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Dark matter and its candidate particles

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Abstract. Theoretically predicted unseen matter called "dark matter" may be present in the universe. Even though it might be the primary component of cosmic matter, it is not a part of any known material that makes up a visible celestial body. Despite the fact that dark matter has not yet been directly observed, there is a wealth of evidence to support its existence, for example, through the autobiographical curve of the Milky Way, the mass distribution of galaxy clusters, the background radiation of the universe microwaves, and the formation of large-scale structures of the universe. Although great progress has been made in cosmic observation, we are still unable to determine what the constituent particles of dark matter are.There are the following speculations about what particles dark matter is composed of: baryon dark matter, such as MACHOs, rogue planets, and other possibilities; Non-baryonic dark matter: Weakly Interacting Massive Particles (WIMPs); Axion; Neutrino, etc.

Keywords: Dark matter, Axion, Weak interaction mass particles (WIMP), Self-interacting dark matter, Primitive black hole, Sterile neutrinos.

1. Introduction

Scientists discovered in the 20th century that the universe does not primarily consist of ordinary baryonic stuff, or matter consisting of neutrons and protons. Instead, the universe was replete with unusual, novel kinds of matter. They refer to it as "dark matter." Its mass is around five times that of the universe's regular matter. Although its existence has not been proved in the laboratory, various research evidences are showing the necessity of its existence. Dark matter is currently the biggest unsolved mystery in cosmology. About 80% of the gravitational matter in the universe is non-luminous, and its nature and distribution are largely unknown. Many theories suggest that dark matter consists of new, yet-to-be-discovered massive particles. How much dark matter does the universe contain? Where is the dark matter These issues are all fundamental issues with the cosmos. First, the performance of dark matter's existence is briefly discussed in order to introduce it. Investigate prospective candidate materials while comprehending the compelling data gathered by physicists and astronomers in the past.However, current physicists have not directly detected dark matter experimentally in the laboratory. However, there is a ton of proof that it is there in the universe in large quantities. Only a few narrowly defined features of dark matter's characteristics are now understood by scientists. Dark matter has mass and first engages

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in gravitational interaction. Second, there is evidence that dark matter is at various stages of cosmic production and that it is quite stable. According to the cosmic age scale, it is steady. Third, it has been demonstrated through computer simulations of the construction of the universe's large-scale structures that dark matter moves slower than light. This is necessary for the cosmos to form the large-scale structures that are observable when gravity is at work. A conclusion can be made when these well-known fundamental features are combined. The elementary particles we are familiar with do not include dark matter particles. The successful mainstream model of particle physics as it stands now is put to the test by this.

2. Evidence and early research of dark matter

2.1. Photometry

Astronomers have long relied on the light emitted by celestial bodies to estimate their volume, mass, and distance. This is not surprising, since in the past, when there were no developed means of observation, the light emitted by celestial bodies was the only information that astronomers could receive. Through rigorous scientific methods, scientists can estimate the information of celestial objects with relatively accurate accuracy.

2.2. The study of mass in galaxies

About 90 years ago, astronomer Oort observed the movement of stars in the Milky Way and discovered that the actual mass of the Milky Way may be much larger than previously predicted. By calculating the velocities of the stars in the Milky Way, he was astonished to find that the stars were very fast, fast enough to break free from the gravitational pull of the luminous matter in the Milky Way. He noted that more mass must be present in the Milky Way galaxy to keep these stars in their original orbits. Other possible explanations are that about 85% of the Milky Way's light is unobservable or that the measurement of the speed of the stars is completely wrong.[1] Around the same time, astronomer F. Zwicky discovered the same mass loss, but on a much larger scale. By observing the velocities of galaxies within the cluster, he was able to calculate the mass of galaxies. Virial theorem tells us the relationship between kinetic energy and potential energy of galaxies:

$$K = -\frac{U}{2} \tag{1}$$

where K is the average kinetic energy and T is the average potential energy. Zwicky observed about 1,000 nebulae and calculated their mass, and he was astonished to find that if the mass was estimated using the light emitted by the nebula, the result was only one-fiftieth of the former. This means that luminescent matter accounts for only a negligible mass, the vast majority of which we cannot observe [2].

2.3. Rubin's discovery

After this, another astronomer, Rubin, while observing the rotation speed of galaxies, found that the rotation speed of the outer part of the galaxy was much faster than expected. Therefore, he speculated that there is a large amount of mass in the galaxy that pulls on the outer part of the galaxy, controlling the outer objects in a stable orbit. The orbits of stars in galaxies are generally considered to be similar to those of planets within the solar system. In the solar system, the planets follow Kepler's three laws and classical mechanics. We can know that the velocity is inversely proportional to the square of the radius of the orbit.

$$v(r) = \sqrt{G\frac{m}{r}} \tag{2}$$

Rubin's results differ greatly from the predictions based on the distribution of luminescent matter, showing that the speed of the star increases with its radius until it reaches a limit. With a simplified

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model, we can intuitively understand this result. We can think of a galaxy as a sphere with uniform mass, and by direct analogy with Gauss's law in the electric field, we can get the relationship between the gravitational field and the mass.

$$\oint \vec{g} \cdot d\vec{A} = 4\pi G M_{encl} \tag{3}$$

The flux of the gravitational field through a closed surface is directly proportional to the mass within this closed surface. That is, as the mass inside the enclosed surface increases, so does the gravitational field. According to classical mechanics, the velocity at which matter surrounds is directly proportional to the gravitational field and the mass within the enclosed surface. If the mass inside remains the same as the closed surface increases, then the orbiting velocity of the matter decreases. A large amount of luminescent mass in the Milky Way is concentrated in the center, and as the radius increases, there is little or no increase in luminescent matter. Therefore, the matter on the outer reaches of the Milky Way should move at a slower speed to be expected. But not really. This inevitable result tells us that the mass in the Milky Way is not concentrated in large quantities in the center of the Milky Way, and the luminescent matter cannot represent the distribution of mass in the Milky Way [3-4].

3. The study of dark matter in modern physics

3.1. Galactic lens

About 50 years ago, cosmologists used Einstein's theory of relativity to develop new ways to detect dark matter: gravitational lensing. The theory of relativity tells us that objects with mass bend space-time, and this theory explains the motion of planets around stars, which in the same way that bends the path of light, similar to a lens. By studying the distortions of distant light sources and solving the equations of relativity, we can find out how much mass is in space-time.

$$\theta = \sqrt{\frac{4GM}{c^2}\frac{d_{ls}}{d_l d_s}} \tag{4}$$

Where G is Newton's gravitational constant, M is the mass of a celestial body that bends light, c is the speed of light,d_{ls},d_l , d_s and are respectively the distance between the lens and the light source, the distance to the lens and the distance to the light source (It is important to note that due to the expansion and curvature of the universe, the distance here is different from the concept of distance as we usually understand it, and is the angular diameter distance) [5].

3.2. Galactic rotation curves: Observations versus predictions

The galaxy rotation curve describes the relationship between the orbital speed of visible objects in spiral galaxies and their distance from the center of the galaxy. According to the observation of the mass distribution of visible objects in the spiral galaxy and the calculation of the law of universal gravitation, the rotation speed of the outer celestial body around the center of the galaxy should be slower than that of the central object. However, measurements of a large number of spiral galaxy rotation curves show that the speed of peripheral objects is almost the same as that of internal objects, much higher than expected. This implies that there is huge mass of invisible matter in these galaxies. Combined with the potential force theorem, the distribution of matter in galaxies can be calculated by the dispersion velocity distribution of visible objects in galaxies. This method is also suitable for measuring the material distribution of elliptical galaxies and globular clusters. The results show that, except for some, the distribution of matter in most galaxies and clusters is inconsistent with the observed distribution of visible matter, and the mass of visible matter accounts for only a small part of the total mass of galaxies and clusters [6].

3.3. Cluster observation of galaxies

The mass distribution of the galaxy cluster can be obtained by three different means: (1) Observing the motion of galaxies in the galaxy cluster is calculated by gravity theory. (2) Observe the X-rays produced by the galaxy cluster. There is a common hot gas in the galaxy cluster that can emit X-rays. When the gas reaches the hydrodynamic equilibrium in the gravitational field of the galaxy cluster, the mass distribution of the galaxy cluster can be inferred from its temperature. (3) Gravitational lensing effect. According to general relativity, the light from behind the galaxy cluster bends when it passes through the massive cluster, which is similar to the lens in optics. The distribution of matter in the galaxy cluster can be calculated according to the degree of bending of the background light. These three methods do not affect each other and prove each other, making galaxy cluster observation an important means of studying dark matter. These observations consistently show that the total mass of matter in the galaxy cluster far exceeds the total mass of the visible matter.

3.4. Cosmic microwave background radiation

On the cosmic scale, the total amount of dark matter in the universe can be determined by fine observation of the anisotropy of cosmic microwave background radiation in the universe. Observations show that 26.8% of the total energy of the universe is contributed by dark matter, only 4.9% of the conventional matter that constitutes celestial bodies and interstellar gases, and the remaining 68.3% is dark energy that accelerates the expansion of the universe.

3.5. The formation of large-scale structure of the universe

The N-body gravitational simulation of the evolution of the universe by large computers shows that low-speed dark matter particles without collision gradually gather into clusters under the action of gravity, which can form the large-scale structure we see today [7-9]. The dark matter distribution of these structures has a universal mass distribution. Low-speed moving dark matter is conducive to the formation of large-scale structures. And high-speed moving particles tend to smooth the structure. Therefore, neutrinos are not supported as the main dark matter particle candidates.

4. Dark matter candidate particles

4.1. Weak interaction mass particles (WIMP)

Weak interaction mass particles (WIMP) is one of the most discussed dark matter candidates. It is a stable particle that is generated through the thermal decoupling method, and whose mass and interaction strength are near to the electroweak scale. WIMP shouldn’t directly participate in electromagnetic and strong interactions because it should be electrically and color-neutral in general. Although the neutrino is not involved in strong or electromagnetic interactions, it is nevertheless categorized as “hot dark matter” since it moves nearly as fast as light in the universe. However, this does not make it the primary constituent of dark matter. In the particle physics standard model known to human beings, there are no particles that meet these properties at the same time. This means that WIMP is a new particle that exists outside the standard model. According to theoretical prediction, the lightest supersymmetric companion particle in the supersymmetric model belongs to WIMP, such as the superneutralino; the smallest Kaluza-Klein excited state particles in the extra-dimensional theory; and the T-odd in the Little Higgs model particles [10].

4.2. Axion

The axion is a hypothetical elementary particle, which is very light, with a small mass and electrical neutrality, and it is predicted to be very weak in interaction with other particles. The Axion experiment aims to detect these elusive particles through predictive coupling with electromagnetic fields. It is related to the charge conjugate-non-uniform inversion binding symmetry fracture in the strong interaction. The axis interacts through a very small force, so it cannot be in thermal equilibrium with the background radiation, so the residual abundance will not be obtained by thermal decoupling, but it can become cold

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dark matter through the fracture of the vacuum state. Axial ion theorists also think deeply about axial ion coupling g and ordinary substances [11] For example, astrophysical constraints from stellar evolution usually provide good guidance for the size of these couplings. Generally speaking, there is no theoretical bias. If axial ions are found, it will open the door for experimental testing of these far-reaching theories [12].

4.3. Self-interacting dark matter

This is a modification of the WIMP model, which proposes that dark matter particles can interact with each other through unknown "dark forces". This will explain some differences between the prediction of the standard cold dark matter model and the distribution of dark matter observed in the galaxy. In fact, the current cosmic logic data from Plancksat 3 and its predecessor WMAP, 4 to allow DM abundance means strict restrictions on the search for new targets of the collider, such as those implied by supersymmetry (SUSY). From the perspective of astrophysics, compared with the expectations of standard FLRW cosmology, DM is simply regarded as the "missing" mass in the universe. It has been studied mainly in a model-independent way through N-body simulation of non-specific Newtonian massive objects. This simulation aims to reproduce the large-scale structure of the (observable) universe and is closely related to the mass range and properties of (although not explicitly dependent) particles and the physics of decoupled from the original plasma.[13]

4.4. Primitive black hole

The primorative black hole is a black hole in the hypothesis proposed by scientists. They believe that during the Big Bang, its extraordinary forces squeezed some matter very tightly, forming a "native black hole". Although it is not a particle, the primitive black hole formed in the early universe can explain some or all of the dark matter. These will be much smaller black holes than the black holes formed by the collapse of stars. Since LIGO/Virgo detects a combined double black hole with a mass range of 10 to 50M, The idea that dark matter could contain PBH in the medium mass range has recently gained a lot of interest.[14] Because black holes are larger than expected, some individuals believe they constitute a new population, however the consensus view holds that they are still a relic of ordinary stars.[15] Another option, more pertinent to current concerns, is that LIGO/Virgo black holes are primitive in nature, such as reference.[16]Despite the fact that this potential has been enhanced, the estimated merger rate is dependent on the period of binary file generation and unknown astronomical parameters. This limit is highly dependent on the projected merger rate.[17] In reality, the results of LIGO/Virgo have been utilized to constrain the PBH dark matter fraction.[18]

5. Debate on neutrinos as dark matter

The neutrino is part of the standard model of particle physics. They are neutral, very small in mass, and have very weak interactions with other substances, mainly through weak nuclear forces and gravity. Because they are so elusive and detectible, they were initially considered potential candidates for dark matter. However, there are some major problems that make standard neutrinos less suitable as the main form of dark matter.

5.1. The problem of standard neutrinos as dark matter

As an important gateway particle, particle physicists and astrophysicists experiment with a variety of different more likely particle dark matter hypotheses in response to the standard model neutrino. Many people were unaware that there were any problems that needed to be solved when scientists started to think about the role of neutrinos in cosmology, but despite this, their contributions helped lay the groundwork for the field of particle dark matter later on.

5.2. Sterile neutrinos

These hypothetical neutrinos are called "sterile" neutrinos, because they can only interact with other particles through gravity, and the three known neutrinos can also interact through weak forces. But they

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may affect other neutrinos, because these particles have a strange characteristic: they can "oscillation" or change the taste. For example, a particle starting with an electron neutrino can be transformed into a τ or μ neutrino, and vice versa. Usually, this transformation occurs when neutrinos move at a certain distance, but in the liquid scintillation neutrino detector (LSND) of Los Alamos National Laboratory and its subsequent MiniBooster neutrino experiment (MiniBooNE) of Fermilab, this The transformation seems to happen faster. Scientists believe that μ neutrinos may oscillate into sterile neutrinos and then oscillate into electron neutrinos, which may occur faster than simple μ neutrinos to electron neutrinos.

6. Conclusion

This paper mainly studies the exploration of dark matter and candidate particles. Through the observation of the galactic rotation curve, galaxy cluster, cosmic microwave background radiation, etc., it is found that the observation results do not match the theoretical results, so the concept of dark matter is proposed. Regarding dark matter, it is usually considered to be composed of new particles, so in the active search for answers to dark matter detection and collision aircraft, the existence of dark matter has been widely recognized. However, there is little understanding of the properties of dark matter, and there are also some limitations. As for candidate particles, there have also been many discussions. Among them, the weak interaction particle (WIMP) is one of the most widely discussed dark matter candidate particles. At the same time, warm dark matter is theoretically between cold dark matter and hot dark matter, which makes astrophysicists search for energy in various parts of the universe. Theoretical matter. For a long time, the dark matter particles in the dark matter that are most favored are only the elementary particles in the hypothesis. They have the characteristics of long life, low temperature, and no collision similar to magnetic monopole particles. For example, if the axions axis exists, it can not only explain the source of dark matter, but also explain why the universe is mainly composed of Material composition. At the same time, Self-interacting dark matter, Primitive black hole, neutrino, etc. are also widely discussed. There are still many unsolved puzzles in the universe, and the dark matter question is still not well answered. The future of the universe also depends on these dark matters. It seems that more things need to be explored to realise the truth of the cosmic problem.

Authors' contributions

Yuhan Zhang and Zidong Zeng contributed equally to this work and should be considered co-first authors.

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