Comparison Of the Detection Scenarios of Wimps And ALP

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Abstract. Contemporarily, the dark matter remains a mysterious part of cosmology beyond standard model, which has not been detected yet. Plenty of different detection methods have proposed in order to ensure the existence of dark matter. In addition, its exotic properties have also been identified as beyond the standard model of particle physics, which led to the emergence of different dark matter candidates one by one. With this in mind, this paper will select two kinds of well-explored candidates (i.e., WIMPs and ALP) to discuss the detection scenarios and progress. To be specific, this study will introduce the two detectors and then compare the efficiency and performance of the Organic Crystal Detectors and KAGRA's relative to exploring WIMP and ALP dark matter candidates. Finally, this research will discuss the current shortcomings of the two state-of-art detectors as well as their future outlook. Overall, these results shed light on guiding further exploration of dark matter candidate investigation.

Keywords: WIMP; ALPs; Dark matter detection; Organic crystal detector; KAGRA.

1. Introduction

In the 20th century, people's understanding of the laws of nature had a dramatic revolution, and the Standard Model (SM) from particle physics was finally founded. It precisely described every experiment result from the study of particle physics. But some still believe that SM is not the ultimate theory for nature. Einstein successfully described this point a few years ago through his General Relativity. As a result, it must be extended into a complete theory. Nowadays, one can rely on credible observational results. Maybe the most pressing comes from cosmology; Einstein's Gravitational equation has a well-described cosmology, an expanding universe, tiny Quantum fluctuation trigger some primitives during the exponential expansion phase [1]. Inhomogeneity is what is called original expansion. This beautifully describes something not in the SM, i.e., the Dark Matter (DM).

Swiss-American astronomer Frits Zwicky can say he is the most famous person who discovered this field. In 1933, while studying redshifts from various star clusters, he noticed a massive difference in velocity in eight galaxies in the coma clusters, with a contrast of 2000 km/s [2]. This discovery from Zwicky was made by observing that the combination of galaxies in the coma cluster required massive non-luminous matter [3]. First, using Virgin's theorem to determine the mass of the cluster. He discovered "that dark matter is present in a much greater amount than luminous matter [2]. From now on, what Dark Matter was made up of became an essential question in particle physics and cosmology. For many years, evidence from experimental physics continued to increase, but because all the evidence are all based on the gravitational effect, scholars still have no idea and concepts what Dark Matter is [3].

Current mainstream dark matter candidates are WIMPs, supersymmetric remodeling of the Standard Model, and axion particles. WIMPs, supersymmetric reconstruction of the Standard Model, and Axion Particles are the current leading contenders for dark matter. Theoretically, Weakly Interacting Massive Particles (WIMP) are the most well-known contenders for CDM. It was developed by Lee and Weinberg and can function as a CDM in the form of stable heavy left-handed neutrinos. When considering axinos' place in the cosmos, it is essential to consider whether it was built using the entire DM density or only a portion. It contained LTP from the Little Higgs Model and LTP from the Supersymmetric Model [3]. Supersymmetric (SUSY) is another possible candidate under the same theoretical framework. The circuit diagrams may be equivalent to or dominant over the Higgs exchange contribution since the neutron mass does not impede them [3]. The Little Higgs

Model [2] has been the subject of the majority of phenomenological analyses [5], because it is straightforward and affordable. Unfortunately, accurate, weak current fitting greatly restricts this model. It is possible to think of the axion of axion-like particles (ALP) as a background, classical field. They are often considered of as theories of physics that go beyond the Standard Model. It is possible to compute time-varying moments via couplings for this field, such as a nuclear electric dipole moment and axial nucleon and electron moments, and to take into account a way using NMR techniques to look for the induced spin precession [6].

The article will have an in-depth understanding of WIMP and ALP, the instruments used for detection, the principle components of the devices, and the detection results. Finally, this study will compare the differences between the two detectors and the differences in dark matter detection, and explain the prospect of foreign research.

2. WIMPs

2.1. Descriptions of WIMPs

Dark Matter can form gravitational interacting structures, commonly though similar to "normal" matter. Microlensing surveys have yet to discover enough dark matter to create Massive Compact Halo Objects (MACHOs). After the discovery of gravitational waves, primordial black holes (PBH), created in the early Universe before the Big Bang nucleosynthesis, emerged into the public eye. However, with too few observable events, the total number of Dark Matter could not be described. Some limitations come from the microlensing searches of cosmic ray data for stars, Type Ia supernovae, or Voyager 1, and essentially exclude PBHs from all dark matter in any mass range [7]. The predicted masses for multifarious important dark matter candidate particles span many magnitudes [7].

Observations from constraints on the strength of interactions or constraints on the large-scale structure and ionization history of the universe in colliding clusters such as the Bullet Cluster can ultimately infer information about dark matter particles [7]. The physical characteristics of dark matter particles have been measured using three different direct techniques. These dark matter particles are created at the Large Hadron Collider and have properties similar to the mass, coupling, and interaction cross sections of baryonic matter. Direct discovery of WIMP nuclear scattering events in ultrasensitive low-background studies, as well as the detection of product, decays after dark matter annihilation processes in galactic centers and dwarf galaxies with high dark matter densities [7]. Fig. 1 shows the mass for different types of dark matter.

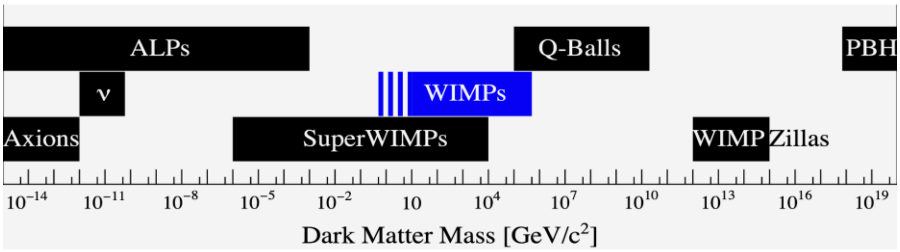

Fig. 1 The mass for different kinds of dark matter.

2.2. Organic Crystal Detectors

This semiconductor detector's energy resolution is outstanding (Ge: 2.9eV, Si: 3.6eV), which may produce numerous signal carriers with little energy. The high levels of electrical noise make it impossible to build enough detectors owing to the slow signal (1 s) and the massive capacitance of Ge diodes, which exceeds the O (1) kilogram scale. In recent investigations, incredibly low threshold, (i.e., even as low as 160) have been achieved using p-type point-contact HPGe crystals on a kilogram scale. Due to their shorter rise times and weaker electric fields close to the n+ region, big n+ surfaces can impact background events less than bulk events. Some projects use silicon crystals (Z = 14) in the shape of CCD chips to increase their sensitivity to low-quality WIMPs [5].

It is well known that directional aniso-trophies exist in the scintillation responses of organic crystal scintillators to heavy-charged particles, including anthracene and stilbene as shown in Fig. 2 [4, 5]. The internal scattering of WIMPs generates protons and carbon ions, and the direction of their migration affects the scintillation responses, the focus of the WIMPs from these anisotropies. One must calculate the nuclear recoil's scintillation efficiency or quenching factor to use scintillation detectors to view WIMPs. The directional fluctuations of the quenching factor are how the aniso-trophies of the scintillation responses are manifested for organic crystal scintillators [6]. The stilbene crystals are 2 cm×2 cm in size and were bought from Amcrys-H. At standard temperature, the molecular crystals of stilbene, an anisotropic aromatic hydrocarbon with two benzene nuclei, form. GORE-TEX was used to cover the crystal to reflect scintillation light, and used optical grease to keep their cleavage surfaces attached to the PMT (H1161-50, Hamamatsu Photonics) [6].

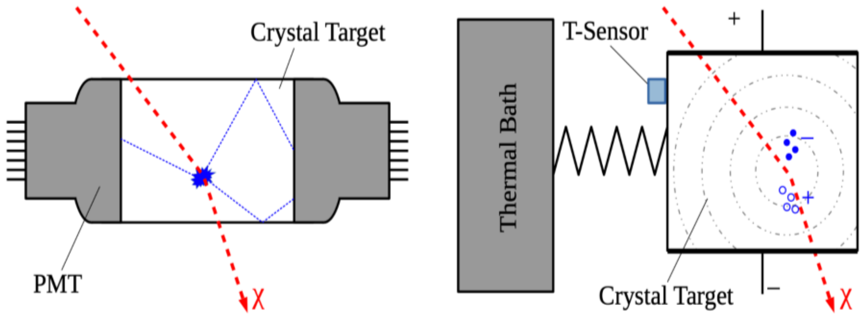

Fig. 2 A sketch of the detector of scintillating crystals searching.

Several investigations improve the target mass using high-purity scintillator crystal arrays, especially NaI (Tl) and CsI (Tl). Their benefit is a simple detector that operates consistently for extended periods. Scanning kilogram-scale crystal arrays with low-background photomultipliers produces a considerable target mass. I (A=127) and Cs (A=133) are more vulnerable to spin-independent interactions because of their high mass numbers. The relatively high inherent background level of this detector (the long-term world record for NaI crystals is roughly 1 count/kg/d/keV) and its inability to drastically reduce noise via benchmarking are its drawbacks. Level-based discrimination, NR/ER. Investigations using this approach focus on putative dark matter-induced low-energy signals because of the continuous input from the background and the more significant fraction of the unmodulated WIMP signal. There are no candidates for dark matter on an event-by-event basis. Although DAMA/LIBRA has recently published data for 1keVee, the standard criteria are 2keVee (8keVnr, 12keVnr, and 22keVnr for Na and CsandI, respectively) [5].

2.3. LSP

The lightest neutral point in the supersymmetric (SUSY) model is the most well-known example of a new particle that is present in many Standard Model (SM) theories that extend the electroweak interaction [8]. The Standard Model of Minimal Supersymmetry, or MSSM, "predicts new fermion partners for the fundamental SM boson (fermion) and additional Higgs doublets in its most basic realization. These brand-new SUSY particles or sparticles may offer a sophisticated answer to gauge-level issues. The number of baryons and leptons in the r-parity minimum supersymmetric Standard Model is no longer conserved by all renormalizable couplings, according to theory. The LSP, which can only be created in pairs under the R parity conservation paradigm, is stable. One neutron, which is typically thought to be this; one may offer a natural candidate for dark matter. A feature employed to look for SUSY signals in the research provided here is that the neutron LSP, if produced in a proton-proton collision, would evade detection and result in a significant number of missing lateral events with excess momentum higher than anticipated for the SM process [9].

2.4. LTP

The "Little Higgs" (LH) model, a novel class of hypotheses that extend the Standard Model at the TeV scale, has just been put forth.[8] T-parity stabilizes the lightest T-odd particle and considerably improves the Little Higgs model's compliance with accurate electroweak evidence (LTP). When time is turned around, physics principles are supposedly symmetry. In the Littlest Higgs model with T parity, LTPs are typical T odd-heavy photons with weak interactions that can serve as dark matter [8]. In most tiny Higgs models, T-parity may be attained by adhering to the most general structure of the theory's low-energy counterpart. The existence of T-parity significantly impacted the phenomenology of the Little Higgs hypothesis. It may also be a great candidate for dark matter. Charged LTP is undesirable since it results in cosmological issues. It is most likely the B' gauge boson since the weak U (1)Y coupling and, generally, the U (1) generator's normalization factor suppresses the LTP mass in the T-invariant model. Other neutral scalars, but are also conceivable. T odd-numbered particles decaying into jets or leptons plus lost energy may make up a typical collider signal for neutral LTP. This is how phenomenology is similar to supersymmetry theory, where R-parity and KK-parity are conserved in the Universal Extra Dimension (USD), and the LSP and the lightest KK-odd-numbered particle (LKP) are also stable because collider experiments would not pick them up if they were neutral. Like LSP and LKP, LTP has the potential to be a promising dark matter candidate. A striking feature of the T-invariant small Higgs theory is the persistence of a T-double-heavy leading quark partner in the top sector, whose phenomenology is unaffected by T-parity. One must create pairs of T odd particles (LTP) to create the most stable, lightest anomalous particles. Neutral lips produce missing energy signals that approximate supersymmetry at the collider [7].

3. ALP

3.1. Description of ALP

It may search for coherent effects over the whole classical dark matter field rather than concentrating on the hard scattering of individual dark matter particles, as with WIMP detection [4]. Axions, also known as "QCD axions," are pseudoscalar fields first proposed to solve the great CP problem in QCD physics. Many axion-like particles are predicted by high-energy physics, such as string theory, from the crunch of extra dimensions in recent years. In the future, we'll refer to them as "axes." Axions often have tiny masses, m "eV, and behave as non-relativistic fluids in the current universe because of their oscillating activity. As a result, axion dark matter candidates are cosmologically sound. Another crucial feature is how the axion interacts with the measuring boson. The weak and restricted interaction between axions and photons, a standard prediction for high-energy physics, offers one significant potential to detect axions using well-established photonics techniques [10-12].

Many physics hypotheses outside the Standard Model generally predict the existence of axion and ALP particles. They are global symmetry-broken Goldstone bosons called fa. The scale fa suppresses all of their interactions, and they are derivatively connected in these interactions, which is a manifestation of the Goldstone attribute of their genesis. They wouldn't be a dark matter if they were pure Goldstone bosons, which are entirely massless. However, they could lose their generational character if their pure Goldstone nature is altered [4].

The Standard Model's (SM) strong interaction, in particular, suffers from the vital CP issue. The fight against this issue has lasted fifteen years. Although some answers have been uncovered, none are definitive [11]. This mass formation may occur if the pertinent global symmetry is aberrant. For instance, “non-perturbative dynamics at the QCD scale” can result in a mass when this global symmetry is anomalous with the QCD [4]. The following is a mathematical description of mass-produced at the QCD scale by non-perturbative dynamics:

$$m_a \approx 6 \times 10^{-10} eV (\frac{10^{16} GeV}{f_a}) \qquad (1)$$

Here, f_a is high scale scalar.

Strong contenders for a type of dark matter include ultralight scalars, such as axions (a) and axion-like particles (ALPs), whose masses may be considerably lower than weak scales. These particles show up in nature as globally symmetrical Goldstone bosons that have been shattered at particular high-scale fa. [4]. Their derived interactions with the Standard Model reflect their qualities. $\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}, \frac{a}{f_a} G_{\mu\nu}\tilde{G}^{\mu\nu}, \frac{\partial_\mu a}{f_a} \bar{\Psi}_f \gamma^\mu \gamma_5 \Psi_f$. Here, Fμν and Gμν represent the electromagnetic and QCD fields, respectively, while f denotes the fermions of the Standard Model. The first of these interactions is employed in several investigations to discover axions by coupling axions (and ALPs) to photons. These include identifying axions produced in the sun, converting “dark matter axions to photons in the presence of a background magnetic field” [4], and transporting photons past visual barriers with the help of axion-assisted processes. These tests can look for axions at $f_a=10^{12}$ GeV, but their capacity to search at higher energies is constrained.

Atomic electromagnetic fields within materials can also experience axion-to-photon conversion (and the opposite). The Bragg condition, which states that the transition is coherently strengthened if the momentum of the arriving particle matches one of the Bragg angles, is imposed in the case of crystalline media by the area's periodic structure (stud studied a similar Laue-like change in crystals). To locate solar axions with crystal detectors, this idea been used. The Earth's rotation causes a constant change in the axons' relative incidence directions concerning the crystallographic planes, which results in a very typical sharp energy- and time-dependent pattern in the detectors expected to signal can use that to distinguish the potential signal from the background effectively. The benefit of this method is that if they have a low enough threshold and their crystal plane orientation is known (at least in part), they may be employed due to continuous low-background subsurface detectors.

Utilized initially, the approach on tiny Ge detectors in the SOLAX and COSME investigations was later employed as a byproduct in the DAMA, CDMS, and EDELWEISS studies. At the very least, it is also regarded as a component of the CUORE, GERDA, and MAJORANA experiments' physics program. However, the prospects for this method could be more competitive in the quality range where heliostats possess axion-complete, coherent transformations. DAMA, which sets ga 1.7 10^9 GeV (90% C.L.), achieves the best performance. Since these restrictions are looser than those imposed by solar physics, the limitations are not yet self-consistent. Future multi-ton target masses can attain similar sensitivity toga as existing heliostats, even though w will increase this in subsequent findings. When the heliostat's sensitivity drops for higher groups beyond 1 eV, this method does perform better than the earlier one, but as was already noted, astrophysics and cosmology dislike this parameter range.

Axion-photon conversion, a phenomenon where axions and photons change into one another in the presence of a background magnetic field, is the conventional method for finding axions. Axion-photon conversion has been used in several experiments and astronomical investigations, but no signal has been discovered. Recently, however, a novel experimental strategy for axion dark matter discovery has been put out that uses an optical cavity rather than a high magnetic field. Axion dark matter interaction results in two circularly polarized photons with a phase velocity difference, which is what the new method detects. With axion masses in the m 10 eV range, the experimental sensitivity is competitive with previous practical methods and can detect minute axion-photon couplings of the order of ga 10^{-11} GeV^{-1} [12].

3.2. KAGRA

Finding ALPs is frequently done by taking advantage of their parity-violating interactions with photons having a coupling constant of ga. The axion-photon interaction determines the phase velocity difference between the left-handed and right-handed circular polarizations of light. Under the influence of the background ALP field, a(t) = a0 cos (mat + (t)), the phase velocity difference for light with wavelength l = 2 kg is given by c = |cL cR| = c0 sin (mat + (t)).

$$\delta c_0 = \frac{g_{a\gamma} a_0 m_a}{k_l} \simeq 2.1 \times 10^{-24} \left(\frac{\lambda_l}{1064} nm\right) \left(\frac{g_{a\gamma}}{10^{-12}\ GeV^{-1}}\right) \quad (2)$$

One assumes that the local dark matter density and the axion energy density, ma, oscillates at 2.4 Hz (ma/(10^{14} GeV)), are equal. The phase factor (t) fluctuates on the dark matter coherence time scale, where v is the dark matter's local velocity. The polarization flip of specularly reflected light limits sensitivity when an optical cavity is used to look for axion-induced polarization rotation; for example, waveplates or bowtie cavities are required to get around this problem. However, linear holes can also be sensitive if the axion oscillation period is longer than the limited light propagation time between mirrors. The many excursions within the cavity increase sensitivity, especially when the axion oscillation period is comparable to an odd multiple of the round-trip time of the light, currently, the KAGRA detector in Japan is being utilized to search for probable dark matter sources [4].

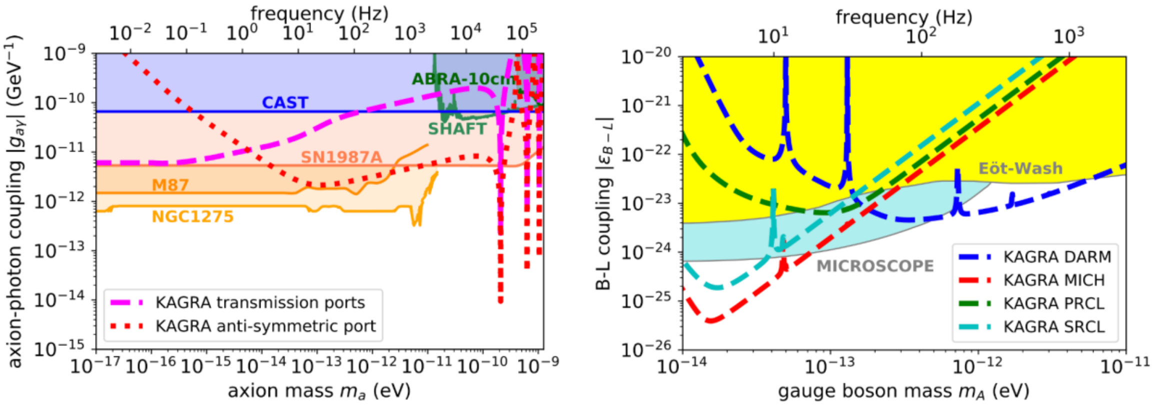

Fig. 3 ALP and B-L vector boson predicted sensitivity, measured over a year by KAGRA.

The expected sensitivity of the KAGRA detector is depicted in Fig. 3 (left), and it was determined using the formula in ref. Searches employing the cavity-reflected beam at antisymmetric ports often offer superior sensitivity because the arm cavity is over-coupled. However, the arm-cavity transmitted beam searches show higher sensitivity at ALPs of inferior grade. This is due to the odd number of times the light at the transmission port travels within the hollow. Flipping does not eliminate the polarization rotation effect at specular reflection [4]. The sensitivity reaches its maximum at ma = (2N 1)/Lcav, where N is N and Lcav is the 3 km length of the arm cavity. As of this writing, polarizing lenses have been put into the X-arm cavity transmission, and the Y-arm is about to be fitted in preparation for the O4 observation run, which is scheduled to begin in 2022. The skech of the KAGRA for ALP is shown in Fig. 5.

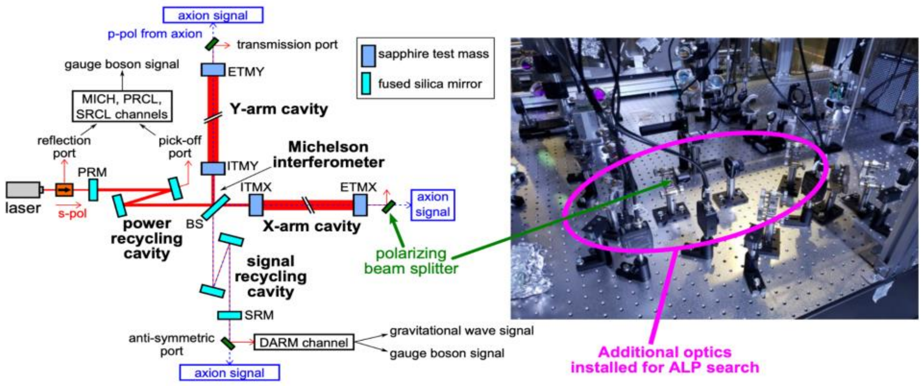

Fig. 4 Schematic of KAGRA for ALP.

New opportunities in the hunt for ultralight dark matter are made possible by laser interferometric gravitational wave detectors. It may do ALP searches by looking for the laser's fluctuating polarization rotation at several interferometer ports. It is also possible to seek mass vector fields that are gauge bosons of type U(1)B by observing oscillation length variations. Since these signals are almost monochromatic, Fourier analysis may be used to investigate them effectively. Polarizing optics have been deployed in the KAGRA project to look for ALP during the following observational run, O4, in 2022. Vector dark matter signals are now being looked for in the KAGRA 2020 data. KAGRA is a particular type of detector that offers auxiliary length channels to look for differential displacements of fused silica auxiliary mirrors and sapphire test masses with various B-L charge densities. To seek for differential displacements of connected silica auxiliary mirrors and sapphire test masses with differing B-L charge densities, KAGRA is a specific sort of detector that provides auxiliary length channels. Because of its increased sensitivity in forthcoming observation runs, KAGRA will be vital in the global network of gravitational wave observations and in the quest to comprehend the composition of dark matter.

4. Comparison

Organic crystal detectors require low energies to generate electron-hole pairs, resulting in many signal carriers and excellent energy resolution in experiments using high-purity scintillator crystal arrays—with increased target mass. While searches using the cavity-reflected beam often have superior sensitivity at the antisymmetric port of KAGRA, searches utilizing the arm cavity-transmitted beam also have better sensitivity for lower-quality ALPs. High-purity germanium (HPGe) crystals weighing 0.72 kg were utilized in tests with organic crystal detectors to look for dark matter-induced charge signals. A popular way to find ALPs is to exploit their interaction with photons with a coupling constant gaγ. The disadvantage of the two detectors is that organic crystal detectors' signals are relatively slow. The capacitance of germanium diodes is too large, resulting in high levels of electronic noise, making it impossible to build large sensors.

In contrast, KAGRA is the opposite. The main advantage of organic crystal detectors is that the detector design is relatively simple and can operate stably for a long time. Nevertheless, it is impossible to detect dark matter candidates on an event-by-event basis, as experiments using this technique have primarily looked for potential dark matter-induced annual modulations in the low-energy signal portion of the unmodulated WIMP signal -- an ongoing and more critical contribution from the background. Overall, with increased sensitivity in upcoming observational runs, KAGRA will be crucial to the worldwide network of gravitational wave observations and the investigation into the characteristics of dark matter. Because organic crystal detectors are in the first generation of WIMP detectors, the progress of WIMP in scientific research will be slower. The overall effect is not as efficient as KAGRA.

5. Conclusion

To sum up, this paper investigates the comparison of the organic crystal detector and KAGRA based on their advantage, function, and aspects that could improve on them. Specifically, Organic crystal detectors have large energy bands and low resolution. KAGRA has a low-energy segment and a large key. According to the analysis. Additionally, investigations employing high-purity scintillator crystal arrays and KAGRA's search using arm cavity transmitted beams have outstanding energy resolution, increasing sensitivity compared to earlier generations for ALPs of lower quality. High-purity germanium crystal detectors that are functionally organic are used to look for charge signals caused by dark matter. Distinctively, KAGRA uses their interaction with photons with a coupling constant gaγ to search for ALPs. Nevertheless, the relatively slow signal of organic crystal detectors makes it impossible to build large sensors. Making smaller detectors degrades their original performance. In the future, more advanced detectors ought to be proposed and constructed. Overall, these results offer a guideline for WIMPs and ALP detection.

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