Searches for Axions in the LUX-ZEPLIN Dark Matter Detection Experiment

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Aim

The LUX-ZEPLIN (LZ) experiment is an extremely sensitive dark matter direct detection experiment that uses xenon as the target to detect signals in a liquid-gas dual-phase time projection chamber. Produced scintillation light (S1) in the liquid chamber and ionization light (S2) in the gas chamber could be the hints of dark matter candidates: axions or axion-like particles. In details, the main topics about dark matter candidates in the LZ are:

- **Limit solar axions masses less than 1 keV/c^2.**
- **Limit axion-like particles' mass in the range of 1-11 keV/c^2.**
- **Explore properties of other dark matter candidates: weakly interacting massive particle, neutrinos, and hidden photon.**

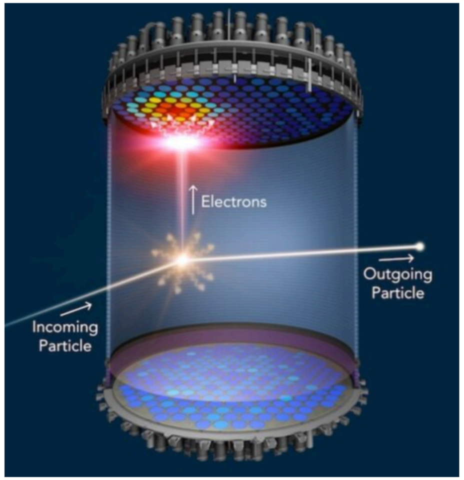

Figure 1. Dark matter detection mechanism in the LZ: in a cylinder of 7 tons of liquid xenon, S1 light is produced by prompt scintillation in liquid xenon, S2 light is generated through electroluminescence when electrons are drifted by a vertical field across the liquid surface into the thin gas phase.

Reference

(1) Aalbers, J.; Akerib, D.; Al Musalhi, A.; Alder, F.; Amarasinghe, C.; Ames, A.; Anderson, T.; Angelides, N.; Araújo, H.; Armstrong, J., et al. Search for new physics in low-energy electron recoils from the first LZ exposure, *Physical Review D* **2023**, *108*, 072006.

Method

Axion Production Mechanisms

Pseudo-scalar Nambu-Goldstone boson axions have theoretical couplings to leptons, hadrons, and photons. As a result, axion production is possible within star like our sun via nuclear and thermal processes.

Coupling	Formular	Process
Axion-electron	$g_{ae} = \frac{C_e m_e}{f_a}$	Atomic, Bremsstrahlung, Compton (ABC)
Axion-nucleon	$g_{aN} = \frac{C_N m_N}{f_a}$	^{57}Fe de-excitation
Axion-photon	$g_{a\gamma} = \frac{C_\gamma}{f_a}$	Primakoff effect

Table 1. Axions and axion-like particles' couplings and mechanisms. C_x is the specific parameter for each coupling. m_e and m_N are the mass of electrons and nuclei. f_a is the relevant decay constant.

In our previous work, only the ABC process was calculated because Primakoff effect is expected to be small in comparison [1]; future work aims to consider both mechanisms.

Axion Detection Mechanisms

Axion detection mechanisms in LZ now are mostly axio-electric effect [1], allowing atomic (xenon) ionization by absorption of axions. The Inverse Primakoff effect is another possible detection mechanism which will be considered in the future.

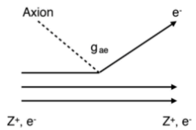

Figure 2. The diagram of axio-electric effect

The Axion's Coupling Constant and Mass

The strength of interactions between axions and normal matter is given by its coupling constants: g_{ae} or $g_{a\gamma}$. Through fitting axions event rate, axion couplings constant g_{ae} or $g_{a\gamma}$ can be derived. After deducing the value of decay constant f_a, the mass of axions will be given by the equation:

$$m_A \simeq \frac{6 \times 10^6 GeV}{f_a} eV/c^2 \quad (1)$$

Axion-like particles have similarly production and detection mechanisms in LZ. The mass of axion-like particles and its couplings constant g_{ae} can also be determined through fitting the event rate.

Result

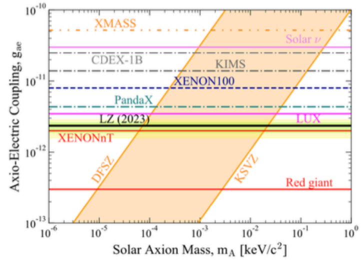

Figure 3. The 90% C.L. upper limit (black line) on solar axion g_{ae} coupling constant $g_{ae} = 2.35 \times 10^{-12}$. The green and yellow bands represent the 1σ and 2σ sensitivity range, respectively, for repeated background-only experiments [1].

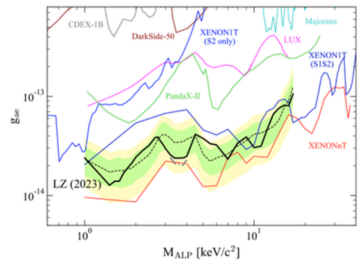

Figure 4. The 90% C.L. upper limit (solid black line) on solar axion-like particles g_{ae} coupling constant. And the dashed black line is the median sensitivity. The green and yellow bands represent the 1σ and 2σ sensitivity range, respectively, for repeated background-only experiments [1].

Discussion

LZ is collecting 1000 days data after a period of calibrations and detector state optimizations. Subsequent science data will benefit from further decay of both ^{127}Xe and ^{37}Ar, which will especially improve the solar axion sensitivity [1].

To limit the space of g_{ae}, in next step, LZ will improve the axion analysis by studying the Primakoff and inverse Primakoff effect in axion production and detection mechanisms.