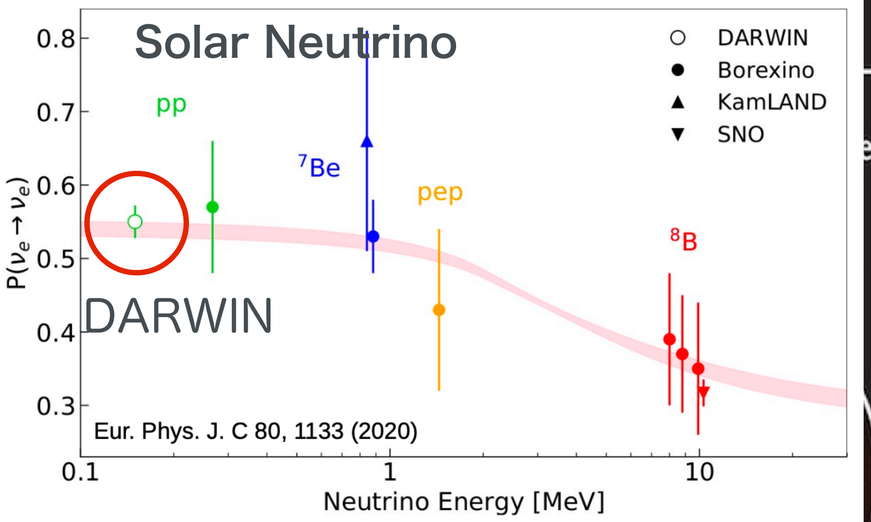
2022/12 Submitted DARWIN/XLZD proposal to the Science Council of Japan (Future Academic Advancement Initiative)

- **White Paper:**
  - **A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics**
  - https://arxiv.org/abs/2203

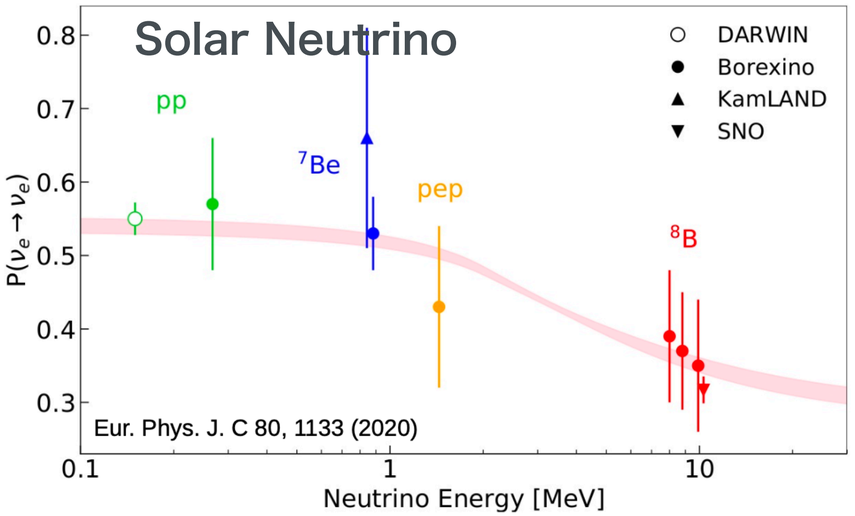
Liquid Xe TPC: Physics



Liquid Xe TPC: Physics

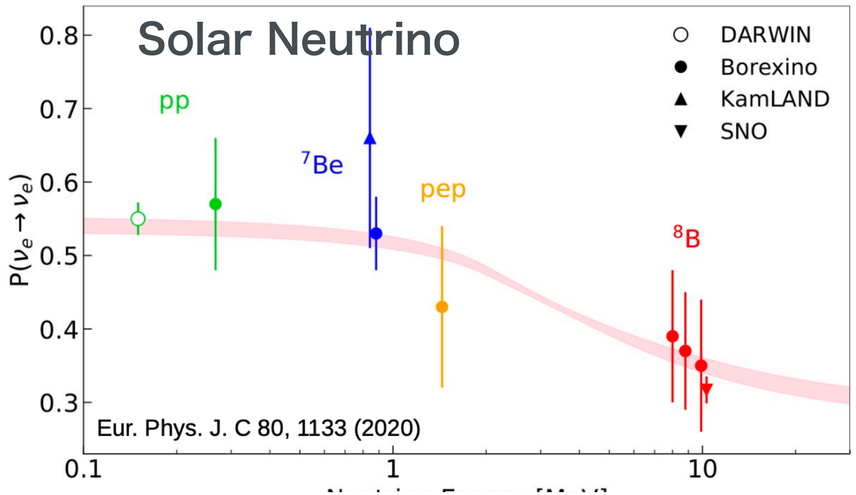


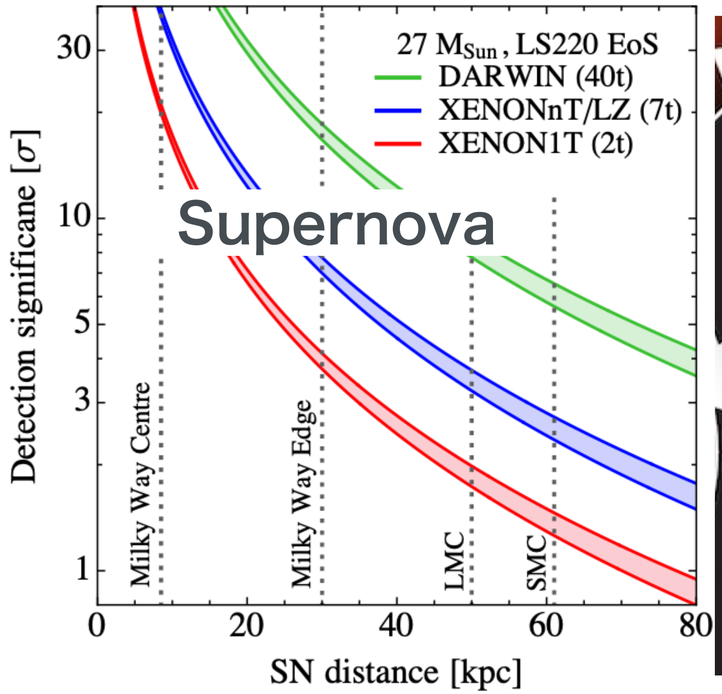
Liquid Xe TPC: Physics in Future

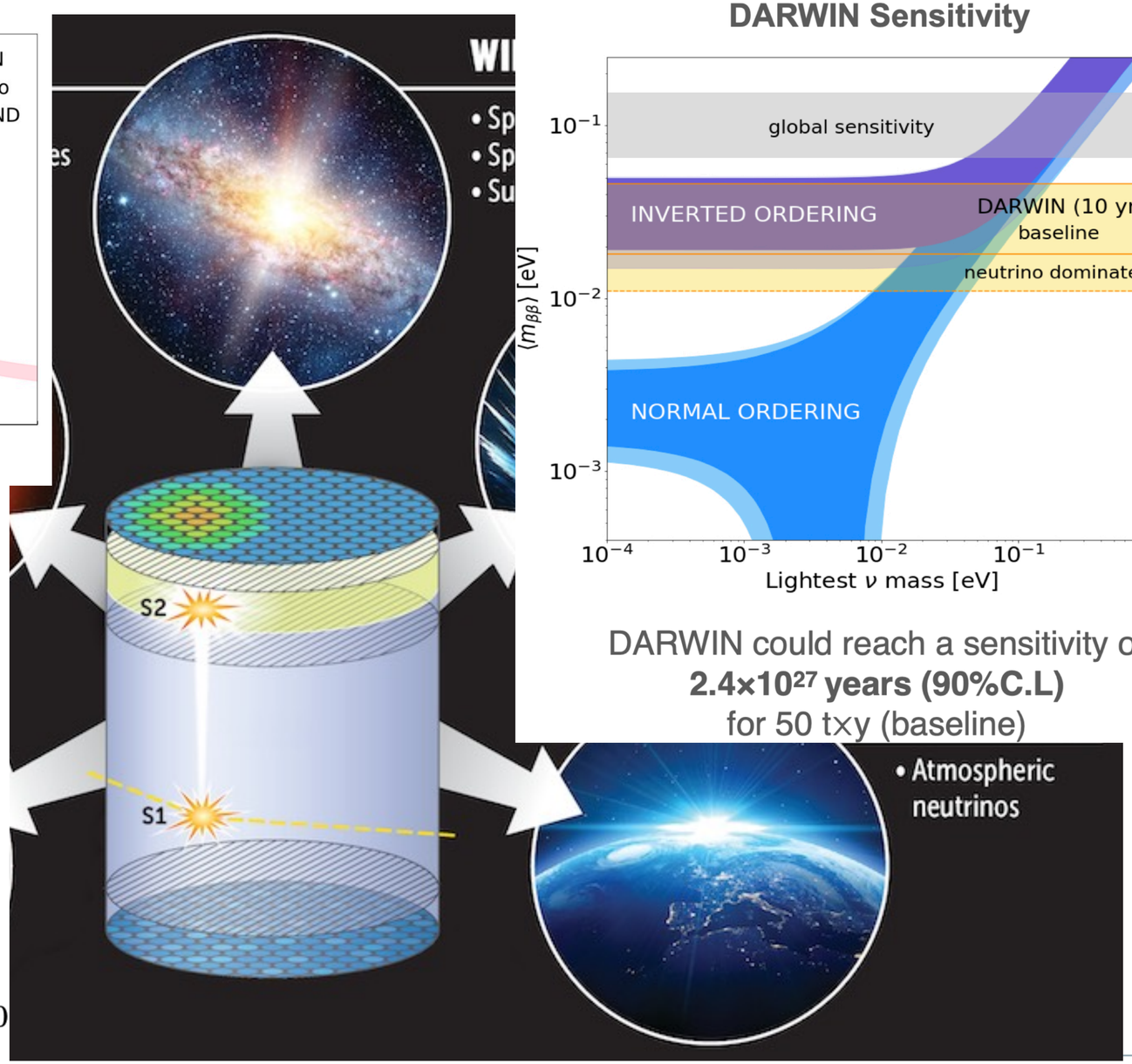


DARWIN could reach a sensitivity of
2.4×10^{27} years (90%C.L)
for 50 t×y (baseline)

Liquid Xe TPC: Physics in Future







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2.4×10^{27} years (90%C.L)
for 50 t×y (baseline)

Conclusion

DARWIN Collaboration
~170 members
33 institutions
11 countries

・DARWIN will be a successor of the state-of-art liquid xenon dark matter detector.

・Ultimate detector for WIMP search (neutrino fog)

- Solar Neutrino
- Double Beta Decay
- SuperNova …

・Recently, we formed the consortium (XLZD) to realize the ultimate dark matter detector with LXe