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Review Of Dark Matter

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Abstract. Dark matter is counted as two of the significant discovery and research topics in the academic and scientific fields. Found later that dark matter does not belong to any of the present areas of known matter, dark matter was discovered in the late 19th century and early 20th century by indirect measuring of the abnormal velocity and mass dispersion pattern detected by multiple astronomers and mathematicians. In the last several decades, scientists from different physics fields have determined the property, location, potential candidate, origin, and interaction of dark matter. Starting with the history of the discovery and research of the dark matter, the dark matter property will be illustrated in the abstract. One of the properties of dark matter is the property that dark matter does not absorb, reflect or interact with any photons and any kinds of electromagnetic waves. The two potential dark matter candidates are WIMP (weakly interacting massive particle) and axion. The reason the scientist suspected that the two particles are the candidate for dark matter is also listed. Experiments about the candidates and other observations and theories are also listed in the paper.

Keywords: Introduction, Candidates, Detection of Dark Matter, Other Dark Matter Observations.

1. Introduction

Dark matter and dark energy are the essential components of the universe. They make up about 96 per cent of the energy proportion of the universe, while the rest 4 per cent are baryonic matter and the rest of the matter made up about 0.01 per cent or even less proportion of the universe. Dark matter is a substance that cannot be sensed through light methods. It also cannot be determined or undefined. Thus, scientists took a long time to find dark matter and determine its properties through direct and indirect methods and determine its properties.

In 1844, mathematician Friederich Bessel became the first person to notice the invisible celestial body by observing the stars Sirius and Procyon. In his prediction, the celestial body was influenced by faint companion stars. The theory was mostly true. However, he may also be a person who noticed an invisible substance in the universe that can affect visible objects. Later, in the 19th century, astronomers also assumed that dark matter existed in nebula-like patterns. [1]

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In 1904, Lord Kelvin analyzed dynamically about amounts of matter in a milky way and predicted that there might be invisible objects that existed in the Milky Way. Later, Frenchman Henri Poincaré argued from the result of the dynamic analysis of Lord Kevin that the amount of dark matter is less than or similar to the amount of visible matter. However, still, they believed that dark matter does not exist in large amounts. [1]

In 1933, Swiss-American astronomer Fritz Zwicky utilized the viral theorem from thermodynamics to analyse the Coma Cluster's mass and velocity dispersion ranging from 800 galaxies in 10^6 light years. The result was that the velocity of the galaxies was quite abnormal and far more significant than the expected mass. In his conclusion, for the first time, he noticed that the total quantity of dark matter is far greater than that of visible matter. In his research in 1937, he got a high mass-light ratio from the analysis. In 1936, Sinclair Smith, who studied Virgo Cluster, found that the average mass of the 500 galaxies in the cluster was far more significant than Hubble had estimated. Although considered the result a mistake, the scientist may still notice that there could be invisible substances that create such mass for the galaxies. Later the investigation and existence of dark matter were confirmed by more and more people in the field. [1]

Dark matter is an invisible matter that cannot be seen and does not release, absorb or interact with electromagnetic waves and photons. [2] Dark matter interacts with gravity; thus contains mass. [3] They are also highly stable in terms of the universe's long history. Their speed should be lower than the speed of light, according to computer simulations of the universe's large-scale structure. Dark matter may occupy a large proportion of mass in the universe on a large scale.

Dark matter also makes the velocities of stars near the edge of a galaxy the same as the ones of stars near the centre. In the 1970s, by analyzing the rotation curve, which is a graph of the orbital speeds of visible stars or gas in that galaxy versus their radial distance from that galaxy's centre [4], of many galaxies, Vera Rubin concluded that there must be some other matter than keeps the speed of stars near the edge of galaxies from decreasing. The other matter forms a halo shape around the disc galaxies, influencing their formation and growth. [5]

In this article, we will talk about the two candidates of dark matter, nine observation projects of dark matter, and two other observation methods suggested by scientists.

2. Candidates

Although there have been many dark matter observations, its composition is still unclear. According to current theories, there are two most likely dark matter candidates: WIMPs and axion.

2.1. WIMPs

WIMPs (Weakly Interacting Massive Particles) are one of the most closely watched candidates. It refers to a particular stable particle with mass and interaction strength near the electroweak scale, which obtains a known residual abundance through a thermal decoupling mechanism.

They are hypothetical particles proposed to solve the composition of dark matter, so the search is still on for a way to discover WIMPs.

In addition, the properties of WIMPs are still being studied. A WIMP is a unique particle with no colour and no electric charge, and its mass is in the range of a few MeV to the electroweak scale. The WIMP exemplification makes up the DM relic density in the universe, which is extremely attractive both experimentally, because of the feasibility of WIMPs searches with some unique methods, and regarding the view of current theoretical physics, as feasible candidates for DM particles have been predicted in a few physical models beyond the SM. [6]

2.2. Axion

Axions are hypothetical particles proposed originally for solving the "big CP problem", which refers to the cosmological matter-antimatter asymmetry. Axion, a very light neutral particle, is associated with the joint symmetry breaking of charge conjugation-parity inversion in solid interactions. [7] Axions interact with each other through tiny forces, so they cannot be in thermal equilibrium with background

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radiation, so they cannot obtain residual abundance through thermal decoupling. However, they can become cold dark matter through vacuum state breaking.

The axion is far lighter and weaklier coupled than the WIMP, and initially, experimental searches for the axion made slow and painful progress toward the theoretically defined goals. [7]

3. Detection of dark matter

The admitted candidates of dark matter are Weakly Interacting Massive Particles (WIMPs) particles or axions. Both of the candidates do not interact much with other matters. Multiple ways can be used to detect dark matter. Since the collision between cosmic dark matter particles and the nucleus of atoms may change the energy state of the nucleus, dark matter can be sensed by sensing the tiny internal energy changes of the ordinary matter caused by the collision between the dark matter stream and the ordinary matter. Scientists established observatories in areas not influenced by cosmic radiation since the assumed candidate of dark matter is probably the WIMP particle hardly interacting with known matter. The observatories are usually underground in depth. Also, dark matter may be detected by indirect detection of particles resulting from dark matter decay. The particle collider may also be used. Since the particles of dark matter hardly react with ordinary matter, they cannot be sensed by the average detector of the facility. However, the collision of different particles may generate the particle of dark matter. The "mass lost" can be sensed by the detector that only can detect known matter and particles. People can indirectly sense the trace of the dark matter through particle collision. The abnormal trace of galaxies and mass and velocity distribution of mass in a cluster or large-scale structure, as mentioned in the previous paragraphs about historical discoveries, can also prove the existence of dark matter. In addition, the law of relativity can be utilized in discovering dark matter and determining the quantity of dark matter. It is based on the fact that the mass of an object influences the density of space around it. When light travels through the twisted space, its path will be bent, and how much the paths are bent will indicate the mass of the object that twists the space. It turns out that there should be vast masses in the universe to cause the light to bend to the specific extent detected on Earth. [8]

3.1. The Large Underground Xenon (LUX) experiment

The Large Underground Xenon experiment, or LUX, was set in the Davis Cavern at the Sanford Underground Research Facility (SURF) at Homestake [The Large Underground Xenon (LUX) experiment] was designed to detect the weakly interacting massive particles (WIMP), which is a possible candidate of the dark matter. The impact between the weakly interacting massive particles and atomic nuclei may generate photons and electrons. The core of the experiment is the chamber of liquid xenon. The facility exerts an electric field on the apprentice and directs the electron up toward the top part of the tank. The photomultiplier (PMTs) are settled on the tank's top and bottom. The top part detector, where the electron escaped from the recombination in the collision between WIMP and xenon nuclei, since the electro-luminescence, the photons generated by the electrons. The bottom detector sensed the photons generated by the collision between the xenon nuclei and WIMP. The detection and record of the time of sensing of photons on each photomultiplier and the position of the photons can help scientists to build a three-dimensional model of the collision of possible dark matter and ordinary matter. [9]

3.2. PandaX-The Particle and Astrophysical Xenon

The PandaX detection project, established in 2009 and supported by the Ministry of Science and Technology in China and supported and consisted by physicists from Shanghai Jiao Tong University, Shandong University, Shanghai Institute of Applied Physics, and the Chinese Academy of Sciences, utilized the same method as the LUX experiment. The experiment was carried out in the China Jinping Deep-Underground Laboratory (CJPL). Similar to the LUX experiment, both experiments were carried out underground to have the best and the most stable environment for dark matter detection. [10]

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3.3. Large Hadron Collider (LHC)

The Large Hadron Collider is another possible method to generate dark matter based on possible reactions between the Standard Model matters, which are matters that had been researched as determined. Since dark matter is the type of matter that cannot be directly detected by the average detector, in the experimental results, if there is a difference between the initial mass of the reactor matter and the final mass of the reactor matter, it is possible that the dark matter, which is the mass that cannot be detected, is generated. [11]

3.4. PICO

The PICO collaboration was formed by combining the group PICASSO and COUPP. The facility was built as the next generation of dark matter detectors using the best technology from the PICASSO and COUPP. Utilizing the superheated liquid technique, the energy and phase transition can be detected to find the trace of WIMP particles. The device utilized bubble chambers to scale the WIMP mass accurately. [12]

3.5. DAMA

The DAMA collaboration had related the galactic halos of dark matter or WIMP with the modulation in nuclear recoils of ordinary matter. The DAMA project discovered an annual and regular modulation in the nuclear recoils. The time of regulation may be related to the velocity of the Earth orbiting the sun. The evidence had shown that the WIMP interaction had happened during several periods in the year. However, still, the result of the experiment contradicted other dark matter experiments such as CDMS and XENON experiments. [13]

3.6. CRESST (Cryogenic Rare Event Search with Superconducting Thermometers)

The CRESST-III detector utilized the target crystals and CaWO4 sticks to detect the heat and light signals that occurred because of the WIMP detection. The facility used a similar method of light detection in order to detect the existence of dark matter directly. The experiment finally measures the interaction between dark matter particles, ordinary matter or legal model matter. The facility is located in the GranSasso underground laboratory in Italy. [14]

3.7. The China Dark Matter Experiment (CDEX)

The China Dark Matter Experiment (CDEX) attempts to use direct detection to prove the existence of light WIMPs. It applies p-type point contact germanium (pPCGe) detectors designed to specifically run low-- background searches such as low-energy nuclear recoils. The results are mainly collected from a series of pPCGe detectors. The experiment mainly works on decreasing the energy threshold as much as possible. With the help of the data collected from the first pPCGe detector (CDEX-1A), the researchers successfully updated a new pPCGe detector (CDEX-1B) with an energy threshold of ~180. However, the process of analyzing the data gained by CDEX-1B is still ongoing. [15]

3.8. XENON1T

The XENON1T experiment, implemented at the Laboratori Nazionali del Gran Sasso, intends to prove the existence of WIMPs by finding signs of nuclear recoils from WIMP-nucleus scattering. The detection process takes place in xenon time projection chambers with two phases. One detects the Xe scintillation light at a few, and another detects the ionization with the transmission of electrons at only one electron level. The result of the experiment improved the limits of the spin-independent WIMP-nucleon interaction cross-section to 35-GeV/c2 WIMPs at 7.7×10^{-47} cm^2. [16]

4. Other observations of dark matter

Instead of focusing on finding the candidates of dark matter, the universe's observations also significantly contribute to its detection. For instance, a team of universities such as NYU and Princeton have proposed that dark matter can be detected by studying the properties, such as the number and temperature, of light elements in the early universe can also reveal the composition of the dark matter. [17] By applying big bang nucleosynthesis (BBN) and the cosmic microwave background (CMB) in the formation of new models, the researchers attempted to prove the existence of a type of dark matter with a mass between the masses of protons and electrons. [17]

In 2022, observations of the Fornax Cluster performed some phenomena that seem to contradict the existence of dark matter. According to the Standard Model, the dark matter halo should prevent events such as distorted dwarfs. However, the fact is just the opposite. In order to fit the observations, researchers applied the Milgromian dynamics (MOND) model, which does not include the dark matter in the components of a galaxy. [18]

5. Conclusion

Dark matter is one of the most important discoveries in the 20th century and 21st centuries. The research started in the mid and late 19th century when the mathematician Friederich Bessel firstly noticed the invisible celestial bodies. Then, in the early 20th century, Lord Kevin noticed that there was an invisible matter in a milky way. However, until the time of 1933, when Fritz Zwicky firstly noticed from analysis of velocity and mass distribution of the galactic cluster the existence of a tremendous amount of dark matter, people still suggested that dark matter exists in tiny amounts.

In summary, the two leading dark matter candidates are still being studied, with progress but no definitive conclusions or evidence. We have a glimpse of the property of WIMP, but there is still a long way to go before we can fully understand it, and the research on it is still going on. Although axion is more complicated to study than WIMP, axion is still one of the mainstream ideas about dark matter candidates.

Scientists have suggested multiple ways to detect dark matter, including the energy change of the nucleus of ordinary matter, mass loss caused by particle collision, and light bending caused by the gravitational effect of the dark matter halos. The facility Large Underground Xenon experiment and PandaX used xenon as a target to detect the collision between the dark matter and the xenon nucleus. Large Hadron Collider tried to generate dark matter from the collision of standard model matters. PICO, DAMA, CRESST, CDEX, and XENON1T projects utilized different ordinary matter to detect the interaction between standard model matter and dark matter and the nuclear recoil of ordinary matter.

Besides experiments done on earth to find the building block of dark matter, observations from the university are also necessary to improve our understanding of dark matter. The research team formed by researchers from many universities in the U.S. has proposed that the component of dark matter can be revealed by analyzing the early light elements. Some phenomena seem to contradict the existence of dark matter, such as the observations of the Fornax Cluster presenting distorted dwarfs, which are supposed to be protected by dark matter.

However, still, the dark matter search is still proceeding. None of the experiments above directly show the physical property of the dark matter except for the mass, quantity, and luminosity of dark matter in space. The experiment had already proceeded deeply, but it is necessary to find new methods or technology for the investments in the dark matter and the indication of the natural candidate of the dark matter.

Authors' contributions

All author's contributions are equal.

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