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Exploring the Origin of Dark Matter in the Early Universe

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Abstract: Dark matter becomes a crucial component in shaping the structure of our cosmos. Evidence of nonluminous matter became known during the 1930s, as investigations into the Doppler shift in star spectra within the galactic disk revealed inadequacies in explaining the gravitational influence suggested by observed velocities. The confirmation of this discovery was subsequently achieved by assessing the velocity dispersion within abundant galaxy clusters. Galaxy formation models assume the presence of dark matter, considering it an essential foundational element influencing their structural evolution. However, the Big Bang theory struggles to unravel the elusive origin of dark matter, lacking a conclusive model that provides clear insights. In this study, we postulate an eleven-dimensional spacetime, as proposed by string theories, and explore the notion that symmetry breaking catalyzed the formation of two distinct spacetime manifolds. One is the familiar four-dimensional spacetime we observe and experience, while the other represents an additional dimensional manifold dominated by dark matter. To reinforce this point, we examine three existing studies, encompassing both observational and theoretical aspects that strongly support the suggested involvement of dark matter in the universe. Additionally, the proposed model places restrictions on the feasibility of using traditional detection methods to identify dark matter particles, thereby accounting for the absence of their detection thus far.

Keywords: Dark Matter, Early Universe, Parallel Universe.

INTRODUCTION

Dark matter has been at the forefront of cosmological investigations, as well as experimental and theoretical physics, for the last two decades. Compelling indications propose that dark matter constitutes a minimum of 85% of the total mass in the universe. Evidence pointing to the presence of this imperceptible matter surfaced in the 1930s. Oort initially hinted at the potential existence of dark matter by examining the Doppler shift in star spectra within the galactic disk. His conclusion was that the mass of observable stars fell short in explaining the gravitating matter indicated by the measured velocities [1]. Zwicky later reinforced this discovery by studying the Coma Cluster of galaxies, determining that the velocity dispersion in abundant galaxy clusters was insufficient to account for the immense mass needed to maintain their cohesion, a phenomenon unexplained solely by the visible galaxies within them [2].

The most persuasive indication substantiating the existence of dark matter comes from examining the mass of individual galaxies. Assessing galaxy mass involves deriving it from the velocity dispersion of rotation curves of stars and gas constituting the galaxy, along with considering the position and velocities of globular clusters and satellite galaxies.

Studies suggest that the predominant portion of this imperceptible matter is dispersed within the galactic halo [3-7].

Primary candidates for dark matter encompass weakly interacting particles (WIMPs) and massive compact halo objects (MACHOs) [8, 9]. The consideration of WIMPs as potential contenders stems from the fact that primordial nucleosynthesis explains only 0.2 of the cosmological density parameter ($\Omega o = 0.2$), whereas inflationary theory and observational evidence suggest $\Omega o = 1$ [10-12]. Primordial black holes also emerge as plausible candidates for dark matter. An alternative explanation for dark matter is proposed through Modified Newtonian Dynamics (MOND) [13, 14]. However, this model falls short in explaining certain observational data, such as the collision of the Bullet Cluster of galaxies.

In recent times, researchers have developed innovative approaches to directly observe dark matter by mapping its distribution in the universe via gravitational interactions with ordinary matter [15]. This method has demonstrated its effectiveness as a viable approach for investigating dark matter.

This work is driven by the following objectives: *i*) to offer a succinct overview of existing models of dark matter and the observational evidence substantiating its presence; *ii*) to investigate a symmetry-breaking-based model that explains the origin of dark matter in the early universe; *iii*) to scrutinize the implications of this model in the context of recent observational data and theoretical studies.

EVALUATING DARK MATTER THROUGH OBSERVATIONS

As introduced earlier, Fritz Zwicky provided one of the earliest suggestions of the presence of DM in the Coma Cluster of galaxies. In this context, he employed the virial theorem to characterize the gravitational interactions among galaxies [1]. Zwicky determined that the average mass-to-light ratio, in solar units, of the galaxies in the Coma Cluster is approximately 400 [16, 17]. A notable advancement took place forty years later when Rubin et al. [18] utilized a spectroscopic method to examine the rotational curves of galaxies. Interestingly, all recorded rotation curves displayed nearly flat, and in some cases, slightly increasing regions of velocities extending to the outermost visible matter. Considering luminous matter alone, the stars' velocity should decrease with increasing distance from the center, as anticipated for Keplerian systems.

Gravitational lensing offered an extra hint regarding the presence of dark matter. Employing this method, the outcomes obtained for the mass-to-light ratio were consistent with those derived from dynamical investigations [19].

Another strand of evidence affirming the presence of dark matter arises from Big Bang nucleosynthesis, investigations into structure formation, and scrutiny of the anisotropies in the Cosmic Microwave Background, as gauged by COBE, WMAP, and Planck missions. WMAP succeeded in delivering a precise measurement of the power spectrum of the Cosmic Background Radiation. The initial peak in the power spectrum corresponds to baryonic matter, while the discerned third peak is directly linked to the density of dark matter [20, 21].

The aforementioned observations present compelling evidence supporting the existence of dark matter. Additionally, WMAP succeeded in formulating the ΛCDM model, which currently serves as the standard model of cosmology. In this model, the universe is flat and predominantly influenced by dark energy and dark matter [20]. However, direct and extensive age measurement of supernova (SN) host galaxies reveal a significant (5.5σ) correlation between standardise SN magnitude and progenitor age, which is expected to introduce systematic bias with redshift in SN cosmology [21].These authors came to the conclusion that the universe is not accelerating as previously postulated, and the notion of dark energy does not fit recent analysis of SN data.

DARK MATTER CANDIDATES

The leading candidates often discussed in connection with dark matter are weakly interacting massive particles (WIMPs). These entities attract interest as potential contenders for dark matter due to considerations spanning particle physics, astrophysics, and cosmology.

WIMPs are theorized to be stable particles [23]. The cosmological appeal of WIMPs lies in their ability to adjust their masses, potentially yielding a Ω_{DM} that could extend to unity. Numerous hypothetical particles have been suggested as potential candidates for WIMPs. Axions are among these particles, distinguished by their lack of electric charge, very small mass, and extremely limited interaction cross-section [24]. Nevertheless, the existence of axions is questioned by some authors.

Supersymmetric particles present a diverse range of potential candidates for dark matter (DM). The gravitino, serving as the supersymmetric partner of the graviton, stands out as a stable particle with a spin of 3/2, distinguishing it from a typical Weakly Interacting Massive Particle (WIMP). The stability criteria for the gravitino lead to two plausible scenarios. The first scenario posits that it is a stable particle adhering to R-parity conservation. However, in such a case, the calculated density of stable gravitinos exceeds the observed dark matter density [25]. The second possibility entails the gravitino not being a stable particle and not contributing to the dark matter density. In this scenario, it decays with a gravitational interaction lifetime on the order of M_{Pl}^2/m^3, where M_{pl} = hc/G = 1.2×10^{19}GeV is the Planck mass, and m is the mass of the gravitino, assumed to be on the order of TeV, implying a lifetime of 10^5 seconds. This timeframe extends well beyond the nucleosynthesis era, and the decay product of the gravitino would obliterate almost all nuclei formed during that period, presenting a stark contrast to observations [26].

The elusive sneutrino emerges as a candidate in the enigmatic realm of dark matter particles. Yet, within the framework of the Minimal Supersymmetric Standard Model (MSSM), the sneutrino finds itself excluded from the role of a dark matter particle due to its notable characteristics, notably its substantial scattering and annihilation cross section. Experimental endeavors in direct detection, spanning masses proximate to $m_{weak} \approx 10\ \text{GeV} - 1\ \text{TeV}$, have yielded outcomes devoid of conclusive evidence [27, 28].

Among the intriguing array of supersymmetric dark matter particles, the neutralino stands out prominently [29, 30]. Within the confines of the Minimal Supersymmetric Standard Model (MSSM), four fermionic neutralinos emerge, each electrically neutral and born from the intricate amalgamation of three superpartners sharing a common quantum number—the photino, the zino, and the higgsino. In models where R-parity is conserved, the neutralino assumes the role of a stable particle. The designation of the lightest neutralino

(LSP) as a leading contender for dark matter in the cosmos is well-founded. Detection of its presence hinges on the identification of gamma rays and neutrinos stemming from annihilation events. Up to this point, experimental endeavors have yielded no conclusive evidence of the elusive neutralino.

A distinctive variety of neutrino has emerged as a potential dark matter candidate, operating within stringent coupling conditions within the framework of the Standard Model (SM). In contrast to quantum field theories that involve fermion masses through terms coupling left and right-handed fields, the Standard Model does not predict a right-handed neutrino field. Consequently, all observed neutrinos display left-handed helicities, with spins oriented antiparallel to momenta. Similarly, all antineutrinos exhibit left-handed helicities, resulting in neutrinos and antineutrinos being massless. Nevertheless, the introduction of a right-handed neutrino through a mechanism generating mass for quarks and charged leptons allows them to acquire mass. The method entails the introduction of a Majorana mass term into the Lagrangian, thereby expanding the Standard Model to encompass two sterile neutrinos. Following electroweak symmetry breaking, the resulting mass eigenstates predominantly consist of a fusion of a left-handed neutrino, denoted as the active neutrino, and a right-handed neutrino, termed the sterile neutrino. The sterile neutrino, devoid of any fundamental interactions in the Standard Model apart from gravity, generally does not emerge as a viable dark matter candidate—except within a specific range of Yukawa couplings in the SM. Oscillations at a temperature of approximately $T \approx 100$ "MeV" can give rise to the creation of sterile neutrinos [31]. Additionally, the sterile neutrino, being a neutral particle, refrains from engaging in electromagnetic, weak, or strong interactions with established particles, posing a formidable challenge for detection. Despite this elusive nature, their gravitational interaction persists due to their mass, and their substantial weight serves to provide a plausible explanation for dark matter.

SuperWIMPs, denoting super weakly interacting particles, exhibit the essential relic density necessary for consideration. In a proposed scenario within the early universe, it is postulated that WIMPs undergo freeze-out but subsequently decay, giving rise to superWIMPs that contribute to the observed dark matter in the present cosmos. The highly subdued interaction of superWIMPs in comparison to WIMPs ensures minimal interference with the early universe's WIMP freeze-out. Consequently, WIMPs decouple with a relic density $\Omega_{WIMP} = \Omega_{DM}$. The relic density of superWIMPs is inherited from WIMPs, effectively contributing to the required dark matter density. Assuming gravitational interactions exclusively for superWIMPs, the timescale for WIMPs to decay into superWIMPs is estimated to be approximately $1/Gm_{weak}^3 \approx 10^3$ to 10^7 seconds [32]. SuperWIMPs could potentially emerge post-reheating, a phase occurring during the epoch when the inflation potential transitions to Standard Model (SM) particles. Elevating temperatures to sufficiently elevated levels lead to the substantial generation of SuperWIMPs [33, 34]. The relic density of SuperWIMPs demonstrates a linear correlation with the reheating temperature (T_{Re}), with a constant of proportionality determined by the gravitino production cross-section [32]. Adhering to the constraint on dark matter density (Ω_{DM}) and assuming a gravitino mass ($m_{gravitino}$) not exceeding 100 GeV, the implication is that the reheating temperature (T_{Re}) should not surpass 10^{10} GeV [35]. Hence, the gravitino emerges as a representative SuperWIMP particle [36, 37]. An alternate example of a SuperWIMP manifests as the axino [38, 39], serving as the supersymmetric partner to the axion. In cases where both axions and axinos contribute to dark matter, an intriguing multicomponent dark matter scenario arises [40]. SuperWIMP possibilities also extend to Kaluza-Klein (KK) graviton and axion states within the framework of universal Extra Dimensions (UED) models [36]. The KK graviton attains the status of the lightest KK state when R^{-1} equals or surpasses 800 GeV, with R representing the compactification radius [41]. The lightest stabilized KK states, subject to KK parity conservation, exhibit remarkably analogous properties to their supersymmetric counterparts [32]. To sum up, a diverse array of SuperWIMP candidates exists, inheriting their relic density from WIMPs and thereby emerging with the requisite relic density.

KALUZA-KLEIN DARK MATTER

The notion of extra spatial dimensions traces its roots back to the investigations conducted by Kaluza-Klein (KK) in the 1920s. Within the paradigms of universal extra dimensions (UED), the most lightweight Kaluza-Klein excitation pertaining to neutral electroweak gauge bosons assumes the role of a stable, weakly interacting massive particle [42].

An alternative perspective to weak scale physics emerges through the incorporation of extra spatial dimensions. The proposition of the lighter Kaluza-Klein state (LKK) as a promising dark matter candidate hinge on the assumption that the Standard Model (SM) particles propagate within these extra dimensions while preserving KK parity. In the context of the Universal Extra Dimensions (UED) model, all particles are confined to traverse a flat compact extra dimension with a size of 10^{-18} m or smaller. In the minimal UED scenario, a single extra dimension of size R is compactified onto a circle, with every SM particle possessing a mass at each KK level denoted as nR^{-1}. The requisite mass for the LKK (mg) is constrained within the range of 600 GeV ≤ mg ≤ 1.4 TeV.

Detecting KK dark matter particles can be accomplished through elastic scattering, facilitated by their coupling with nuclei via the exchange of Higgs bosons and KK quarks. The realm of indirect detection for KK dark matter presents a set of appealing attributes. A noteworthy aspect is that nearly 60% of KK dark matter undergoes annihilation, resulting in charged lepton pairs (20% for each generation), 33% generating pairs of quarks, and 3.6% producing pairs of quarks. The remaining 3.4% yields down quarks and Higgs bosons. Another appealing feature is the maximum possible velocity cross-section for a thermal relic. Additionally, the spin-dependent elastic scattering cross-sections of KK dark matter for protons can exhibit considerable magnitude, rendering the capture of such particles in the Sun an efficient process that leads to the generation of substantial neutrino fluxes.

PRIMORDIAL BLACK HOLES

In the early 1970s, Hawking's initial theoretical inquiries unveiled the potential formation of primordial black holes (PBH) stemming from early universe inhomogeneities [43]. Hawking postulated that PBHs could materialize across a broad spectrum of masses, spanning from 2.17×10^{-8} (equivalent to the Planck mass) up to 10^{17} solar masses [44, 45]. The genesis of PBHs transpires when gravitational attraction in specific over-density regions within the early universe prevails over pressure forces and the expansion velocity. This condition is met when the potential energy from self-gravitation surpasses the kinetic energy of expansion.

Hawking's work showcased the role of quantum effects in instigating the creation and emission of radiation near the event horizon of a black hole. The temperature of this radiation, known as the black hole temperature, is expressed as $T = hc^3 / (16\pi k_B G M_{BH})$, where h, k_B, and G represent the Planck, Boltzmann, and gravitational constants, respectively, and M_{BH} denotes the black hole's mass. Noteworthy is the inverse relationship between the Hawking temperature and the black hole mass (MBH), implying that as the black hole emits radiation, its temperature escalates. A dimensional analysis indicates that the black hole's lifetime will be shorter than the age of the universe only if M_{BH} is less than or equal to 10^{15}g [46]. A non-rotating primordial black hole (PBH) with an initial mass of 5×10^{15}g would have evaporated within the current age of the universe, while a maximally rotating one would have done so with an initial mass of 7×10^{15}g. If the Big Bang generates PBHs with sufficient mass, they could manifest as dark matter. The evaporation of black holes has been the focal point of extensive research. According to the Hagedorn model [47], the mass of the PBH will rapidly convert to hadronic matter at a temperature T_{PBH} around 140-160 MeV.

In their exploration, Cline and Sanders [48] delved into the quark-gluon deconfinement phase transition, determining that the liberated free quarks and gluons would undergo hadronization at a consistent distance from the primordial black hole (PBH) horizon, occurring at a temperature of approximately T~100-300 MeV. The scattering of gamma rays within the galactic halo presents a potential gauge for assessing PBH density in the galactic halo and, by extension, dark matter [48, 49]. Employing a clumping factor of 5×10^{15}g, equivalent to a PBH density in the galactic halo reaching 10^{10} pc^{-3}, Cline and Sanders derived an estimated count of 10^{22} PBHs [50]. Assuming a decay rate of 3×10^4 s^{-1}, they computed a photon flux of approximately 10^{33} erg/s released into the halo. Furthermore, Cline [51], adopting a Page-Hawking bound of 2×10^4 pc^{-3}, arrived at a diffuse gamma-ray flux of 0.12 photons m^{-2} s^{-1} sr^{-1}. It is crucial to note that the aforementioned estimation of the galactic flux hinges on the assumption that the evaporation is confined to PBHs with masses corresponding to the present epoch.

D. D. Dixon, et al., claim that there is evidence for a Galactic Gamma-Ray Halo

Astrophysicists have been actively engaged in the pursuit of detecting primordial black holes (PBHs) ever since their proposal in the 1970s. The theoretical framework suggests that the evaporation of PBHs is accompanied by a release of particles and gamma rays [52]. Thus, the identification of PBHs relies on a meticulous analysis of the signals generated during the evaporation process. D. D. Dixon, et al., claim that there is evidence for a Galactic Gamma-Ray Halo [53]. It is anticipated that gravitational wave signals may be received from PBHs of sufficient mass interacting with other compact objects within the Galactic halo. Notably, all gravitational waves detected by LIGO and Virgo thus far have originated from extragalactic sources.

SUPERSYMMETRY AND DARK MATTER

The concept of supersymmetry stands as a noteworthy milestone in unraveling the intricacies of the microworld. Positioned as an essential facet of quantum gravity theories, it embodies the notion that a fundamental symmetry should exist in nature between fermions and bosons. Within the framework of supersymmetry, each fermion and boson state finds its counterpart in the form of a superpartner. Our preceding discussion contemplated the prospect that the Lightest Supersymmetric Particle (LSP) could serve as a viable candidate for dark matter. A plausible explanation for the non-detection of this particle posits that supersymmetry manifests as a broken symmetry, resulting in superpartners with masses surpassing those of known elementary particles. The anticipated mass range for a typical superpartner, aligning with various arguments, falls within the realm of 100 GeV to 1000 GeV, in harmony with electroweak symmetry breaking. The revelation of superpartners hinges primarily on accelerators capable of attaining exceedingly high energies, exemplified by the Large Hadron Collider (LHC). Therefore, should supersymmetry hold true, physicists possess substantial grounds to anticipate the unveiling of the predicted spectrum of supersymmetric particles. However, the absence of detection in future experiments does not categorically negate their existence, as there is no compelling evidence mandating their presence within our spacetime manifold.

SUPERSTRING THEORY AND DARK MATTER

In recent decades, superstring theory has gained prominence as a frontrunner in the quest for a comprehensive framework that unifies the description of fundamental particles and forces, incorporating gravity.

Within this framework, particles manifest as excitations of minuscule strings. The dynamics of interactions are straightforwardly dictated by the geometric splitting and joining of these strings. Initial inquiries suggested the existence of five types of superstring theories, yet subsequent developments revealed that what was initially perceived as a collection of entirely distinct theories is various perspectives on the same underlying concept. These theories are interconnected through dualities, coalescing into a unified framework known as M-theory. Notably, among the superstring theories, the $E_8 \times E_8$ heterotic string theory stands out with its symmetry group. Historically, this theory has been deemed particularly promising in elucidating physics beyond the standard model [54].

The symmetry group $E_8 \times E_8$ intricately delineates the existence of two parallel universes coexisting. Naturally, each of the E_8 symmetries has the potential to undergo spontaneous symmetry breaking, ultimately reducing to the symmetries employed in particle physics for elucidating our own universe. According to this model, merely one component proves sufficient for describing the intricacies of our universe. The symmetry between the two halves of the group underwent disruption during the Planck era, marked by the gravitational force diverging from other forces in nature. Some theorists interpret the $E_8 \times E_8$ group as representative of two interpenetrating universes that solely interact through gravity. A speculative notion posits the existence of another realm as a shadow universe, potentially identified with dark matter. An intriguing avenue for exploration involves investigating the prospect that the E_8 component signifies a "supersymmetric universe," inhabited by supersymmetric particles, tethered to our universe solely through gravitational interactions. Although this concept is currently speculative, it offers a framework that accommodates numerous observed properties of dark matter, substantiated by theoretical investigations and observational data, as elucidated in the subsequent section. This trajectory in research may potentially hinder the conventional methods of discovering supersymmetric particles using particle accelerators, with the prospect of missing energies serving as an indirect means to assess their existence.

The potency inherent in the $E_8 \times E_8$ symmetry group lies in its innate capacity to provide a coherent rationale for the genesis of dark matter, skillfully sidestepping certain extraneous intricacies typically demanded by theories delving into the origin and evolution of the universe. These details encompass facets such as the inflationary scenario and the discord between $\Omega_0 = 1$, as stipulated by inflation, and $\Omega_0 = 0.2$, as deduced from primordial nucleosynthesis.

DARK MATTER AS A PARALLEL UNIVERSE

A pivotal inquiry revolves around the possibility of dark matter constituting a distinct parallel universe. Early glimpses into this prospect were provided by Nodland and Ralston in 1997 [55]. While these researchers did not explicitly propose dark matter as a parallel universe, their investigation delved into the anisotropy of electromagnetic propagation across cosmological scales. Analyzing archival data from 160 remote galaxies, they reported a systematic rotation of the plane of polarization of electromagnetic radiation, akin to the universe exhibiting birefringence. This observed effect proved independent of Faraday rotation and displayed correlation with the angular positions and distances to the sources. The dependence on redshift precluded attributing it to a local effect. The implications of this discovery range from the possibility of light traveling at two distinct speeds based on direction to the notion that the Big Bang emitted two universes, each characterized by an opposite twist. However, critiques of this paper highlight significant concerns, including the contention that the observed effect lacks statistical significance.

A significant contribution to this discourse comes from Schulman [56], who presented a model involving two weakly coupled systems that uphold opposing thermodynamic arrows of time. Schulman's conclusion posits a tangible prospect wherein regions at a distance from us may manifest distinctive orientations for the arrow of time. Propounding the extended absorber theory, he argued that we would perceive these regions, constituting another universe, at an epoch subsequent to our own due to the travel time of light to them. Additionally, Schulman delved into the origins of these regions and contemplated the potential for a future Big Crunch in our universe. He demonstrated that these regions lack electromagnetic communication capabilities and aligned the properties of their content with those attributed to dark matter. Schulman's theoretical framework suggests the existence of a dark matter universe evolving within distinct spacetime dimensions. If these findings are taken at face value, they align with the overarching characteristics of the $E_8 \times E_8$ heterotic string theory.

Exploring the arrangement of dark matter (DM) across the cosmos stands as a valuable avenue for unraveling its intrinsic nature and its interconnectedness with the observable universe. Recently, an international team of astrophysicists unveiled a map delineating the distribution of dark matter in the universe [57]. The construction of this map relied on gravitational lensing data, revealing that the spatial arrangement of galaxies within it serves as direct evidence of the presence of dark matter. Notably, the map illustrated that DM exhibits a tendency to aggregate along filaments spanning hundreds of millions of light years, where these filaments intersect to form nodes characterized by higher-density dark matter. A pivotal revelation from these findings is the propensity of dark matter to aggregate and give rise to extensive structures on a cosmic scale, mirroring the patterns observed in the distribution of visible matter throughout the universe. This perspective lends support to the notion that the $E_8 \times E_8$ heterotic string theory contributes valuable insights into the spacetime framework governing dark matter.

In a more contemporary context, a group of researchers employed artificial intelligence techniques to meticulously map and analyze images of a staggering one hundred million galaxies. This investigation focused on the shapes of these galaxies, examining spots of light composed of roughly ten pixels to ascertain if they exhibited signs of stretching. The ambit of this international project is situated within the purview of the U.S. Department of Energy's Fermi National Accelerator Laboratory, encompassing the collaborative efforts of four hundred scientists hailing from twenty-five institutions.

Given that matter induces curvature in spacetime, the gravitational lensing effect becomes a viable means to chart the distribution of distant galaxies. This mapping endeavor encapsulates a quarter of the southern hemisphere's sky, relying on the distorted configurations of hundreds of millions of remote galaxies, as captured by the Dark Energy Camera in Chile. The resultant map unveils a pattern of dark matter akin to the distribution of visible matter within galaxies, manifesting as a web-like structure interspersed with dense matter clusters and expansive voids. Intriguingly, the findings depart slightly from prevailing theories, revealing a smoother and more diffuse distribution than anticipated. This observation, veering from Einstein's theory of general relativity, introduces a perplexity for researchers. Within the framework presented earlier, we posit that dark matter constitutes a separate parallel universe governed by a distinct spacetime manifold, potentially operating under different physical laws. This consequential inference will undergo further exploration in the subsequent section.

IMPLICATIONS OF DARK MATTER AS A PARALLEL UNIVERSE

The examination in the preceding section suggests a compelling prospect: that dark matter might embody a discrete spacetime manifold, which we recognize as a parallel universe. This inference, drawn from specific observational data, aligns cohesively with the $E_8 \times E_8$ heterotic string theory. The proposition of dark matter as a parallel universe carries profound implications for our comprehension of the perceived world and the philosophical contemplation of humanity's position in the broader scope of existence. Investigating the nature and features of other universes may exhibit an inevitably important speculative component that proves challenging to circumvent. The sole universe within our grasp is the one we inhabit, offering a vantage point from which we can cautiously speculate about the potential attributes of other universes. The fundamental essence of our universe is defined by a meticulously tuned set of constants, facilitating the formation of atoms, the evolution of stars, and the emergence of galaxies. Within the microcosmic realm of our universe, the intricacies are delineated by the principles of quantum mechanics, while the overarching structures adhere to the governance of general relativity.

A pivotal characteristic of our universe, as envisaged by string theory, is its composition encompassing ten dimensions. Within this framework, six dimensions undergo a process of compactification down to the Planck scale, ultimately yielding the three spatial dimensions observable to us. The compactification engenders intricate geometric and topological entities, denoted as Calabi-Yau manifolds. These geometries, emerging from the process, are not arbitrary but signify a specific type of manifold characterized by properties such as Ricci flatness. Each aperture in the Calabi-Yau space is associated with a set of low-energy vibrational patterns. Given that string theory posits elementary particles as manifestations of low-energy string vibrations, the existence of multiple apertures leads to the categorization of string patterns into distinct groups or families.

An intriguing aspect of the Calabi-Yau manifold lies in its ability to generate diverse types of observable particles within our universe through the geometry of compactified dimensions. When the Calabi-Yau manifold exhibits three apertures, the Standard Model of particle physics anticipates the presence of three distinct particle families. Consequently, a correlation emerges between the spacetime geometry of compactified dimensions and the Standard Model. It is essential to note, however, that this connection is not necessarily applicable to alternative universes with disparate spacetime configurations, and extending the Standard Model to such universes lacks a robust scientific basis. Moreover, the fundamental constants in hypothetical alternate universes, if they indeed exist, are likely to differ. This further underscore the notion that the Standard Model is not universally applicable across diverse cosmic realms.

If the aforementioned reasoning holds, then attributing dark matter to WIMPs and other particles derived from the Standard Model becomes an exercise in futility. It is crucial to acknowledge, however, that the postulated dark matter manifold is an integral component of the $E_8 \times E_8$ heterotic string. Consequently, the dark matter universe, in this construct, is not a distinct entity but rather harbors relic features from our own universe. In this scenario, we conjecture that WIMPs and supersymmetric particles, if associated with the dark matter manifold, elude observation in our universe through conventional techniques. This potential explanation may offer insights into the ongoing lack of detection of these particles.

CONCLUSION

Exploring the enigma of dark matter stands as one of the most formidable challenges in cosmology over the past eight decades, captivating the endeavors of both experimentalists and theoreticians. This discussion underscores the intricacies entailed in the current detection approach, primarily reliant on theoretical models that remain incomplete. A myriad of particle candidates has been posited for dark matter, yet despite the escalating sophistication of detection systems, none of these propositions has yielded a conclusive discovery thus far. The Large Hadron Collider (LHC) looms as the pivotal apparatus capable of charting the trajectory for discerning valid theoretical models in particle physics. With the energies of supersymmetric particles falling within the LHC's capabilities, the absence of their detection may not necessarily negate their existence. Instead, it prompts contemplation about their elusive nature and prompts a reconsideration of the strategy for their detection, potentially stimulating scientists to embark on novel avenues in the realm of physics.

MACHO investigations, on a different note, remain inconclusive in addressing the enigma of the elusive mass. Additionally, prematurely embracing Primordial Black Holes (PBH) and Holeums as plausible candidates for dark matter lacks substantiation at this juncture of exploration, given the absence of signals from their purported evaporation, despite exhaustive search efforts. Nonetheless, the non-detection of these signals does not definitively discount their existence; indirect inferences might be drawn through alternative search strategies, such as assessing the intensity of the Galactic gamma-ray background—a significant constituent of their evaporation byproducts.

The $E_8 \times E_8$ Heterotic string theory has been demonstrated to provide a comprehensive framework for comprehending the essence of dark matter. Notably, it aligns with specific experimental data and theoretical models that contemplate the potential evolution of dark matter within an alternative spacetime manifold. This outcome resonates with the principles of Kaluza-Klein theory, which posits the necessity of extra dimensions to accommodate Kaluza-Klein particles. Additionally, attention was drawn to observations from dark matter surveys utilizing the microlensing technique, revealing the presence of an extensive structure of dark matter that mirrors the distribution of ordinary matter constituting the visible Universe.

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