Light Dark Matter Searches in Kamioka Laboratory

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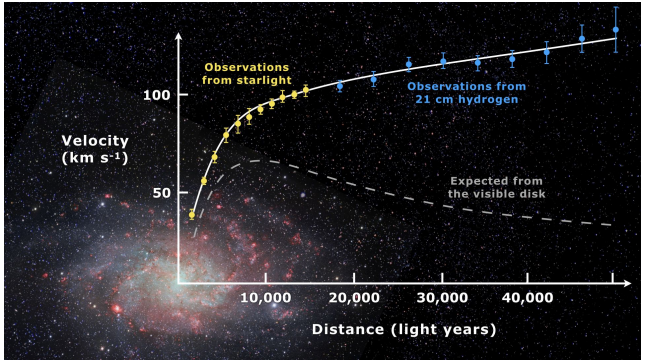
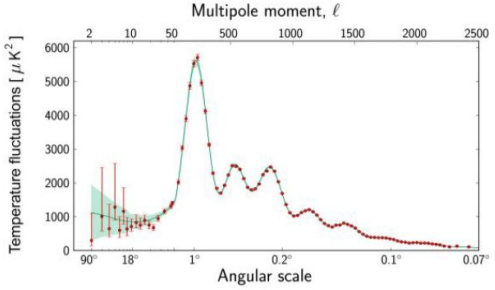
2025-04-08

QUP Workshop

The “Discovery” of Dark Matter

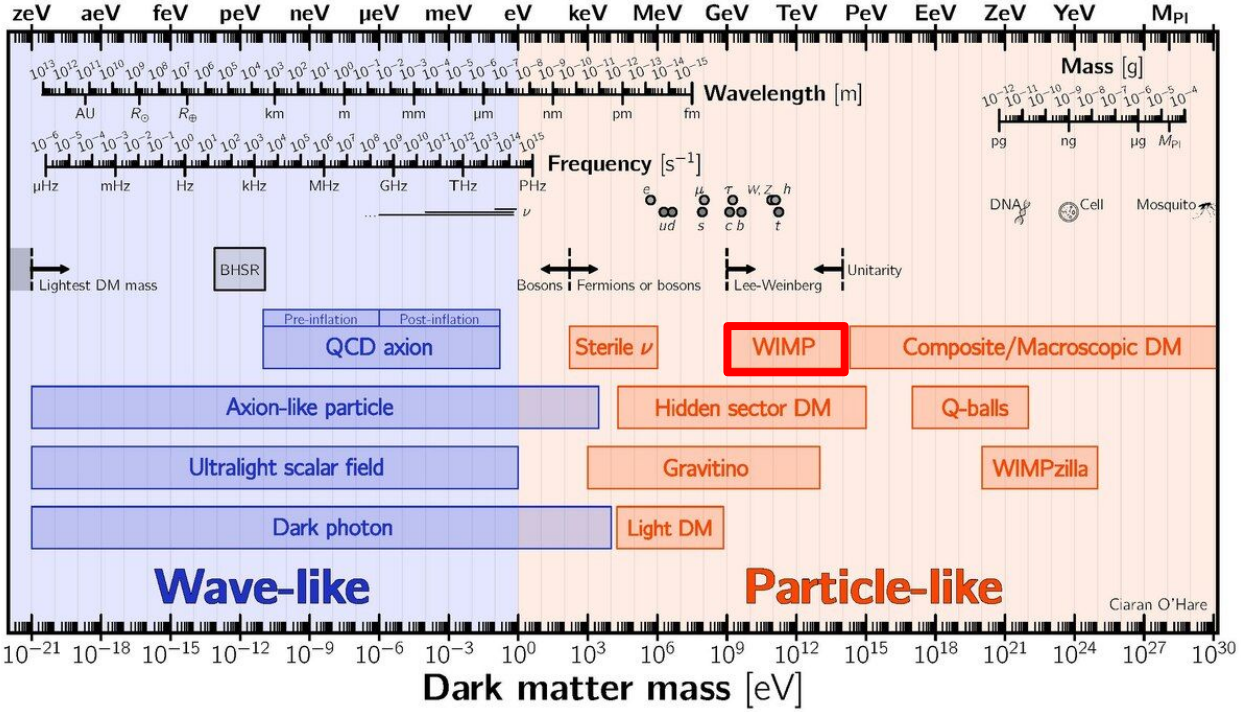
- pre-1900: Early hints comes from Lord Kelvin and Poincare when estimating starts near the Sun using the viral theorem
- 1933: Zwicky and the Coma cluster
- 1978: V. Rubin and the galaxy rotation curve
- ~1990: Lambda-CDM model
- 2000+: gravitational lensing, bullet cluster, …





Dark Matter Candidates

- Universe is 5% ordinary matter, 27% dark matter, and the rest dark energy



The WIMP Paradigm

- 1977: Weinberg suggests heavy neutrino as a mechanism for closure of the Universe
- 1981 & 1982: gravitino proposed, MSSM neutralino solves 2 problems at the same time
- 1980s - 1990s: proposes direct detection by elastic scattering of nucleus

Today, almost all WIMP experiments uses directly or indirectly the elastic scattering of atomic nuclei.

WIMP Direct Detection

- Given the typical WIMP mass and Earth’s velocity in the galaxy, a collision with WIMP particle will make the nucleus recoil with keV-scale energy.
- This energy scale coincides with ionizing radiation.
- ***Fortunately and unfortunately, we can detect WIMP with a radiation detector.***

fortunately, it is detectable
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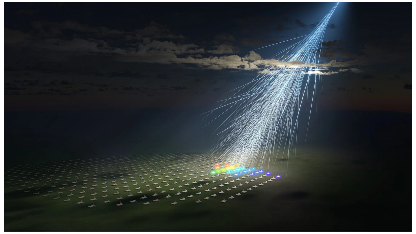
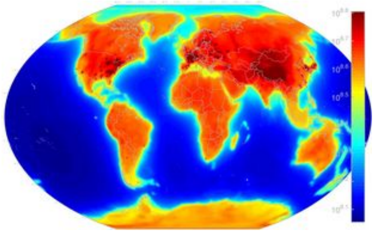
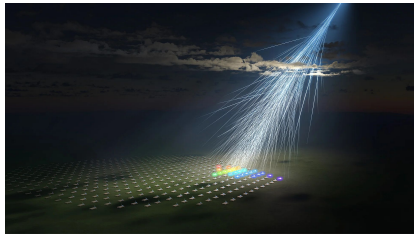


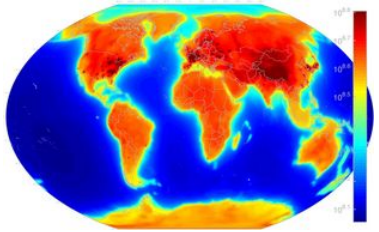
unfortunately, it is affected by huge radiation background (ó﹏ò｡)



Source of Radioactive Background



- cosmic (muons, protons, neutrons)
- ambient (U-238, Th-232, K-40)
- internal (highly dependent on materials being used)



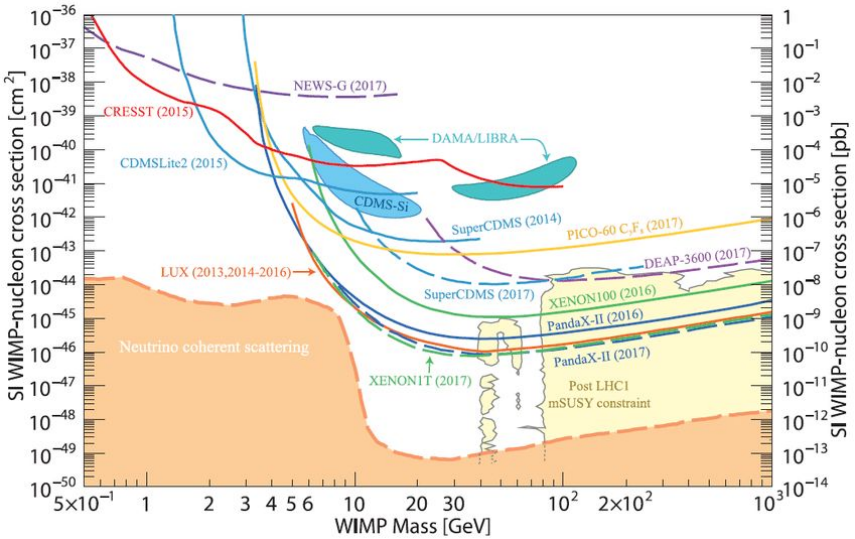
therefore:

- underground (attenuate muons, block protons and neutrons)
- shielded (high-Z for gamma, high-H for neutron)
- radiopure (various purification techniques, radio-cleanliness)

The WIMP Exclusion Curve

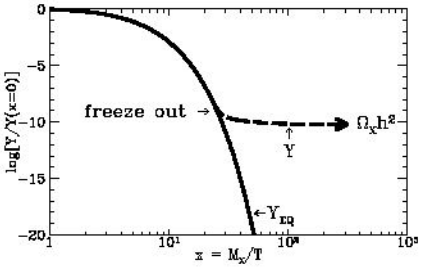
- once experiment is done, for each given WIMP mass, certain cross section can be excluded
    - “if WIMP exists in this region, with XX probability, should have seen WIMP events”

- current multi-ton noble liquid TPC detectors already sensitive to the “neutrino fog”
- Next generation requires even larger mass + directionality
- or alternative models?

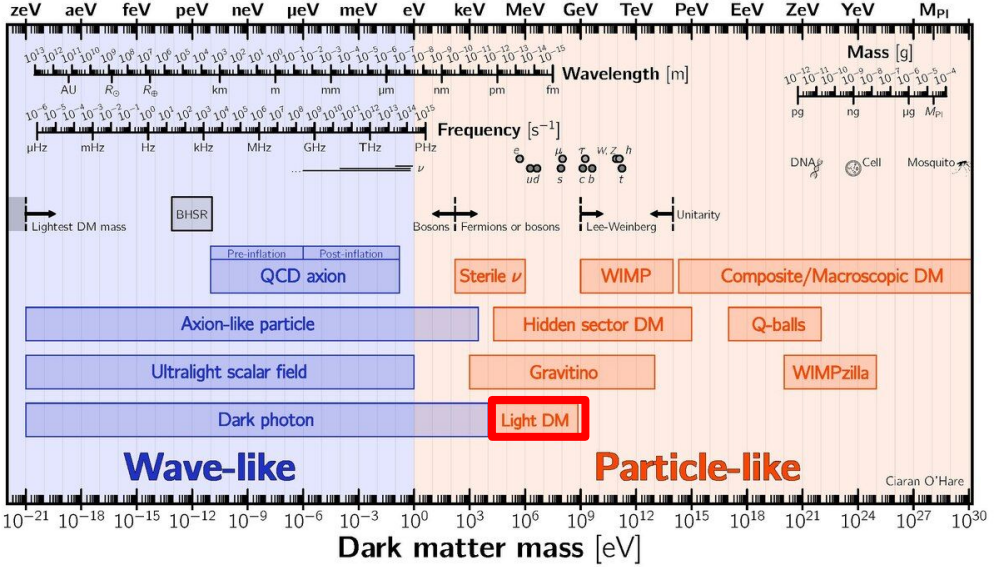


The Light Dark Matter

- WIMP mass constrained due to thermal freeze out mechanism + observed relic density



- if thermal freeze out is relaxed, then the allowed mass range is enlarged => ***light dark matter***



When WIMP mass becomes small…

- during collision with atoms, momentum transfer becomes less effective

smaller energy deposit

- given total mass of dark matter, if individual mass is smaller, the number is larger

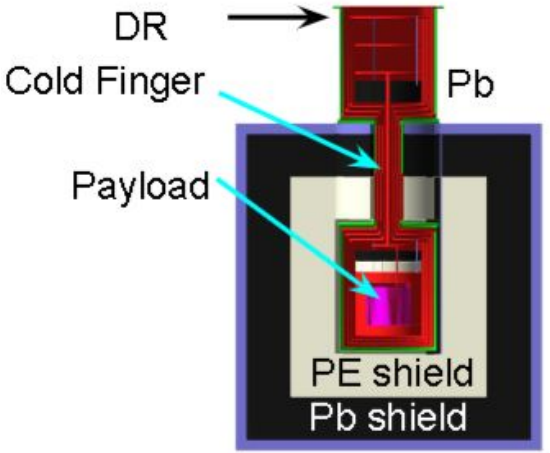
higher flux

these two factors favors relatively small but more sensitive detectors.

Low-background + Low-temperature + Multi-target

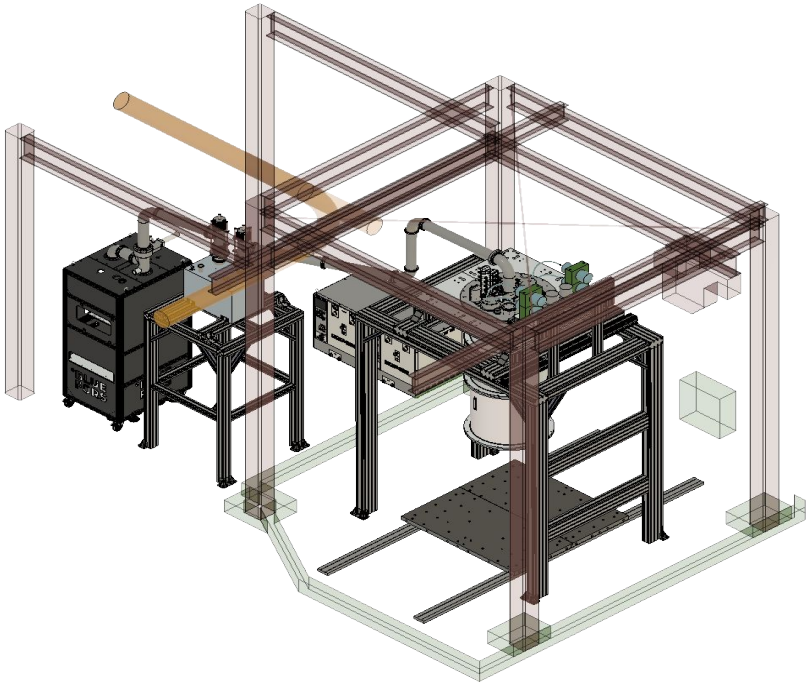
- even though background is reduced by using small sensors, the dark matter search is background limited as long as more than 1 event is observed
- this indicates all the precautions for traditional WIMP search still applies to low-mass dark matter

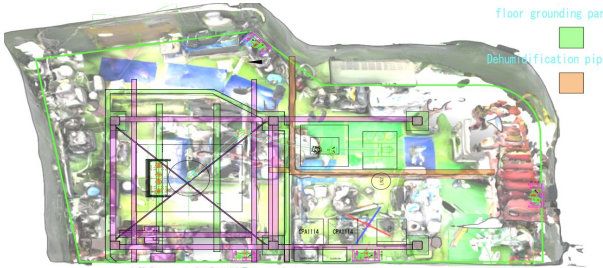
- Kamioka LDM Project:
  - a new underground low-background cryogenic facility in Kamioka
  - passive lead + PE shielding for background suppression
  - collaboration with Spice/HeRALD experiment for phase 1
  - QUP payload for phase 2 (see Kaori's talk)

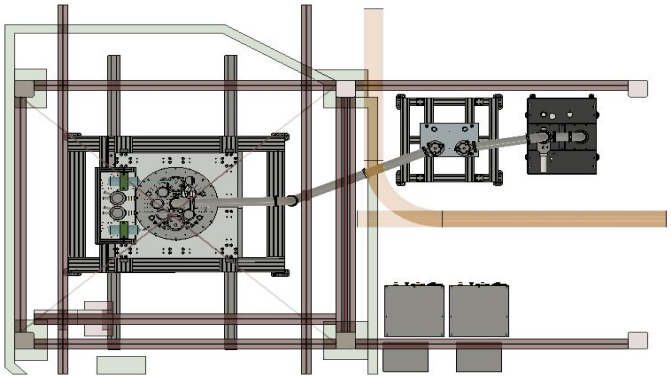


Where are we now?

- Dilution Refrigerator relocation to Kamioka last November







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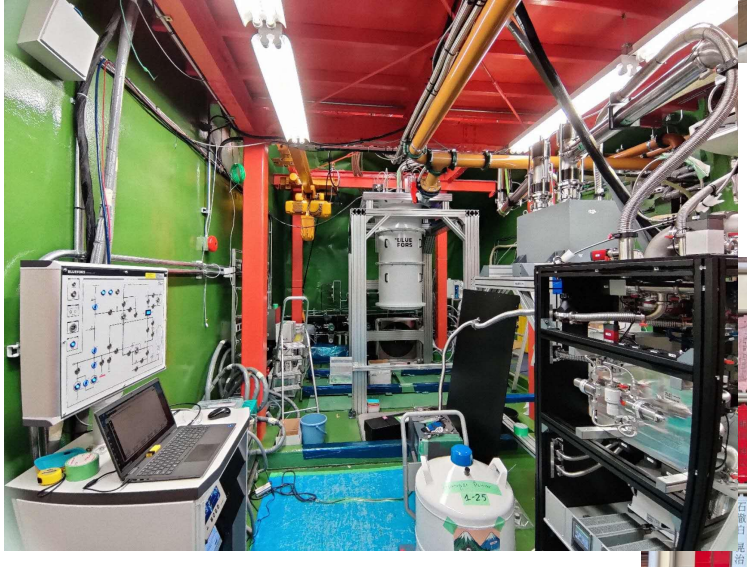


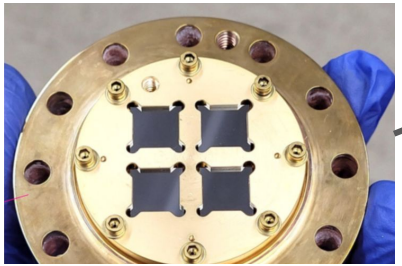
Where are we now?

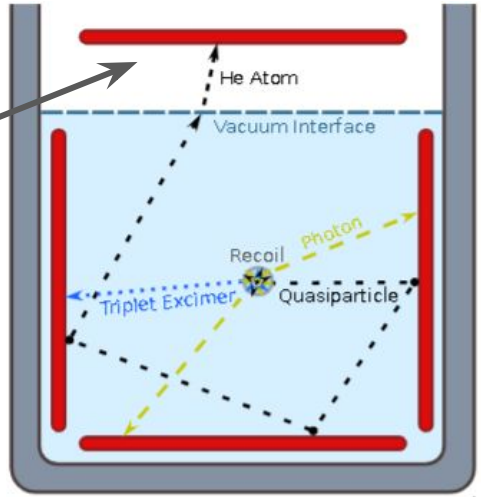
- Dilution Refrigerator relocation to Kamioka last November
- Gamma background measurement undergoing (Mar. 25 - Apr. 15)
- DR vibration measurement (scheduled, April 15 -)
- Neutron measurement with He-3 PC (undergoing)
- lead/PE shielding design (under fabrication)
- Neutron measurement with liquid scintillator (under preparation)
- SQUID characterization underground (under preparation)
- 1st payload (under preparation & test at Berkeley)

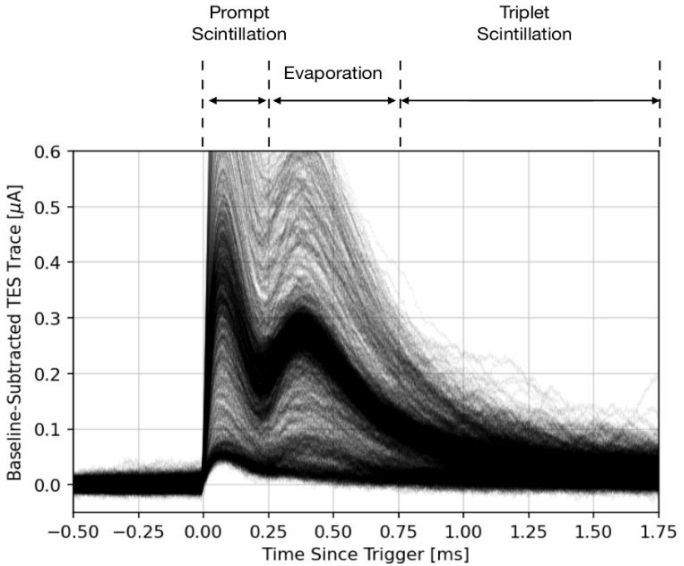
HeRALD LHe Payload

Helium is a good target for LDM:

- two-channel (light v.s. heat) readout
- gain by quantum evaporation
- easy to remove impurity, no long-lived radioisotope => extreme radiopurity!





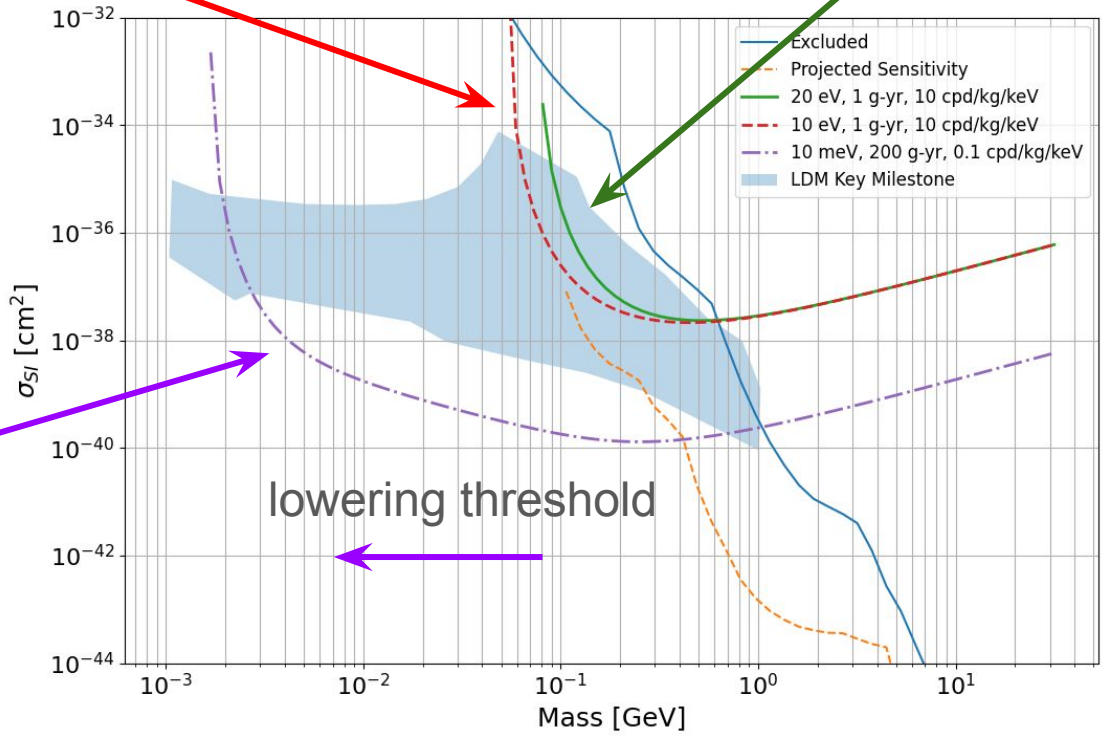


arXiv:2307.11877

HeRALD LHe Payload

near-term goal

performance already achieved



increasing exposure

(until bkg limited)

ultimate wish

lowering threshold

Summary

- Dark Matter is one of the key questions of modern physics
- In the past few decades, almost all attempts to detect WIMP have failed
- Recently, attention has shifted to alternative DM models, including low-mass dark matter
- QUP’s Kamioka LDM Project is a good chance to probe the unknown LDM parameter space for the first time using a low-background & low-temperature setup
- First Phase in collaboration with Spice/HeRALD (TESSERACT), followed by QUP’s own payload.