Analysis Of the Different Analytical Model for Different Dark Matter Candidate

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Abstract. As a matter of fact, dark matter candidate searching always been a key puzzle and challenge for contemporary physics. In retrospect, various approaches have been proposed in order to realize the detections and plenty of analytical models are given for possible searching. Nevertheless, there is no strong evidence for existence of certain type dark matter. With this in mind, this study will demonstrate the history and various different proposed models for dark matter candidate. To be specific, the WIMPs and axion, two most widely investigated candidate, will be discussed in detail. According to the analysis, the basic concepts, analytical descriptions, detection facilities as well as the state-of-art results will be illustrated. In the meantime, the current limitations for detections as well as searching for further research will be evaluated. Overall, these results shed light on guiding further exploration of dark matter as well as pave a path for dark matter candidate searching to confirm the physical model based on the upgrade of the advanced facilities.

Keywords: Dark matter; WIMPs; axion.

1. Introduction

The dark matter, as the content of science frontier situations, except been researching by the pioneer scientists, some appears in middle schools. In the Biological Physics Olympiad, even be covered in the test questions for the college entrance examination in some countries. Dark matter significantly play a key rule of modern cosmology for people to explore and understand the whole universe, as they account for about 23% of the content of the universe today, which far beyond the baryonic matter (4%) used to contact in the daily life, yet the understanding to them still fairly little in human's cognition [1-3]. They dominate the universe evolution in the middle and later stages of the universe, but one still lacks sufficient understanding of the dark matter, neither the physical properties nor the history [2]. Especially considering to the historical perspective, the materials or the literature which can explain or confirm any of the long mysterious history of dark matters are too rare. The evidence is hard to find out even a little, because at the very beginning stage, most of the aims were just focused around 20th centry's work of galaxy clusters and galactic rotation curves (by Fritz Zwicky, Vera Rubin around 20th centry) [1].

The presence of dark matter was already mentioned by Galileo, although he didn't come up the concept, but he did observed something in space through telescope. The light waves in the universe was produced by countless stars, and that there were some satellites invisible to the naked eye presenting in solar system [1]. This phenomenon just reveal a fact which related to dark matters: There are some matter in the universe existing while unable to be perceived by simple observations. Speaking about the substance invisible, there was also a very early concept came from Greek philosophers which known as ether. Aristotle once argued that nature is averse to vacuum. Therefore, he proposed the theory of the five elements, which holds that everything below the moon layer is composed of the four elements earth, water, air, and fire, The celestial bodies above the moon layers are made up of the purer fifth element"Ether" composition - as a basic unit of matter appeared in the science of ancient Greece, the Ether referred as an abstract concept of matter, similarly does the dark matter.[4] It was reasonably that first cosmology model idea came from the the ancient Greeks.The atomists from ancient time argued that all matter was also contained indivisible building blocks besides the basics materials. [1]The concept of dark matter was early predicted by ancient Greeks, but the way people actually found out their presence was still convinced by analysis and calculation. Astronomers analyze the mass of galaxies from two main perspectives:

The first is the optical angle, through the measurement of the luminous intensity of the galaxy, through the appropriate mass-to-light ratio (the ratio of mass to luminous intensity) to convert the mass, the mass obtained by this method is called "photometric mass". The second is the kinetic point of view, through the acceleration of the celestial body and Newton's laws of motion to estimate its mass, this method to obtain the mass is called "kinetic mass". In the 70s, Rubin measured the rotational speed curve of spiral galaxies and found that there was a significant deviation between the photometric mass and the kinetic mass. These deviations say that there are large amounts of non-luminous matter in star clusters and galaxies, which provide additional gravitational pull. Since then, a large number of astronomical observations have been observed from the rotational velocity curves of a large number of galaxies, the gravitational lensing effect, and the cosmic microwave background radiation, which shows that there is a large amount of invisible matter in the universe, that is, dark matter [3]. Dark matter may contain a variety of astrophysical matter, but humans cannot detect it with existing telescopes because these non-emitting nor reflecting particles that only participate in gravitational interactions are too faint [4]. As the time passes, more and more particle physicists moved into the territory of cosmology and started to research the dark matter problems. Around the late 20th centry, the assumption of dissapearing mass composed by some subatomic particle became the dominant mainstream dark matter model as it kept owning a growing number of supporters. This perspective was acknowledged by most particle physicists and astrophysicists - particle astrophysics. Considering about this, there are three known types of dark matter candidates: neurtinos, WIMPs, supersymmetry and QCD .

As mentioned earlier, dark energy and dark matter occupy about 95% of the energy component of today's universe, but it still lack sufficient understanding of their physical nature where there is a hard to imagine if there are any sorts of potential interaction between the two dark components. If so, it will certainly have a significant impact on the evolution of the universe. It’s worth to expect theoretical exploration of the underlying interaction will provide a more advanced understanding of the physical property and nature of dark matter, moving up next level of understanding to the whole unknown universe. This article will introduce the basic definition of dark matter as a description, and talk more about different dark matter candidates in details.

2. Basic Descriptions

According to the physical properties, the energy components of the universe can be divided into four categories: dark energy, dark matter, baryon matter and radiation. This link to the Particle physics, the study of the composition of elementary particles and their interactions. Based on quantum field theory and gauge theory, the particle Standard Model mainly describes three fundamental interactions: electromagnetic interactions, weak interactions, and strong interactions. While Dark energy and dark matter do not participate in electromagnetic interactions; meanwhile, the observations put a strict limit on the strength of dark matter and baryonic matter interactions. Therefore, one expects the negligible interaction of the two dark components with the photon radiation field and the baryonic matter [2]. For many astrophysicists, this missing mass may be made up of objects that are only much brighter than ordinary stars in brightness and nothing else.

Neutrinos, that was first detected from beta decay reaction, are very stable and do not experience electromagnetic or strong interactions. These are the basic characteristics of most dark matter candidates. While dark matter in the form of neutrinos cannot currently covered the whole universe, these particles provide an important template for the hypothetical species which called WIMPs [4]. Even if the mass of neutrinos cannot be determined experimentally, the upper limit of neutrino mass given in the current experiment shows that the mass of neutrinos is much smaller than that of other fermions in the Standard Model. In order to determine the mass type of neutrinos and to naturally introduce neutrino mass terms into the Standard Model, a wealth of new physical models beyond the

Standard Model have been proposed in recent decades around the origin of neutrino mass. Numerous astronomical and cosmological observations have confirmed the existence of dark matter, but its essence is not well known, and its microscopic particle properties are another important research direction in the field of particle physics [5]. Subsequently, from the early 70s of the 20th century, many physicists began to consider that there may be a kind of space-time symmetry between fermions and bosons in nature, that is, "supersymmetry" [2]. Symmetry is the starting point and methodological principle, which governs interaction. Especially after the 70s of the 20th century, symmetry and its expansion of supersymmetry and duality have guided the construction of a new theory beyond the Standard Model [6]. Supersymmetry, on the other hand, requires that each fermion and boson must have the same quantum number, so supersymmetry predicts the supercompanions of neutrinos, photons, Z-bosons, Higgs bosons, and gravitons. If any of these superpartners are stable, they may be cosmologically abundant and may have played an important role in the history and evolution of the universe. Compare to the WIMPs , this model can not only discuss the missing mass from galaxies and clusters, but also can be used in a large scale model. For practically realize the formal supersymmetry model, in December 1981, Savas Dimopoulos and Howard Georgi submitted a model: the minimal supersymmetric standard model (MSSM). This also let scientist starting to considering the superpartners. In MSSM, the consideration of neutralions also added the superpartner of photons, this changes the situation which only the neutralions would be regarded as the only candidate of dark matters in past 35 years. Besides, there is another general direction of dark matter research, and after all the measurements, quantum chromodynamics (QCD) is a very successful theory. It is a very accurate description of strong forces, quarks, and gluons [1]. In addition to the neutrinos, scientist gradually accepted the suggestion of which most of the mass in the universe are composing by nonbaryonic particle, the last type of dark matter is consists of many unknown elementary particles known as WIMPs are widely confirmed by more and more astrophysits.

3. WIMPs

Since Zwicky found out the Coma cluster, for gravitational binding the galaxies, what exactly consisted the dark matter have been a vital stage on the research in astrophysics and cosmology [1]. Besides, Lee and Weinberg, based on $2 \to 2$ interactions, first performed the study of heavy stable particle has weak interaction with the visible particles. To A particle X which has a mass mX , it will definitely stays stable as no particles lighter than the total mass of those particles with total quantum number is X: i.e., $mX<\sum Pm_i$. For instance, Proton and electron are stable particles, according to baryon number conservation and electric charge conservation. If the baryon number B is absolutely correct, the proton will be exactly stable. However, if B is broken, the proton might also decay to a particle which is much lighter. When using the discrete symmetry,the discussion may be similar: X is absolutely stable without the combination of lighter particles (which have a mass below mx) with the same discrete quantum number, as the discrete symmetry is correct. If the discrete symmetry theory is broken, then X is not absolutely stable. The nonabelian discrete symmetries mainly considered for the lepton mass matrix texture,but because some non-singlet representations also contained in ‘nonabelian’, so it may not suitable for WIMP while the WIMPs only considered about the absolutely stable particle.

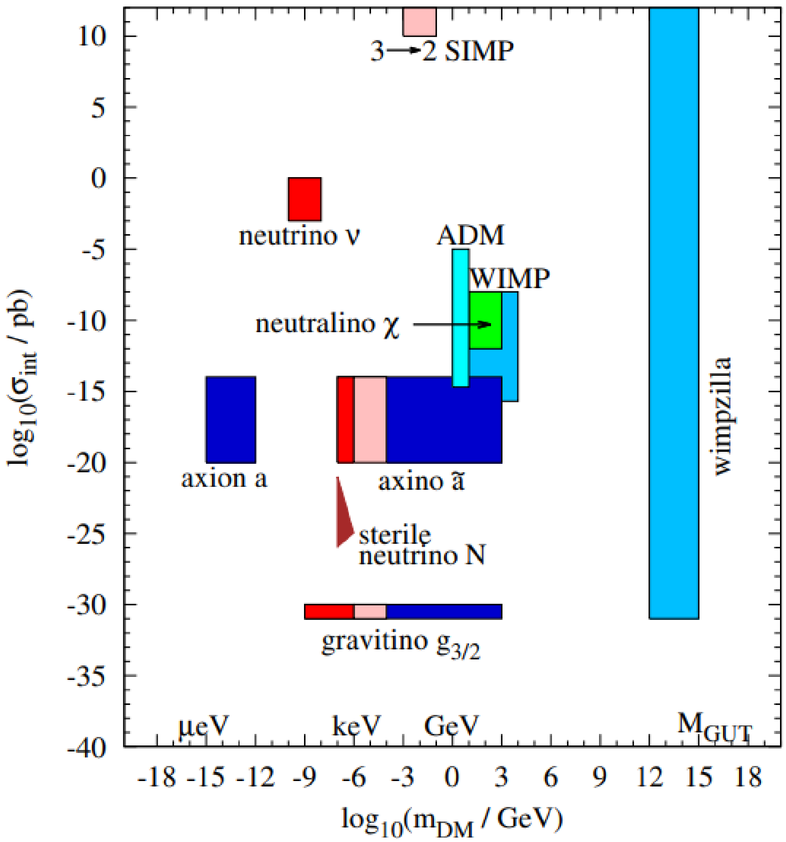

Fig. 1 Cross section for different candidate [7].

Fig. 1 shows the overview of mass vs the detected cross-section plane, representing interaction from several dark matter candidates to the normal substances The y-axis shows the detection cross section's magnitude of each candidate. The WIMPs interact with massive particle candidates weakly as thermal relics, the mass of them stays in a range between a few GeV and several ~ 100 TeV from unitarity constraints [7]. For getting the data of thermal relic abundance of a species to associates the dark matter's density, the dark matter particles have to self-annihilate with a cross section at a range of σv ∼ 10−26 cm3=s (the v is relative velocity between the annihilating particles). For example, during the annihilation of a stable neutrino with a mass about some GeV, experiencing the exchange of Z boson, the relic abundance will freeze-out which basically same as the measured density of dark matter in magnitude. Furthermore, the theory can also apply to a wide range of other electroweak-scale candidates, as the stable particles with MeV–TeV masses interacting the exchange of mediated electroweak-scale particles. This theory and observation lifted WIMPs to a dominant candidate among the all. For supporting the WIMPs candidate, first suggested by Drukier, Freese, and Spergel, they searched for the variation in the rate of dark matter every year, affected the combination of the Earth's orbiting and the Sun's motion through the dark matter halo from a predicted to result. This technique also be used to recognize the signal emits by dark matters. The most famous group using this detection method was the DAMA/NaI Collaboration and later DAMA/LIBRA. The original DAMA/NaI experiment composed by some sodium iodide crystals, located in a underground Laboratory in Italy. Their reports have becoming more and more significant and persuadable during these two decades [1].

4. Axions

Another important candidate, Axions-or Axion like particles (ALPs) which are broken at some scale fa, are the Goldstone bosons of global symmetries. All interactions are limited by this scale fa and they are coupled appered in these interactions. In one case that they would be totally massless is when they existing as pure Goldstone bosons, therefore they would not be the dark matter anymore, yet the pure Goldstone nature can be distroyed and leading to the mass generation. This can occur under an irregular global symmetry. For example, non-perturbative dynamics can generate a mass ma $\sim\Lambda_{QCD}$ at the QCD scale as ma$\approx 6\times10^{-10}$ eV (10^{16} GeV/fa). The Goldstone boson is the axion. There are many ways to produce axions. Among all measures, quantum chromodynamics (QCD) was successful in explains the strong force, the quarks and gluons precisely. The QCD Lagrangian contains the following term:

$$L_{QCD}\sim\frac{\Theta g^2}{32\pi^2}G^{a\mu v}\tilde{G}_{a\mu v} \tag{1}$$

The $G^{a\mu v}$ is the gluon field strength tensor, and Θ is a quantity which linked to the phase of the QCD vacuum. For example, by thermal, but since the thermal relic abundance is too small to account the dark matter density. While, another production mechanism suggests, Although the quantity Θ is tuned to 0 by the mechanism suggested by Peccei and Quinn, it was more likely a larger value, probably due to a random process. As Universe's temperature dropped below T $\sim\lambda_{QCD}$ while Θ was also down to 0, the energy stayed in the Peccei-Quinn field produced a nonthermal axion population. For this situation, the misalignment production is predicted to produce a density of axions that is similar to the dark matter density for masses on the order of ma$\sim10^{-5}$ eV [8]. There are several methods to test hypothesis of axions: the cavity technique, wire and dielectric plate detectors, magnetic resonance methods, the LC circuit approach, and atomic transitions. Solar axions can converted to x-rays and cause axioelectric effect through the magnetic field and crystals in the laboratory. While converting photons to axions from one side and backconversion on the other side, Axion will affects in many particles such as atoms, molecules, nuclei and so on. This is a new way of axion dark matter detection: using strong light beam to stimulate cold dark matter axions to decay [9].

5. Limitations and Prospects

Dark matter is a substance with mass; therefore, it is influenced by universal gravitation. However, it does not interact through electromagnetic mechanisms like ordinary substances, so it is invisible. In other words, dark matter does not reflect or absorb light. Meanwhile, it doesn't have charge, dark matter is also intangible. At this level, it makes its detection very difficult because ordinary observation methods are not applicable [10, 11]. Although there are many speculations from existing models, most of them are based on theoretical level and are not observed through many experimental phenomena like other physical theories. At present, there are more than ten experimental teams around the world placing dark matter detectors underground. For example, the most sensitive existing human detector is the Large Underground Xenon LUX detector located at the Sanford Underground Research Facility in South Dakota, USA. However, physicists are deeply concerned about this. The Large Hadron Collider (LHC) at the European Center for Nuclear Research (CERN) in Geneva, Switzerland, has not found any evidence of supersymmetry during its 6-year operation. Due to limited human understanding of dark matter, its properties are difficult to detect, and considering the high cost of experimental equipment, continuing the experimental search of WIMP will face enormous difficulties. Even physicists with an exploratory nature cannot pursue it endlessly without any gains [10].

6. Conclusion

In conclusion, there are many candidate types of dark matter, each with a systematic theory and detection method. Based on strong theoretical support and verification of formula models, breaking through the mysterious unknowns of dark matter will undoubtedly be a big step towards modern cosmology and even modern science. Each type of dark matter, however, is extremely difficult to observe due to its almost non-reactive nature, and there are also many difficulties in implementing the detection process into specific actions. Considering the cost of professional detection equipment, the prospect of detecting dark matter has become even longer. With the increasing development of technology and the continuous improvement of existing theories, there is still great hope for further breakthroughs in the future. Once the essence of dark matter can be understood, which accounts for a large part of the mysterious matter in the universe, it will be a great success in promoting human understanding of the evolution and essence of the entire universe.

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