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Recent progress in dark matter detection experiment

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ABSTRACT
Dark matter, as a dominant material form in the universe but has not been directly detected, has always been an important topic in the study of physics and astronomy. In recent years, dark matter detection experiments have made remarkable progress in both technology and theory, providing new clues to understand the nature of dark matter and its origin. This paper aims to review the recent progress in dark matter detection experiments and to analyze current theoretical models on the origin and properties of dark matter. By combing the relevant research results at home and abroad, this paper discusses the future development direction of dark matter exploration, and discusses the potential impact of dark matter research on modern physics and cosmology.

KEYWORDS
dark matter; detection experiment; theoretical model; supersymmetry; dark Big Bang

1 Introduction

Dark matter, as a mysterious substance in the universe that neither emits light nor absorbs light, accounts for about 85% of the total mass of the universe. However, despite its crucial role in the structure and evolution of the universe, scientists have yet to directly detect dark matter particles. The detection and research of dark matter is not only about our understanding of the nature of the universe, but it also could lead to a new revolution in physics. In recent years, with the continuous progress of the detection technology and the increasing improvement of the theoretical model, the dark matter detection experiment has made many remarkable progress. This paper will review and analyze the latest achievements of dark matter exploration from two aspects of experimental progress and theoretical model.

2 Recent advances in the dark matter detection experiments

2.1 Direct detection experiment

Direct detection experiments are one of the most straightforward ways to find dark matter particles. Such experiments typically detect the presence of dark matter using weak signals resulting from the interaction of dark matter particles with ordinary matter. At present, direct detection experiments are mainly divided into several types: scintillator detector, semiconductor detector and cryo-temperature detector.

2.1.1 The scintillator detector

The scintillator detector detects dark matter using the photon flicker effect of dark matter particles collide in matter. Among them, the LUX dark matter detector experiment is one of the more famous scintillator detector experiments. The experiment uses liquid helium and liquid neon as scintillators to measure the energy distribution of the scintillation photon signal through a vapor photoelectric amplifier. By comparison with the simulated signals, LUX experiments successfully excluded some dark matter candidates, which provides an important reference for dark matter detection.

2.1.2 Semiconductor detectors

Semiconductor detectors use transistors to sense signals from dark matter particles. Such detectors have extremely high radioactive exclusion capabilities and are easier to make accurate measurements than conventional liquid or gas detectors. CDMS (Cryogenic Dark Matter Search) is one of the representatives of semiconductor detectors. The experiment uses cryogenic semiconductor materials as a detector to detect dark matter by monitoring the ionization effect of dark matter particles in semiconductor crystals. CDMS experiments have excluded a variety of dark matter candidates and are constantly improving detection sensitivity and accuracy.

2.1.3 Low-temperature detector

Low temperature detector is a new type of dark matter detector developed in recent years. Such detectors usually place the detector at extremely low temperatures to reduce the interference of thermal and background noise and thus improve the detection sensitivity. For example, the PandaX experiment is a cryogenic detector using liquid xenon as a detection medium. The experiment monitors the weak signal from the collision of dark matter particles and liquid xenon atoms by cooling the liquid xenon to extremely low temperatures. PandaX A number of important achievements have been made, including the exclusion of some dark matter candidates and improving the detection sensitivity.

In addition to the above direct detection experiments, there are several other types of direct detection experiments in progress. For example, the XENON1T experiment uses liquid xenon as a detection medium to detect dark matter by measuring the ionization signal generated from the collision of dark matter particles with liquid xenon atoms. The experiment has excluded a variety of dark matter particle candidates, and is constantly improving the detection sensitivity and accuracy. In addition, SuperCDMS, EDELWEISS and other experiments are also under the direct detection of dark matter.

2.2 Indirect detection experiment

Unlike direct detection experiments, indirect detection experiments detect dark matter by observing processes such as the generation and decay of dark matter particles in the cosmic space. These processes release dark matter-invisible particles, such as high-energy γ -rays, neutrinos, etc., which are the targets of indirect detection.

2.2.1 γ -ray detection

The γ -ray is a type of high-energy particles, with much higher energy than visible light and X-rays. Dark matter particles may produce high-energy γ -rays when they decay or interact with other particles. Therefore, the presence of dark matter can be detected indirectly, by observing the high-energy γ -ray radiation in the universe. The Fermi satellite, for example, is a satellite dedicated to observing high-energy γ -rays. The satellite has discovered multiple sources of high-energy γ -rays, some of which may be related to dark matter. However, due to the difficulty of the complex background of high-energy γ -ray radiation, indirect detection of dark matter still faces many challenges.

2.2.2 Neutrino detection

Neutrinos are an elementary particle with no charge and of minimal mass. Because of their extreme penetration, neutrinos can pass through solid materials such as the Earth without being absorbed. Therefore, neutrino detectors can observe neutrino signals from the depths of the universe. Dark matter particles may release neutrinos when they decay or interact with other particles. The presence of dark matter can be detected indirectly, by the observation of these neutrino signals. Currently, there are multiple neutrino detectors in operation, such as IceCube, Super-K, etc. These detectors have observed multiple neutrino events, some of which may be related to dark matter. However, due to the limited sensitivity and precision of neutrino detectors and the complexity of neutrino signals, indirect dark matter detection still needs more experimental data and theoretical analysis to support it.

2.2.3 Other detection methods

Besides direct and indirect detection, there are some other methods that can be used to detect dark matter. For example, dark matter is detected by observing the polarization of the cosmic microwave background radiation (CMB). The cosmic microwave background radiation is the afterglow left after the Big Bang, and its polarization phenomenon can provide important information about the structure and evolution of the early universe. The presence of dark matter has an impact on the polarization of the cosmic microwave background radiation. Therefore, the existence of dark matter can be detected indirectly, by observing the polarization phenomenon of the cosmic microwave background radiation. In addition, there are some dark matter detection experiments based on accelerator technology. These experiments use accelerator-generated beams of high-energy particles to bomb the target material and detect dark matter particles by observing the products of collisions. However, such experiments are still in their infancy due to the complexity and cost of accelerator technology.

2.3 Theoretical model and analysis of dark matter

2.3.1 The origin and properties of dark matter

There is no final conclusion on the origin and nature of dark matter. However, scientists have proposed a variety of theoretical models to explain the existence and properties of dark matter. These models include supersymmetry models, axion models, massive weak interacting particles (WIMPs), etc.

2.3.2 Supersymmetric model

The supersymmetric model is a widely studied theory of physics that offers the possibility of the existence of a dark matter. The theory suggests that there is a supersymmetric particle in the universe corresponding to known particles. These supersymmetric particles have the same mass and spin as the known particles, but properties such as charge may differ. In the supersymmetric model, the dark matter particle may be the lightest mass state of some kind of supersymmetric particle. The supersymmetric particles are difficult to detect directly. However, the correctness of the supersymmetric model can be verified indirectly, by observing phenomena such as energetic particle events in the universe.

2.3.3 Axion model

The axion model is another theoretical model to explain the existence of dark matter. The model suggests that the dark matter particle may be an elementary particle called the axons. Axions are very light, uncharged particles that may be about a trillions onth of the mass of the electron. Axions are difficult to detect directly.

However, the axion model can explain some cosmological observational phenomena, such as the polarization of the cosmic microwave background radiation. In addition, axons may be produced in high-energy physics in the early universe and remain today.

2.4 Large-mass number of weakly interacting particles (WIMPs)

Massive weak interacting particles (WIMPs) are one of the most popular dark matter candidates. Such particles have larger masses (usually tens to hundreds of times larger than protons) and weaker interaction strength (compared to ordinary particles). WIMPs are difficult to detect directly because of their very weak interactions with ordinary particles. However, scientists have indirectly speculated that WIMPs may exist in the universe by observing the energetic particle events and the cosmic microwave background radiation in the universe. Moreover, some direct detection experiments have also begun to search for signals from WIMPs, and some preliminary results have been achieved.

2.5 Theoretical basis and challenges of dark matter exploration

The experimental progress of dark matter detection cannot be separated from the support of the theoretical basis. However, there are still many uncertainties and challenges in the current theoretical model of dark matter. These challenges include the properties of dark matter particles, the way that dark matter interacts with ordinary matter, and the distribution and evolution of dark matter in the universe.

2.5.1 Properties of the dark matter particles

There is no jury on the nature of dark matter particles. Different theoretical models propose different dark matter particle candidates, such as supersymmetric particles, axons, WIMPs, etc. These candidates have properties such as different masses and interaction strengths. Therefore, searching for dark matter signals in experiments requires targeted detection according to different theoretical models. However, due to the uncertainty of theoretical models, it is difficult to determine which candidate particles are true dark matter particles. This increases the difficulty and uncertainty of dark matter detection.

2.5.2 The way that dark matter interacts with ordinary matter

The way that dark matter interacts with ordinary matter is also one of the most important challenges. The dark matter signal is difficult to detect directly because of the very weak interaction between dark matter particles and ordinary particles. To solve this problem, scientists need to develop more sensitive and accurate detection techniques to improve the detection sensitivity and accuracy. Moreover, intensive studies of the interaction mechanisms between dark matter and ordinary matter are needed to better understand the nature and behavior of dark matter.

2.5.3 The distribution and evolution of dark matter in the universe

The distribution and evolution of dark matter in the universe is also one of the most important challenges. Because dark matter does not emit light or absorb light, it is difficult to directly observe the distribution and evolution of dark matter. However, the distribution and evolution of galaxies in the universe, galaxies and the cosmic microwave background radiation of objects in the universe. These observations have important implications for understanding the nature and behavior of dark matter. However, due to the limitations of observational data and the uncertainty of theoretical models, there are still many controversies and uncertainties about the distribution and evolution of dark matter in the universe.

2.5.4 Future development direction and prospect of dark matter exploration

With the continuous progress of detection technology and the increasing perfection of theoretical model, the future development direction of dark matter detection experiment will be more clear and broad. Here is a look for the future of dark matter exploration:

As a frontier field of contemporary physics and astronomy, the future development direction and prospect of dark matter detection have attracted much attention. The following is a detailed description of the future development direction of dark matter exploration:

2.5.5 Deepen the direct detection technology

Direct detection of signals generated by the collision of dark matter particles with the nucleus is one of the most important detection methods. In the future, with the continuous progress of the detector technology, such as improving the sensitivity of the detector and reducing the background noise, the direct detection experiments are expected to make breakthrough progress. China has a certain research basis in the direct detection of dark matter, such as the second phase of Jinping Underground Laboratory. In the future, we should continue to make good use of these research facilities to deepen the research of direct detection of dark matter.

2.5.6 Expand the use of indirect detection methods

Indirect detection is an indirect proof of the existence of dark matter by observing the stable particles produced after their decay or interaction. In the future, with the continuous development of space detection technology and ground observation facilities, the indirect detection means will be further expanded. For example, with the launch of more dark matter detection satellites and the construction of more advanced ground observation stations, gamma rays, positrons and antiprotons.

2.5.7 Strengthen international cooperation and exchanges

Dark matter detection is a global scientific problem, which requires the joint efforts of scientists from all countries. In the future, international cooperation and exchanges should be strengthened to jointly promote the development of dark matter exploration and research. By participating in international accelerator experiments and building international dark matter exploration facilities, we can gather global wisdom and accelerate the process of dark matter exploration research.

2.5.8 Explore new detection technologies

With the continuous progress of science and technology, more new detection technologies may be used for dark matter detection in the future. For example, using advanced technologies such as quantum computing and artificial intelligence can improve the efficiency and accuracy of dark matter detection. In addition, the research results of astrophysics, cosmology and other fields can also be explored to assist the research of dark matter detection, forming a multi-disciplinary research pattern.

3 Look into the distance

In the next few decades, with the continuous progress of the detection technology and the deepening of the international cooperation, the dark matter exploration research is expected to achieve breakthrough results. For example, the direct detection of dark matter particles, the indirect detection of stable particles produced by dark matter decay, etc. The success of dark matter exploration will not only reveal the basic composition and evolution laws of the universe, but may also may promote a new revolution in physics. For example, the discovery of dark matter particles will potentially fill the gaps in the Standard Model and open up new directions for the development of particle physics. Dark matter detection research is a highly comprehensive scientific research project that requires knowledge and technology involving multiple disciplines. Therefore, the development of dark matter detection research will promote the progress of related disciplines and technologies, and promote scientific and technological innovation and social development.

To sum up, the future development direction of dark matter exploration includes deepening direct detection technology, expanding indirect detection means, strengthening international cooperation and exchanges, and exploring new exploration technologies. With the continuous development of these directions, the research on dark matter exploration is expected to achieve reakthrough results, promote the physics revolution and promote scientific and technological progress and social development.

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