Understanding the Concept of Dark Energy and Dark Matter: A Unified Theory

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Abstract

There is mounting evidence that the vast majority of the universe is made up of two mysterious "dark" components: dark matter, which is responsible for holding galaxies together and preventing them from colliding, and dark energy, which is responsible for the expansion of the universe. So yet, no satisfactory explanations have been found for their make-up or the physics of their interactions. With one dark matter family, an adjustment may be made that allows for similar but different results to those anticipated by the model's theoretical predictions. The new generation of cosmological tests that rely on the idea of structure creation may be beneficial in determining how closely the cosmic parameters are restricted. For one family of dark matter particles, it is possible that the scalar field will be stuck at a mass close to zero. This is a good illustration of the dark sector's potential for intricacy.

Keywords: - Dark matter, dark energy, cosmology, theory.

1. INTRODUCTION

Understanding the fundamentals of dark energy and dark matter is a primary goal of this study. In the last section of this study, I will outline four requirements for a brilliant theory that might adequately describe the ideas behind dark energy. Although several ideas of dark energy have been proposed, none of them have yet been shown to be adequate in describing the nature and consequences of this mysterious force. Finding out what kinds of matter there are in the cosmos and how much of each kind there is is an important goal of modern cosmology. Observational investigations of dark energy have shown that it is almost constant throughout cosmic time and space. The history and composition of dark energy have been the subject of several speculations. These include the inhomogeneous model, modified matter models, gravity models, and the simplest and most natural choice, the cosmological constant as the vacuum energy density, which has not been confirmed but is the most widely accepted. The cosmological constant, has a fixed equation of state parameter, $w = -1$, and a fixed energy density. However, there are two significant flaws with the cosmological constant: one relates to coincidence, and the other relates to extreme fine-tuning. Dark energy, under the context of classical general relativity, acts much as vacuum energy does within the framework of quantum physics. According to quantum physics, it is possible to create energy out of thin air. According to this theory, there are particles and antiparticles in empty space, and they may make and destroy each other without breaking the rule of conservation of energy. The energy in the cosmos comes from the continual, fleeting arrival and disappearance of these particles. The expansion of the universe is sped up by the accumulation of vacuum energy as more and more empty space is created. But if we give weight to quantum effects, it foretells a number that is around 10-12 degrees off from what we've seen so far. A solution to the cosmological constant issue, which is the difficulty of explaining observable dark energy within the framework of conventional quantum mechanics, looks almost impossible. Many other explanations for dark energy have been proposed by scientists, but they are limited by the assumptions of the classical and semi-classical models. As a result, the exact make-up of dark energy is yet unknown.

It is expected that the expansion pace would slow down, since the combined gravity of the universe's components should decelerate it after it has begun to grow. Q0 was intended to have an expected value of 4 as the deceleration parameter. If q0 is negative, it would mean that the cosmos is expanding at an increasing rate, with negative pressure and negative gravity. Type Ia supernova readings have confirmed this. To explain this rapid proliferation, the so-called "dark energy" is being blamed (DE). Several long-running efforts to look for theorized DM particles have so far produced no conclusive evidence. So yet, these investigations have only established the lower and lower bounds of their masses at the lower and lower ends of the spectrum. Absence of evidence does not prove absence, appears to be the slogan. However, if subsequent studies fail to uncover any evidence for the existence of DM, it may be necessary to explore for other explanations in the future. Mercury's orbit was used to deduce Vulcan's orbit and location; here is an excellent illustration of this. The missing planet was blamed for its orbital deviance, which was anticipated by Newtonian gravity (DM). However, Einstein's adjustment of Newtonian gravity, not DM's, was the key to resolving this difference. This is in contrast to Uranus, where the DM (Neptune) hypothesis was used to successfully predict and detect its existence.

Starting point for this paper's physics is the premise that the mass of the DM particle is controlled by its interaction with a scalar field whose energy density is the DE. The accepted theory of material in the optical domain, which attributes the masses of quarks and leptons to their interactions with the Higgs field, suggests that interacting with a scalar field gives a particle its mass. In our scenario, DM and DE would reside in a disconnected "black sector" or "brane," which would make the situation extremely natural, save for the ever-present conundrum of the DE's numerical value today. DM interactions with ordinary matter in models do not enter into our discussion since we do not believe that this scenario can occur naturally and without negative repercussions.

2. LITEARTURE REVIEW

Theophanes Grammenos (2021) The major concern of the current investigation is whether or not unusual stars tainted with dark energy are among the possible options for dark energy stars. After a specific, as-yet-unknown critical condition within the quark stars, our research reveals that quark matter atcs as dark energy. Our model shows that odd stars infused with dark energy have a stable model that's consistent with physics and can be used to infer information about dark energy stars. The mass-radius relationship, in addition to entropy and temperature, demonstrates the reasonable relationships. When it comes to the anisotropic properties of the spherical star system, we emphasise the role that a two-fluid distribution plays.

Dipak Nath (2018) - There are protons, neutrons and electrons that make up the visible cosmos, which includes the sun, other stars and galaxies. Both dark matter and dark energy, which work against gravity, account for the overwhelming portion of the cosmos we can't see (70 percent). Based on astronomical evidence gathered over the course of many decades, we may conclude that most of the mass and energy in the universe are either dark matter or zero-point energy, which we regard to as "dark matter" or "dark energy" accordingly. Throughout this post, I'll be focusing on the experimental data that supports the existence of dark matter and dark energy.

Emma Kun (2018) - Our BEC model, which is non-relativistic, fits the rotation curves of 12 dwarf galaxies using a Newtonian or Yukawa potential via which light bosons interact gravitationally. The surface luminosity profiles of the galaxies are used to generate the baryonic component's properties, which are represented as an axisymmetric exponential disk. Because the baryonic fit is inadequate, we must include dark matter in our model. The BEC model provides a very accurate description of the rotation curves of five different galaxies.

Manahel AR Thabet (2014) - Cosmic components and how much of each element there is are the focus of current cosmology. Based on measurements, we know that dark energy makes up 72.8% of the universe's total mass, whereas dark matter accounts for 22.7% and baryonic matter contributes just 4.53 %. It was Fritz Zwicky (1936) who used Doppler redshift to measure the velocities of eight galaxies in the Coma Cluster. He discovered that the galaxies in the cluster were moving at 10 times the speed he had predicted. Only a small fraction of the mass needed to propel galaxies forward was supplied by the visible matter, and this fraction was far too little to make a difference. When Rubin, Freeman and Peebles obtained more trustworthy data in the 1970s, they discovered that galaxies' high velocities could not be explained by luminous matter alone. In spiral galaxies, the quantity of light that stars produce diminishes as you go closer to the outer edges, and if all matter were bright, the rotational speed would drop accordingly. The truth is that this isn't the case. There is no doubt that the rotation curves of galaxies are flat. The motions of galaxies, clusters of galaxies, and the Cosmic Microwave Background (CMB) all point to the existence of an unobservable substance, known as dark matter, that interacts gravitationally but not electromagnetically.

Katherine Garrett (2011) - One of cosmology's biggest unanswered questions is the nature of dark matter. As much as 80% of the universe's gravitational matter is non-luminous; its composition and distribution remain mostly unknown. We aim to provide an accessible yet thorough introduction to the mystery of dark matter in this article, which covers its history, astrophysical evidence, candidates, and detection techniques. Advanced students and researchers who are just beginning to explore dark matter will find a comprehensive reference list in this article.

3. INCORPORATING DARK MATTER AND DARK ENERGY INTO A SINGLE SYSTEM

Different models for this extension of CDM are explored from a scientific and astronomical perspective, all under the assumption of general relativity, standard physical theory, and a Yukawa coupling of DE to DM particles. Many aspects of theoretical physics, as outlined in §3, the information exists, but it has not been gathered and applied to astrophysicists in its entirety. The following is an example of one such application §4, Credible predictions may be made using the model, which differ from CDM (which assumes a monophyletic DM family) while still being consistent with the model. The example given in 5, Two DM Families, allows for a fascinating combination of early periods of tight equivalence to CDM and later eras of subtle departures from this model.

In making judgments about where we are currently in the development of this notion, we may draw on the vast history of thought on the subject. In §2 we've compiled a list of the most significant events in the development of this technology.

For easy reference, here are the two names we'll be using to describe our actions in the dark sector. The first is the DE model, which is well-known.

$$S_{\rm DE} = \int d^4x\sqrt{-g}\left[\tfrac{1}{2}\phi_{,\nu}\phi^{,\nu} - V(\phi)\right], \qquad (1)$$

where the task is being carried out V(Ø) scalar field of the classical real DE Ø is selected to mimic the influence of Einstein's field equation's cosmological constant Λ on the field stress-energy tensor. The power-law potential is used in numerical examples

$$V(\phi) = \frac{K}{\phi^{\alpha}}, \qquad (2)$$

The DM word, as it has been most often employed in this, is 2141

$$S_{\rm DMf} = \int d^4x\sqrt{-g}\left[i\bar{\psi}\gamma\partial\psi - y(\phi - \phi_*)\bar{\psi}\psi\right]. \qquad (3)$$

Here we have an action that is represented in terms of the wave function, as shown by the subscript "DMf" ψ for a spin-$\frac{1}{2}$ DM field. Whereas Ø* is a constant with energy units (with $\hbar = 1 = c$). The whole mass of a particle is owing to its interaction with the field if Ø* in equation (3) is negligible. Because we may require this field in order to account for the DE, this is a very appealing option. Nongravitational interactions in the dark sector are possible because of interactions between the DM and DE. In the presence of another DM family, these effects may be countered Ø*, as we discuss in §5, or by making the best possible selections Ø* and V(Ø) for one family (§4).

Completeness may necessitate considering the scalar DM particle counterpart of equation (3).

$$S_{\rm DMb} = \int d^4x\sqrt{-g}\left[\tfrac{1}{2}\chi_{,\nu}\chi^{,\nu} - \tfrac{1}{2}y^2(\phi - \phi_*)^2\chi^2\right]. \qquad (4)$$

Both DM actions are equivalent to the classical gas model of point-like particles with action in the boundary state that may be relevant to cosmology, when the standard deviation of the DE field is substantially larger than the de Broglie wavelengths of the DM particles.

$$S_{\rm DMp} = -\sum_i \int y|\phi(x_i) - \phi_*|\, ds_i. \qquad (5)$$

The path's invariant interval $x_i^{\mu}(t)$ of the i[th] particle is $ds_i = (g_{\mu\nu}\, dx_i^{\mu}\, dx_i^{\nu})^{1/2}$. Mass of DE particles is $m_{\rm eff} = y|\phi - \phi_*|$.

Reflections on the Past and Present of Ideas

The variable effective mass of equation (5) is shown in this equation Nordstro¨m's (1912) Minkowski spacetime gravity scalar field model, in the form $L_i \propto e^{-\phi/\phi_*} ds_i$. Many recent studies of the potential relationship between DM and DE include this linear coupling.

In the visible sector, particle mass ratios and other dimensionless constants may be close to standards, but in the dark sector, particle masses may be quite variable. Precision experiments on gravity in the visible sector have made it possible to make fascinating deviations from mainstream cosmology. As Damour and coworkers have shown, a scalar-tensor theory for gravity physics is likely to be used in many future studies (1990). To keep things simple, we'll utilise GR, visible-sector physics, and one scalar field to determine particle masses in the dark sector.

A phenomenon known as a "fifth force" has been discovered in the dark sector, where scalar interactions are only existent. Damour et al. recognized this from the beginning of current talks, and this form of fifth force has far less empirical restrictions than the Eotvo's experiment in the visible sector (1990). In Amendola, we get the first numerical evidence of the fifth force's impact on the expansion of mass density fluctuations in the expanding cosmos (2000). To account for the constraints imposed by the new observations, one must find DM-DE models in which the fifth force and DE field develop weakly enough to be consistent with the data but strongly enough to provide an interesting departure from CDM.

The attractor notion, which holds that physics may have the quality that astrophysics is indifferent to beginning circumstances, has affected the quest for models. Equation (2) has the DE power-law potential proposed by Peebles and Ratra (1988) because of this attractor characteristic. Like Franc a & Rosenfeld (2002) show, the physics need not have an attractor, as in the case of Wetterich's (1988) potential and the appropriate beginning circumstances. Models of this kind are discussed in detail in §4.

For all intents and purposes, the playing field has been levelled out to its weakest point. This attractor instance is not acceptable in the models discussed in §4 because the fifth force is too big.

The dilaton potential may also be influenced by attractors. Damour & Polyakov (1994) proposed a scenario in which the masses of all particles exhibit universal minima as a function of the dilaton field $Ø_m$; when the fifth force is at its smallest, it scales as $(\phi - \phi_m)^2$. These comics demonstrate that comics may rise in value as a result of their development Ø of the dilaton field to be close to $Ø_m$. Consequently, the fifth force is suppressed.

Our models include those with a small enough DM particle mass that the DE's interaction with the DM contributes significantly to the potential energy. Although this level of DM in galaxies is plainly unacceptable, two families of DM particles may be envisioned by varying the value of * in equations (3) and (4). Whenever there are enough DM particles of a particular family, the DE field will be locked to zero, making those particles relativistic. As a result, the fifth force is suppressed, preventing the growth of the DM particle mass and DE density. However, the field can only be emitted in an expanding universe, when the particle number density has fallen to an acceptable level.

The theoretical physics theories presented here show a certain degree of conservatism. Dirac's suggestion that the gravitational interaction's intensity may be varied led to the development of the scalar-tensor theories, which served as a guide for the development of precision tests for gravity physics. Superstring situations and the ongoing curiosity with nature's varied parameters are two of the reasons this activity has recently reappeared. It is also analogous to the Yukawa interaction, which was established for totally different goals in the realm of meson and weak interactions, to the Nordstro m action in the form of equation (5). This is the question that has to be answered.

4. BASIC RELATIONS

The DM particle model's physics is laid out in equation (5). However, we haven't seen all of the findings presented here in one or more of the studies listed above. Equation (3)'s relationship between the particle model and the field model, as stated in §3.4, may seem self-evident, but it's worth double-checking.

Particle And Field Equations

In this section, we simplify the notation by taking to be positive and * to zero. Everywhere, y is on the positive side.

The particle action in equation (5) gives the equation of motion

$$\frac{d}{ds} y\phi g_{\mu\nu} \frac{dx^\nu}{ds} = \frac{y\phi}{2} \frac{\partial g_{\rho\sigma}}{\partial x^\mu} \frac{dx^\rho}{ds} \frac{dx^\sigma}{ds} + \frac{\partial y\phi}{\partial x^\mu}. \qquad (6)$$

Because it's helpful to remember that the four-momentum of a particle is, we've decided to leave the constant y in this equation. $p^\mu = y\phi a \, dx^\mu / ds$. The equation of motion, in the limit when variations in spacetime curvature may be disregarded, is

$$\frac{d a\boldsymbol{p}}{dt} = \frac{d}{dt} \frac{a y \phi \boldsymbol{v}}{\sqrt{1 - v^2}} = -y\sqrt{1 - v^2} \frac{\partial \phi}{\partial \boldsymbol{x}}, \qquad (7)$$

The proper unusual velocity is and the proper world time t yields the cosmic expansion factor a(t). $\boldsymbol{v} = a \, d\boldsymbol{x}/dt$. Momentum is preserved when the spatial fluctuation of the DE field is small enough to be ignored, and if the appropriate unusual velocity is nonrelativistic, the speed scales as $v \propto 1/[a(t)\phi(t)]$.

As such, galaxies and galaxy clusters need a nonrelativistic DM. The weak-field limit of gravity provides a satisfactory description of these systems provided that the gravitational potential meets

$$\frac{\nabla^2 \Phi}{a^2} = 4\pi G \rho_b(t) \delta(\boldsymbol{x}, t). \qquad (8)$$

Mass density contrast is the average non-relativistic mass density and the mass density means. The DE field is represented as

$$\phi = \phi_b(t) + \phi_1(\boldsymbol{x}, t), \qquad (9)$$

where b(t) is the mean background field as a function of world time, and linear perturbation theory may be used to deal with the deviation 1 from homogeneity.

$$\frac{d\boldsymbol{v}}{dt} + \left(\frac{\dot{a}}{a} + \frac{\dot{\phi}_b}{\phi_b}\right)\boldsymbol{v} = -\frac{1}{a}\boldsymbol{\nabla}\left[\Phi + \frac{\phi_1}{\phi_b(t)}\right], \qquad (10)$$

There is a derivative with regard to the time t shown by the dot. Slowing strange velocities are a typical result of expanding universes, whereas the DE field's development creates a term that may either enhance or reduce the peculiar velocities. The right-hand side of the equation has a fifth force component as a result of the DE field's spatial fluctuation. It is this force that tends to reduce the mass of DM particles yØ

From the action of equations (1) and (5), the DE field equation is

$$\frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^\mu} \sqrt{-g g^{\mu\nu}} \frac{\partial \phi}{\partial x^\nu} + \frac{dV}{d\phi} + \frac{dV_I}{d\phi} = 0. \qquad (11)$$

The DM interaction yielded the following term:

$$\frac{dV_I}{d\phi} = y\sum_i \frac{ds_i}{dt}\frac{\delta(\mathbf{x}-\mathbf{x}_i)}{\sqrt{-g}}$$
$$\simeq y\sum \sqrt{1-v_i^2}\,\frac{\delta(\mathbf{x}-\mathbf{x}_i)}{a^3}. \qquad (12)$$

Forgetting about how variations in spacetime curvature affect the DM source term in the DE in the previous equation.

When the particles are relativistic, this becomes apparent, $v_i \to 1$, the source term $dV_I/d\phi$ vanishes. As an equation of state, this idea is expressed by Damour & Polyakov (1994). The correct number density of DM particles is what we've found to be the most practical alternative.

$$n(\mathbf{x},t) = \sum_i \frac{\delta(\mathbf{x}-\mathbf{x}_i)}{a^3} = \sum_i \delta(\mathbf{r}-\mathbf{r}_i), \qquad (13)$$

where $\delta\mathbf{r} = a\,\delta\mathbf{x}$ is a proper relative position. The original word may be represented as

$$\frac{dV_I}{d\phi} = yn(\mathbf{x},t)\left\langle\sqrt{1-v^2}\right\rangle. \qquad (14)$$

The Fifth Force

One nonrelativistic DM family model has a fifth force that we investigate. Equations (8) and (10) provide a very good estimate of the DM in galaxies and galaxy clusters. Here we return to the general situation when * is positive, where the spatial mean of the field equation may be written as

$$\frac{d^2\phi_b}{dt^2} + 3\frac{\dot{a}}{a}\frac{d\phi_b}{dt} + \left\langle\frac{dV(\phi)}{d\phi}\right\rangle \pm yn_b = 0, \qquad (15)$$

where nb(t) is the mean particle number density and b is the mean field strength. The last phrase is denoted by the symbol both here $\phi - \phi_*$. The equation holds for every value of 1 that deviates from the region of the field where everything is the same.

$$\frac{d^2\phi_1}{dt^2} + 3\frac{\dot{a}}{a}\frac{d\phi_1}{dt} - \frac{1}{a^2}\nabla^2\phi_1 + \frac{d^2V}{d\phi^2}\phi_1 \pm yn_b\delta = 0. \qquad (16)$$

The DM number density contrast $\delta n/n$ mass contrast has taken its position $\delta = \delta\rho/\rho$ Because, as we will show later, the fractional disruption to the field is negligible compared to $\delta n/n.$

As density variations on scales less than the Hubble length are of importance for our study of structure development at moderate redshifts. The term $d^2V/d\phi^2$ This, together with being tiny in many circumstances of relevance, makes it a good approximation to the field equation

$$\frac{\nabla^2\phi_1}{a^2} = \pm yn_b\delta. \qquad (17)$$

Using Eqs. (8), (10), and (17), we can deduce $\rho_b = y|\phi_b - \phi_*|n_b$ that in the dark sector the ratio of the fifth force to gravity is

$$\beta \equiv \frac{|\nabla \phi_1|}{|\phi_b - \phi_*|\nabla \Phi} = \frac{1}{4\pi G(\phi_b - \phi_*)^2}. \qquad (18)$$

Mass density contrast development in linear perturbation theory conforms to

$$\frac{\partial^2 \delta}{\partial t^2} + \left[2\frac{\dot{a}}{a} + \frac{\dot{\phi}_b}{(\phi_b - \phi_*)}\right]\frac{\partial \delta}{\partial t} = 4\pi G \rho_b (1+\beta)\delta. \quad (19)$$

The distinguishing element between this and the standard phrase is $1+\beta,$ which considers the fifth force and the component $\dot{\phi}_b/(\phi_b - \phi_*)$, the growing number of DM particles.

Now we can check that $\delta n/n \simeq \delta\rho/\rho.$ Equation (17) applied to a particle concentration with contrast δ and size r says

$$\frac{\delta m}{m} = \frac{\phi_1}{(\phi_b - \phi_*)} \sim \frac{-y n_b r^2 \delta}{|\phi_b - \phi_*|}, \qquad (20)$$

In where H is the Hubble constant. The m/m mass shift has a sign that's the polar opposite of δ, commensurate with the fifth force's appealing character.

$$\frac{|\delta m|}{m} \lesssim \beta (Hr)^2 |\delta|. \qquad (21)$$

This is small because β cannot be much bigger than 1, because density changes on sizes less than the Hubble length are of relevance to us.

5. CONCLUSION

A scalar field, which may be the cause of the DE, has been investigated in models in which the DM particles are Yukawa coupled. These models may have characteristics and beginning circumstances that make the model feasible but considerably different from classic CDM cosmology, which is our main conclusion. cannot be much bigger than 1, because density changes on sizes less than the Hubble length are of relevance to us, for example. Depending on your preferences, you may set up the initial circumstances in such a way that, no matter how many families you add, the DE field will always be locked at mass 0. Here's an illustration of how a dynamical model of the DE might seem exactly like Einstein's cosmological constant from an observational standpoint. When the density of DE particles drops low enough, the DE field is freed. There is a wide range of possible outcomes when this occurs. An important cautionary example is the sort of model explored here, in which the masses of one or potentially multiple DM families are established by their interaction with an arbitrary dynamical field.

6. REFERENCES

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