Comparison of Different Detection Paradigm for WMIPs

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Abstract. Based on astrophysics observation, dark matter accounts for approximately 84% of all matter in the universe, with the remaining 16% being ordinary matter. According to the prevailing scientific model, dark matter particles are supersymmetric particles with a mass of 100 GeV (about the mass of 100 protons) with the density about 5000 particles m^{-3}. Yet such a dominant substance dominates the universe, but one has not detected yet. Among various candidate, WIMPs are one of the most appealing one that plenty of facilities aim to detect. In this essay, the detection principles and some recent results of two representatives of the state-of-art mainstream detection methods were presented, i.e., the 'Wukong' astronomical satellite (DAMPE) and the Jinping Mountains of Sichuan Province, China (CJPL). It was shown that 'Wukong' has successfully detected an electron-positron pairs at an energy of 0.9 Tev. In Jinping, experiments are proposed to detect liquid argon dark matter. In this review, the two methods of detecting dark matter will be compared and the advantages, disadvantages will be analyzed. These results shed light on guiding further exploration of dark matter.

Keywords: Astrophysics; WMIPs; Detection; CJPL; DAMPE.

1. Introduction

Dark matter is always been regarded as an unsolved mysterious in physics. Fritz Zwicky calculated the mass of the Coma cluster in the 1930s by observing the motion of galaxies inside it. The deviation cannot be explained unless the cluster includes significantly more mass than what he observed because the predicted value differs significantly from the actual observed mean velocity. According to Zwicky, dark matter is substantially more prevalent than luminous matter, which is a startling finding. Besides, it was the first time the term that "dark matter" was used [1-5].

Modern theory suggests that dark matter may be composed of some subatomic particles that have yet to be discovered, most of them are thought to be non-baryonic. Candidates for dark matter need to be stable, long-lived, and not affected by electromagnetic fields, the now generally considered candidates are Neutrinos, Supersymmetry, Axions and The WIMP paradigm. Neutrinos are subatomic particles that are very similar to electrons, but have no electric charge and have a very small mass, possibly even zero. It has the basic characteristics of almost all viable dark matter candidates: it is very stable, has a long lifespan, and does not experience electromagnetic or strong interactions. Nature may contain space-time symmetries that relate fermions to bosons, known as "supersymmetry." Supersymmetry requires that for every fermion, a boson must exist in the same number of quanta, and vice versa. Thus, supersymmetry predicts the existence of several new electrically neutral and non-strongly interacting particles. Axions is a hypothetical elementary particle postulated to resolve the strong CP problem in quantum chromodynamics (QCD) by the Peccei–Quinn theory in 1977. If axions exist and have low mass in certain ranges, they are of interest as possible components of cold dark matter. Most of candidate for dark matter is some new kind of elementary particle that has not yet been discovered, particularly weakly interacting massive particles (WIMPs). Broadly speaking, WIMPs interact through gravity and any other forces, potentially not part of the Standard Model itself, which is as weak as or weaker than the weak nuclear force, but also non-vanishing in its strength [1, 6-9]. The 3-D map of the dark matter is presented in left panel Fig. 1.
In order to investigate the recent progresses on the discovery of dark matter, this paper focuses on comparing two recent technologies: underground detection and in space detection while providing a brief aspect for future research on the discovery of dark matter.

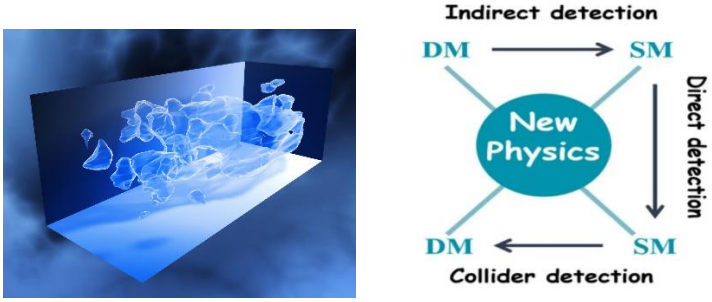


Fig. 1 3-D map of the large-scale distribution of dark matter (left panel) and detection methods (right panel).

2. Description of WIMPs

WIMPs are particles that are still in the theoretical stage, which should have the following two characteristics:

The particles interact only through the weak nuclear force and gravity, or the interaction cross section of the particle is smaller than the weak nuclear force interaction cross section.

Compared with ordinary particles, the mass is larger.

It is because they do not participate in the strong nuclear force, so they basically do not interact with ordinary matter; because of their large mass, they move relatively slowly, so they can cluster together. According to the above characteristics, WIMP is considered to be the most likely candidate for "cold dark matter". WIMPs with masses and interaction strengths around the electroweak scale, with known residual abundances obtained through thermal decoupling mechanisms. WIMPs predicted by existing theories include: the lightest supersymmetric partner particle in the supersymmetric model, such as neutralino; the smallest Kaluza-Klein excited state particle in the extra-dimensional theory; the T-odd particle in the Little Higgs model. As a weakly interacting particle, the abundance of WIMP particles comes from thermodynamic decoupling. We understand the generation mechanism of this particle as thermal generation. The research shows that if the interaction strength and mass of dark matter are near the electroweak energy scale, the abundance of dark matter in the universe can be explained naturally. In the calculation of WIMP dark matter abundance, the accidental cancellation of various physical quantities (such as CMB temperature, Hubble constant, Planck constant, etc.) leads to the final required dark matter mass near the electroweak mass scale, while the WIMP particle The mass of is also just around the electroweak mass scale. The remaining abundance of WIMP dark matter is consistent with the density of dark matter observed in cosmology today, which is called the WIMPs miracle [6, 7].

3. Detection scheme I: China Jinping Underground Laboratory

The idea of dark matter discovery has been proposed for many years. In order to find dark matters, astronomical measurements were first employed, but they were unable to provide a solution to the existence of it. While the latter uses the recoil of the target matter caused by the collision of dark matter with the target matter in the detection instrument to demonstrate the existence of dark matter, the former uses the signal of ordinary matter particles generated by the collision of dark matter with each other, typically through ground-based or space-based telescopes. The issue of substantial background interference, or the presence of a cosmic ray particle that may travel deep underground and is a significant source of interference in dark matter investigations, poses the greatest challenge to direct detection. Scientists mostly employ a few highly sensitive shielded detectors in direct detection investigations. Dark matter particles have weak interactions and can therefore get through the detectors, whereas conventional particles cannot because of the shielding around them. Due to their weak connections, dark matter particles frequently have a possibility of colliding with the

detector's atoms. The quantity of collisions is a function of the mass and density of the dark matter, the collision cross section, and the quality of the working medium of the detector [10].

The detector must therefore be placed deeply in an underground laboratory to minimize interference. The more protected and easier it is to perform high sensitivity detection, the deeper the underground laboratory. With a rock depth of over 2400 m and an equivalent water depth of about 6720 m. w. e., CJPL is currently the deepest rock buried underground laboratory in the world, with the lowest cosmic ray flux of 61.7±11.7 m-2-y-1, about one billionth of the terrestrial cosmic ray flux level. This means that the transient background effects due to cosmic rays are almost negligible. Several experimental groups, including CDEX and Panda X, are already conducting experiments at CJPL. When CJPL-II is commissioned, in addition to having the deepest rock burial and the lowest cosmic ray flux, it will also be the world's CJPLII will be the largest underground laboratory in the world. Figure 2 shows the rock depths, equivalent water depths, cosmic flux levels, available volumes, access methods, etc. for the major international underground laboratories. The information on rock depth, equivalent water depth, cosmic ray flux level, available volume and access is shown in Figure 2. Together, the CJPL has the best experimental conditions [11].

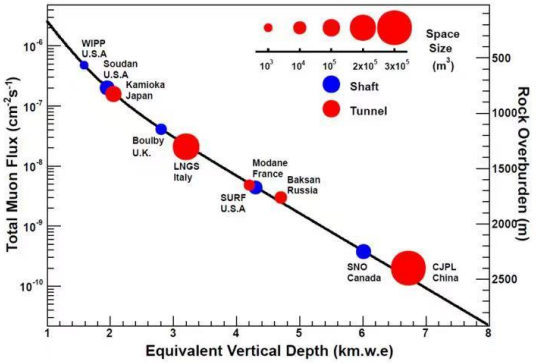


Fig. 2 The rock burial depths and cosmic ray flux levels as a function of equivalent water depths.

The CDEX experiment is one of the main experiments operating at CJPL, using point electrode high-purity germanium detectors for direct dark matter detection. The point electrode high-purity germanium detector offers a good energy resolution and an extremely low energy threshold (below 200 eV). great sensitivity to low mass dark matter, outstanding energy resolution, good operational stability, easy modularization into huge mass array detectors, etc. It is quite sensitive to dark matter with little mass. However, there are difficulties when the sensitivity of detection rises, such as the background control of the PCGe near However, there are difficulties when detection sensitivity grows, such as background control of the material surrounding PCGe, control of the radioactive level of PCGe, and enormous masses of monoliths. The plan is illustrated in Fig. 3 while the detection results are illustrated in Fig. 4. The four phases of the CDEX experiment are being carried out as follows [12]:

CDEX-1: The investigation into the physical analysis, data processing, and performance of a prototype P-type PCGe (PPCGe) at the 1 kg level is the first step in the exploration of direct dark matter detection. In order to establish the groundwork for the following stage, the prototype detector will then be enhanced to boost the signal-noise ratio.

CDEX-10+X: using a 10+X kg PCGe array detector, of which 10 kg was created in partnership with Canberra and X kg was created by the CDEX Collaboration itself, to conduct a direct dark matter detection experiment. to show that tone scale experiments may use high-purity germanium detectors to detect background levels and to investigate the viability of detector manufacturing and modular arrays.

CDEX-100 is an array detector that analyses and detects direct dark matter utilizing 100 kg detector modules.

CDEX-1T: At this point, array detectors for 0 experiments and direct dark matter detection have reached the tone scale.

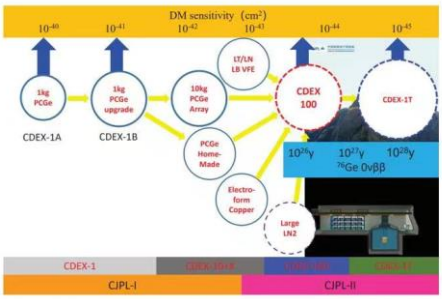


Fig. 3 CDEX Development Plan

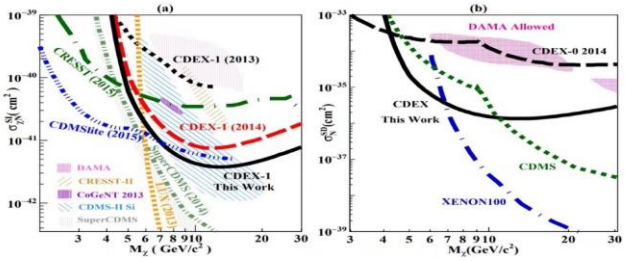


Fig. 4 Direct dark matter detection results from the CDEX-1 experiment (a) spin-independent; (b) spin-dependent

4. Detection scheme II: Dark Matter Particle Explorer 'Wukong'

DAMPE is a potent space telescope for the detection of high energy cosmic rays, electrons, and gamma rays. It searches for and analyses dark matter particles (indirect decay signals of WIMPs). Each of these layers of the facility is made up of two layers of single-sided silicon strip detectors that are used to measure two orthogonal views that are perpendicular to the direction in which the apparatus is pointed. For photon conversion, three layers of tracking layers 2, 3, and 4 are placed in front of three layers of 1mm thick tungsten plates. The STK is followed by an imaging calorimeter constructed of 14 layers of Bismuth Germanium Oxide (BGO) bars arranged in a hodoscopic pattern, with a thickness of around 31 radiation lengths. The bottom of the calorimeter is extended with a layer of neutron detectors [14, 15]. It is the deepest calorimeter ever utilised in space since the combined thickness of the Bismuth Germanium Oxide calorimeter (BGO) and the STK is approximately 33 radiation lengths. Finally, a neutron detector (NUD) is positioned directly beneath the calorimeter in order to detect delayed neutrons caused by hadron showers and to increase the power of electron/proton separation. A photomultiplier reads each of the 16 1 cm thick, 19.5 19.5 cm2 plastic scintillator plates that make up the NUD. A sketch of the detector is given in Fig. 5. The detail three structure are presented in Fig. 6 and corresponding parameters range are listed in Tables. 1, 2 and 3.

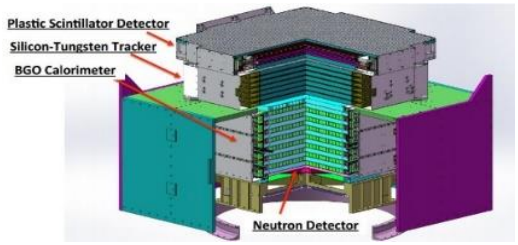


Fig. 5 Schematic view of DAMPE detector

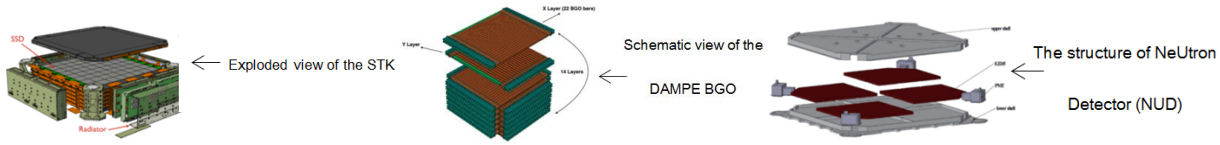


Fig. 6 High-energy electron detection (left panel), gamma ray (middle panel) and cosmic ray (right panel).

Table. 1 High-energy electron detection.

Detect Energy Region	5～10,000GeV
Energy Resolution	1.5%@800GeV
Angular Resolution	0.5@800GeV
Low particle background contamination Ability	>100,000
Geometric Factor	>0.3m2.sr

Table. 2 High-energy gamma-ray detection

Detect Energy Region	5～10,000GeV
Energy Resolution	1.5%@800GeV
Angular Resolution	0.5@800GeV
Electrons and Gamma ray Distinguish Ability	>20
Geometric Factor	>0.2m2.sr

Table. 3 Cosmic Ray Detection

Detect Energy Region	100～100,000GeV
Energy Resolution	Better than 40%@800GeV
Angular Resolution	1.0@1TeV
Geometric Factor	>0.2m2.sr

5. Comparison and Future Outlooks

These two detection methods are represented by the Subsurface Probe (CJPL) and the Extraterrestrial Probe (DAMPE) respectively. The CJPL uses a direct detection method to detect dark matter by detecting the scattering signal of WIMP and Standard Model particles. Dark matter particles can collide elastically with the target nucleus of the detector, transferring some of their energy to the target nucleus, so the recoil signal from the target nucleus can be measured to study the mass, cross section and other properties of dark matter. The experiments are carried out very deep underground and are used to circumvent other rays to a certain extent. However, it is also very costly to dig extremely deep underground laboratories. DAMPE is a typical indirect detection method that detects dark matter by detecting the decay and annihilation products and secondary products of dark matter. These products typically include gamma rays, cosmic rays (positrons, antiprotons and antitritium nuclei), neutrinos, etc. In order to reduce the interference of the Earth's atmosphere, the experiments are carried out in space, which reduces the geographical limitations compared to the former but increases the indeterminacy considerably.

The CJPL detections are likely towards the limits of human capability, but it is difficult to predict the magnitude of dark matter that will be discovered. It is feasible that a 2 or 3 level increase will discover it, however no one is certain of the outcome. For instance, the Swiss proton collider has already used tens of billions of euros to increase detection levels. To increase capabilities by many orders of magnitude, it would likely be necessary for all of humanity to abstain from food and drink. Dark matter is an adjective with the word "dark" in front of it, however for now it is merely "dark."

It is a substance that we have not been able to observe so far, it does not emit light, but in the future there may be other means to "see" it and thus gain further insight into dark matter. Once we understand the composition and properties of dark matter, it will not only broaden our knowledge of the material world, but may also transcend all currently known theoretical models and change our lives, just as quantum mechanics did 100 years ago.

6. Conclusion

In summary, this paper specifically discussess the difference between the Jinping underground laboratory and the 'Wukong' space laboratory and their benefits in discovering dark matter. Current research has built up the fundamentals for dark matter discovery and research in the future. Dark matter is vital to back up current hypothesises. The dark matter theory explains most of the key facts that are currently available. If there is no dark matter in galaxies, then the rotation curve of galaxies cannot be explained. If there was not a lot of dark matter present in the universe, then the universe would probably not be expanding at the current accelerated rate. Humans still haven't detected dark matter yet, but whether it is direct or indirect detection, or even collider detection, although all have limitations, the theories are feasible and there have been major and minor breakthroughs in recent years. It is believed that in the near future we will be able to turn "dark" matter into a real "bright" matter. Overall, these analysis proveds a guideline for dark matter detection.

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