Research on dark matter and its detection methods

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Abstract. In the past few decades, theoretical and experimental research on dark matter is in the ascendant. Various theoretical models of dark matter and direct or indirect detection results of dark matter emerge in endlessly. These scientific research achievements have greatly deepened our understanding of dark matter. Based on the past research, this paper summarizes the detection methods of dark matter.

Keywords: Dark matter, Detection methods, Evidence.

1. The concept of dark matter

Dark matter makes up 85% of the matter in the universe. Astronomical and cosmological observations suggest that dark matter affects the evolution of the universe, leaving its imprint on the distribution of galaxies and the large-scale structure of the universe. The distribution of matter in the universe is usually measured by gravitational lensing. The effect predicted by Einstein is caused by light emitted by distant objects being bent by the gravitational pull of matter between the object and the Earth. Astronomers use gravitational lensing of galaxies to reconstruct astronomical maps, such as DES's map of the distribution of visible and dark matter. Scientists know from these images that dark matter exists, but not in what form. Dark matter is most likely some completely new particle that we've never detected before. We still don't know if dark matter is made up of one or more particles.

2. Evidence

The study of dark matter is a cross research field closely related to particle physics and astronomy. Dark matter has been proposed and the evidence for its existence comes from astronomical observations. However, no particle can be found in the Standard model of particle physics to explain dark matter. This shows that current theories are not completely self-consistent between the small scale of elementary particles and the large scale of observations of the universe, indicating the possibility of new physics beyond the Standard Model.1.1 Evidence for the existence of Dark Matter At present, astronomy has accumulated a variety of evidence for the existence of dark matter. The most direct evidence comes from galactic rotation curve measurements (see Figure 1)[1], which measure the rotation speed of materials around the galactic center as a function of their distance from the center. The observed rotation velocity usually tends to be constant at very long distances from the galactic center, independent of the galactic center distance, and this behavior deviates from Newtonian gravitational behavior. Other galaxy-scale evidence includes weak gravitational lensing effects for distant galaxies [2], Bulletcluster observations related to galaxy collisions [3], etc. Observations on the other hand, the size of the universe, from the microwave background radiation anisotropy can be accurately infer, the total mass density in the universe should be ΏMh2 = 0.1326+-0.0063 [5]. Where h is Hubble's constant in units of 100km·s minus 1·Mpc minus 1. Through the observation of light chemical elements content of substances that may estimate the baryon density of accurate for Ώ Bh2 = 0.02273 +- 0.00062 [5, 6]. As a result, 80% to 85% of the matter in the universe is invisible, non-baryonic matter, or dark matter.

alternatives to dark matter

The reason this is possible is that axons are bosons, not fermions. Fermions (including WIMPs) must abide by the Pauli exclusion principle, meaning that two fermions cannot occupy the same quantum state. On the other hand, because axons are bosons, they can occupy the same quantum state. This means that when we cool the axons sufficiently, they can enter the same low-energy state and behave collectively like individual super particles, known as Bose-Einstein condensation. The traditional axions originated as an extension of Pechey-Quine's theory of quantum chromodynamics (QCD). QCD describes the strong interaction forces among the four fundamental interactions. Despite the success of the QCD model, some of its predictions have never been observed in the laboratory. Pechei and Quine's work resolves this paradox and provides a mechanism for dark matter production. Meanwhile, another idea, called string theory, predicts a series of particles with the same mathematical architecture as traditional axons, called axonion-like particles. Traditional QCD axons are thought to weigh about 10 to 40 kilograms, about 10 orders of magnitude lighter than electrons, while string theory-like axons can be much lighter, as low as 10 to 63 kilograms.

Collaborative research by Herzberg, Martin Luther King, and his postdoctoral advisor Alan Guth disputed the popular idea of how axons could form Bose-Einstein condensates. Physicist Pierre Sikivi caused a stir in 2009 when he proposed that QCD axons form large condensates in the very early universe. His calculations suggest that this would lead to a circular halo of dark matter in the galaxy, rather than the spherical halo that most astronomers, and the WIMP model, had predicted. If this is true, we might be able to tell what dark matter is made of by looking at the shape of the halo.

3. Dark matter detection method

3.1. High purity germanium detector

The techniques fall into two main categories, one that measures only ionization energy and the other that measures both phonons and ionization energy, or phonons and flicker light. The first technique uses a high purity germanium detector operating at liquid nitrogen temperature (77 K). High purity germanium detector is a new type of conductor detector developed in the 1970s. Thanks to the innovation of germanium purification technology, the purity of high purity germanium crystal can reach 12-13 9, that is, the purity of germanium is greater than 99.9999999999% or 99.99999999999%. And 24 karat gold or all gold, that is, jewelry fineness in the highest purity value, but 99.99% purity. The detector has the best energy resolution (e.g., about 3% of the half-width at around 10 keV), a low threshold (1-2 keV), commercial production, and a long-term stable detection state. With the application of high purity germanium in the spot electrode, the capacitance of the detector is effectively reduced, making the noise lower (< 400 eVee, "eVee" means electron equivalent energy). The use of the detectors on the current international main experimental group was CDEX [7-12], TEXO NO[13-15]and CoGeNT (16, 18). The CDEX group has obtained the best exclusion line result [7,11,12]. The CoGeNT experimental group published the results of annual modulation effect in 2013, claiming to find the possible annual modulation signal of dark matter, and giving the allowed mass-cross section region [7]. However, the results of the CDEX group using the same technique excluded the permissible regions of the CoGeNT group. In such experiments, the main background is by far the natural gamma rays in the surrounding environment. The background can be further depressed by careful selection of materials around the detector and tight control of the detector assembly process.

In the second technique, detectors are usually operated at ultra-low temperatures of less than 100 mK. It can measure two different kinds of signals at the same time and use the ratio of the two signals to distinguish the nuclear recoil signal and the electron recoil signal. This method of active case screening opens a new way to detect dark matter. Leading the way internationally is the CDMS laboratory group in the United States, which measures phonons and ionization signals, and then uses Si and Ge for experiments. In 2013, the CDMS-II (Si) experimental group discovered the suspected case of dark matter [8], which has been basically excluded by the results of other experimental groups [7, 20 -- 23]. After the Si detector, the CDMS experimental group used Ge as the detector to measure phonons and ionization, and obtained the first physical results of the SuperCDMS experimental group in 2014, which had certain advantages in the low-energy part [9]. In addition, in 2013, the CDMS experimental group used the same Ge detector but at different high pressures to obtain a more low-energy advantage of CDMSlite[10] experimental group, its threshold reached 170eVee, but could not distinguish nuclear recoil and electron recoil cases under this working condition.

3.2. Liquid xenon detector

Liquid xenon is one of the best materials for direct detection of dark matter. it

Its density and atomic number are large, so the range of γ-rays is short. Most γ-rays cases are distributed around the detector. The cases around the detector are resolved by the position of the detector, and only the central area of the detector is retained as the effective detection area. Therefore, large liquid xenon detectors have a good self - shielding function. Xenon also has no natural radionuclides.

Liquid xenon detectors fall into two categories: one without electric field; A class

And the electric field. The first type of liquid xenon detector measures only the first flash (S1), when the photo multiplier tube is immersed in liquid xenon. The XMASS experimental group uses this method to detect WIMPs particles, in which the total mass of liquid xenon is 835 kg. They plan to use 100 kg effective mass liquid xenon with the innermost and lowest background to detect dark matter, and its threshold can reach 5 keVee.

The second type of liquid xenon detector is also called gas-liquid binary xenon time projection room. The principle is shown in FIG. 4. The detector consists of lower liquid xenon and upper gas xenon, and upper and lower photo multiplier tube arrays. The lower liquid xenon was applied with an electric field of 0.05-4 kV/cm, and the upper gas xenon had an even stronger electric field of about 10 kV/cm. When energy is deposited in liquid xenon, part of the energy is converted into fluorescence, which is immediately detected by the upper and lower photo multiplier tubes, denoted as S1. Part of the deposition energy is converted into electron ion pairs, and the electrons drift towards gas xenon under the action of electric field. Due to the strong electric field of gas xenon, the electrons are "pulled out" from liquid xenon, and then secondary ionization occurs in the strong electric field of gas xenon, resulting in secondary fluorescence, which is recorded as S2. Because in liquid xenon, different ratios of fluorescence and ionization are generated due to nuclear and electron recoils, which can be used to identify and remove electron recoil signals.In addition, the position information in the Z direction can be obtained from the drift time information of electrons in liquid xenon, and the position information in the X and Y directions can be obtained from the upper and lower photomultiplier array, so the detector can be used for three-dimensional position positioning.

3.3. Inorganic scintillator

Inorganic scintillators, mainly NaI and CsI crystals, are also probed

An important detector for dark matterIt is characterized by low cost, sophisticated analytical techniques, good waveform recognition ability, elimination of electron recoil background, and exclusion of other background cases by using the matching signal between detector arrays. Its main disadvantage is that the case rate is not easy to reduce and the stability of the detection system is difficult to maintain in a few years. At present, there are no successful experiments and theories in the world to explain the results. In order to independently verify the results of the DAMA[11] experimental group, several other experimental groups are being attempted internationally. The DM-ICE[12] experiment is using a 17 kg NaI(Tl) detector at the South Pole and plans to upgrade to 250 kg in 2015. The DM-ICE experiment can be used to test whether the annual modulation effect of DAMA is related to the seasons (out of phase in the southern and northern hemispheres) or to Earth's velocity relative to the Milky Way (out of phase in the southern and Northern hemispheres).

Stability of the dark matter

Whether or not dark matter is stable basically means whether or not dark matter decays. The decay lifetime of dark matter is too short to account for the residual density observed by astronomy today. But if dark matter decays much older than the age of the universe, it doesn't contradict astronomical observations. For example, the most recent interpretation of the PAMELA data[13] can be explained by decaying dark matter, which generally requires that the dark matter has a lifetime of ~1026s, much longer than the universe's lifetime of ~1018s. A more general scenario is to assume that dark matter is stable. When constructing new models that include dark matter, a Z2 discrete symmetry is usually introduced, such that the STANDARD MODEL particles[14] have a charge of +1 and the new particles have a charge of -1. Because of Z2 symmetry[15], the lightest particle in the new particle cannot decay into a pair of standard model particles and is therefore stable. For example, the split symmetry in the supersymmetry model is R parity[16], and the extra dimension model is KK parity [17].

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