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Dark matter, dark energy and gravity

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Within the framework of the Generation Model (GM) of particle physics, gravity is identified with the very weak, universal and attractive residual color interactions acting between the colorless particles of ordinary matter (electrons, neutrons and protons), which are composite structures. This gravitational interaction is mediated by massless vector bosons (hypergluons), which self-interact so that the interaction has two additional features not present in Newtonian gravitation: (i) asymptotic freedom and (ii) color confinement. These two additional properties of the gravitational interaction negate the need for the notions of both dark matter and dark energy.

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1. Introduction

According to the prevailing standard cosmological model,[1] the universe is composed of about 5% ordinary matter, 27% dark matter and 68% dark energy. This model was the result of attempts to determine the composition of the universe. Unfortunately, little understanding exists of the nature of either dark matter or dark energy, which form 95% of the total mass–energy content of the universe.

Dark matter is a form of matter hypothesized to account for gravitational effects observed for large astronomical objects, galaxies and clusters of galaxies, that cannot be accounted for by the observed ‘luminous matter’ — stars, gas, dust, etc., assuming the validity of Newton’s universal law of gravitation.

The evidence for a galactic mass discrepancy, especially for spiral galaxies, was accumulated over many years from the 1930s to the 1970s.[2] This evidence was based mainly upon the measurement of the 'rotation curve' for a spiral galaxy, i.e., the dependence of the orbital velocity of the visible matter in the galaxy on its radial distance (r) from the center of the galaxy: the observed rotation curves are essentially 'flat' at the extremities of the visible matter in gross disagreement with Newton's universal law of gravitation, which predicts that the rotation curves should fall off as $1/\sqrt{r}$ outside the luminous parts of these galaxies. Thus, by 1980 it was clear that there existed a serious mass discrepancy problem for spiral galaxies.

The conclusion drawn from the rotation curves of spiral galaxies that 'the mass discrepancy is greater, the larger the distance scales involved' implies that either Newton's universal law of gravitation requires a significant modification in order to provide a stronger gravitational field than expected at large (galactic) distance scales or considerably more mass is required to be present in each galaxy.

Preserving Newton's universal law of gravitation in the conventional cosmological model[3] of spiral galaxies, each galaxy is considered to be embedded in a giant spheroidal halo of invisible (dark) matter, which provides a large contribution to the gravitational field at large distances from the center of the galaxy. However, the hypothesis of a dark matter halo embedding a spiral galaxy to account for the observed flat rotation curve of a galaxy has yet to be verified. There are also several outstanding problems.[2]

First, the nature of the proposed dark matter, which does not interact with photons, is unknown. Second, a dark matter halo has yet to be detected directly, although many searches have been carried out. Third, the density profile of a typical dark matter halo, within Newtonian physics, is required to be fine-tuned in order to produce the observed flat rotation curve of a spiral galaxy. Fourth, the lack of dark matter in globular clusters is still a mystery: large globular clusters have about the same mass as the smallest dwarf galaxies, although their diameter is only about a tenth the diameter of a typical dwarf galaxy, which are considered to have considerable amounts of dark matter. Indeed, in spite of many decades investigating the nature of dark matter, little is known about it.

The only known alternative to the existence of dark matter to provide additional gravitational field for large galactic distances is an appropriate modification of Newton's universal law of gravitation. We shall discuss this in more detail in Sec. 3.

Assuming the existence of dark matter and Newton's universal law of gravitation, two teams of astrophysicists[4,5] investigated the future of the universe. It was expected that the rate of expansion of the universe should be slowing down as a consequence of gravity.

The two teams analyzed supernovae of Type Ia, which are excellent standard candles across cosmological distances and allow the expansion history of the universe to be measured by considering the relationship between the distance to an object and its redshift, which indicates how fast the supernova is receding from us. Both teams, employing a particular standard cosmological model, found that the supernovae observed about halfway across the universe (6–7 billion light years away) were dimmer than expected and concluded that the expansion of the universe was accelerating rather than slowing down.

The conclusion from this observation was that the universe had to contain enough energy to overcome gravity. This energy was named dark energy. The amount of dark energy in the universe was estimated to be about 68% of the total mass–energy existing in the universe.[1]

Dark energy[6] is a hypothetical form of energy, which pervades the whole of space and causes the expansion of the universe to accelerate at large cosmological distances. Currently there exists no accepted physical theory of dark energy.

In Sec. 2, we shall discuss the nature of both mass and gravity within the framework of the Generation Model (GM),[7] a recent advance on the Standard Model (SM) of particle physics.[8] In Sec. 3, we shall indicate how the gravitational interaction of the GM, which has characteristics very different from those of Newtonian physics, leads to an understanding of both dark matter and dark energy. Section 4 states the conclusions.

2. Mass and Gravity in the GM

The GM[7] is an alternative model to the SM of particle physics.[8] The GM provides agreement with the SM for all the transition probabilities arising from every interaction involving any of the six leptons or the six quarks of the SM. The essential difference between the GM and the SM is that in the GM, the leptons and quarks are composite particles rather than elementary particles as in the SM.

Thus in the GM, both leptons and quarks have a substructure, consisting of spin-1/2 massless particles, rishons and/or antirishons, each of which carries a single color charge. The constituents of leptons and quarks are bound together by strong color interactions, mediated by massless vector hypergluons, acting between the colored charged rishons and/or antirishons. These strong color interactions of the GM are analogous to the strong color interactions of the SM, mediated by massless vector gluons, acting between colored charged elementary quarks and/or antiquarks. In the GM, the strong color interaction has been taken down one layer of complexity to describe the composite nature of leptons and quarks. The substructure of leptons and quarks is described in Ref. 7.

The assumption, in the GM, of the compositeness of leptons, quarks and the W and Z bosons, which are elementary particles in the SM, has led to new paradigms for both mass and gravity.[9,10]

In the GM, the mass m of a lepton, quark or vector boson arises from a characteristic energy E, according to the equation $m = E/c^2$, associated with the kinetic energy of its constituent rishons and/or antirishons and the energy of the hypergluon fields. This is completely analogous to the mass of a proton in the SM arising predominently (>90%) from the energy stored in the motion of the quarks and the energy of the color gluon fields, as calculated by approximate quantum chromodynamics calculations.[11–13] Thus in the GM, the mass of a body arises from the energy content of its constituents in agreement with Einstein's 1905 conclusion.[14] Furthermore, the GM provides a unified description of the origin of all mass and has no requirement for a Higgs field[15,16] to generate the mass of any particle.

In the GM, the constituents of a lepton or quark must be very strongly localized, since to date there is no direct evidence for any substructure of these particles. Thus, the constituents are distributed according to quantum mechanical wave functions for which the product wave function, describing the composite particle, is significant for only an extremely small volume of space.

In the case of the colorless leptons, this means that the corresponding color fields are almost cancelled for distances outside the immediate vicinity of the lepton. In the case of the colored quarks, this means that the color charge of the quark is almost identical with that assumed in the SM, since the remaining color fields, corresponding to colorless rishon–antirishon pairs, are very nearly cancelled. Thus the dominant color interaction between quarks is essentially the same as that between rishons so that the composite quarks of the GM behave very nearly like the elementary quarks of the SM.

The mass of each lepton, quark or vector boson corresponds to a characteristic energy, primarily associated with the 'intrafermion' color interactions acting between its constituent rishons and/or antirishons. The mass of a particle will be greater if the degree of localization of its constituents is smaller (i.e., the constituents are on average more widely separated). This is a consequence of the nature of the strong color interactions, which possess the property of 'asymptotic freedom',[17,18] whereby the color interactions become stronger for larger separations of the color charges. In addition, repulsive electromagnetic interactions between charged rishons or between charged antirishons, will also cause the degree of localization of the constituents to be smaller, causing an increase in mass. Indeed, the mass hierarchy of the three generations of leptons and quarks is described qualitatively in terms of the degree of localization of their constituents.[7]

In the GM, between any two colorless particles (electron, neutron or proton) there exists a residual interaction arising from the color interactions acting between the rishons and/or antirishons of one fermion and the color-charged constituents of the other fermion. Robson proposed[9,10] that such 'interfermion' color interactions may be identified with the usual gravitational interaction.

Gravitational interaction acts between bodies with mass. The mass of a body of ordinary matter is essentially the total mass of its constituent electrons, neutrons and protons. In the GM, each of these three particles is composite and is colorless. Indeed, all three particles are considered to be essentially in a three-color antisymmetric state. A neutron or proton contains three quarks with one color charge of each of the three possible color charges: red, green and blue. An electron contains three antirishons with one anticolor charge of each of the three possible anticolor charges: antired, antigreen and antiblue. The behavior of these particles with respect to the strong color interactions is expected basically to be the same, which suggests that the interfermion interactions of the GM between electrons, neutrons and protons have several properties associated with the usual gravitational interaction: universality, very weak strength and attraction.[7,10]

First, the residual interaction between any two of the colorless particles, electron, neutron or proton, arising from the interfermion color interactions, is predicted to be of a *universal* character, since each of these colorless particles has essentially the same color structure.

Second, the residual interaction, mediated by massless hypergluons, is expected to be *extremely weak*, since the constituents of each colorless particle are very strongly localized so that the strong color fields are almost completely cancelled at separations larger than the immediate vicinity of either of the two colorless particles. Consequently, the hypergluon self-interactions are also practically negligible and one may consider the color interactions using a perturbation approach.

Third, using the color factors[19] appropriate for the $SU(3)$ gauge field, one finds that the residual color interactions between any two colorless particles (electron, neutron or proton) are each *attractive*.

Since the mass of a body of ordinary matter is essentially the total mass of its constituent electrons, neutrons and protons, the total interaction between two bodies of masses, m_1 and m_2, will be the sum of all the two-particle contributions so that the total interaction will be proportional to the product of these two masses, $m_1 m_2$, provided that each two-particle interaction contribution is also proportional to the product of the masses of the two particles.

This latter requirement may be understood if each electron, neutron or proton is considered physically to be essentially a quantum mechanical triangular distribution of three differently colored rishons or antirishons. In this case, each particle may be viewed as a distribution of three color charges throughout a small volume of space with each color charge having a certain probability of being at a particular point, determined by its corresponding color wave function. The total residual interaction between two colorless particles will then be the sum of all the intrinsic interactions acting between a particular triangular distribution of one particle with that of the other particle.

Now the mass m of each colorless particle is considered to be given by $m = E/c^2$, where E is a characteristic energy, determined by the degree of localization of its constituent rishons and/or antirishons. Thus the significant volume of space occupied by the triangular distribution of the three differently colored rishons or antirishons is larger, the greater the mass of the particle. Moreover, due to antiscreening effects[17,18] of the strong color fields, the average strength of the color charge within each unit volume of the larger localized volume of space will be effectively increased. If one assumes that the mass of a particle is proportional to the integrated sum of the intrafermion interactions within the significant volume of space occupied by the triangular distribution, then the total residual interaction between two such colorless particles will be proportional to the product of their masses.

Thus the residual color interaction between two colorless bodies of masses, m_1 and m_2, is proportional to the product of these masses, $m_1 m_2$ and moreover, neglecting the self-interactions of the hypergluons mediating the interaction, is expected to depend on the inverse square of their distance of separation r, i.e., as $1/r^2$, in accordance with Newton's universal law of gravitation.

However, the gravitational interaction in the GM, which we have identified with the interfermion color interactions between the colorless particles, electrons, neutrons and protons, has two additional properties arising from the self-interactions of the hypergluons, mediating the residual interaction: (i) asymptotic freedom and (ii) color confinement. These two properties are absent for the electromagnetic interaction, since there are no corresponding photon self-interactions.

In the following Sec. 3, we shall indicate how these two additional properties of the interfermion color interactions provide an understanding of both dark matter and dark energy.

3. Understanding Dark Matter and Dark Energy

In the GM, the usual gravitational interaction has been identified[7,10] with the residual interfermion color interactions acting between the colorless matter particles, electrons, neutrons and protons, which make up most of the ordinary mass of the universe.

In a recent publication,[2] it was shown that such a gravitational interaction leads to a universal law of gravitation, which closely resembles Newton's original law that a body of mass m_1 attracts another body of mass m_2 by an interaction proportional to the product of the two masses and inversely proportional to the square of the distance (r) between the centers of mass of the two bodies:

$$F = H(r) m_1 m_2 / r^2, \tag{1}$$

where Newton's gravitational constant is replaced by a function of r, $H(r)$.

This difference from Newton's original law arises from the self-interactions of the hypergluons mediating the residual color interactions. These self-interactions cause antiscreening effects,[17,18] which lead to an increase in the strength of the residual interaction acting between the two masses, so that H becomes an increasing function of r.

It is known from particle physics that the strong color interactions tend to increase with the separation of color charges in order to confine quarks within baryons, so that one expects $H(r)$ to increase as a function of r. The flat rotation curves observed for spiral galaxies indicate that $H(r)$ is essentially a linear function of r. In this case, the modified law of gravity based upon gravity being identified with the very weak residual color interactions may be written as:

$$g = GM/r^2 + GM\epsilon/(r r_S), \tag{2}$$

where g is the gravitational acceleration and we have used:

$$H(r) = G(1 + \epsilon r/r_S). \tag{3}$$

Here G is Newton's gravitational constant, ϵ is a factor representing the relative strengths of the modified and Newtonian gravitational fields and r_S is a radial length scale, dependent upon the radial mass distribution of the spiral galaxy, i.e., r_S varies from galaxy to galaxy.

In a spiral galaxy, the gravitational interaction of a point mass at a distance r from the center of the galaxy will depend upon two factors: (i) the total mass M distributed within the sphere of radius r and (ii) the nature of the function $H(r)$. Thus for small values of r, these two factors will be entwined, each making a contribution to the orbital velocity of the point mass. However, for large values of r, only the second factor, $H(r)$, will make a significant contribution to the orbital velocity.

In 1983, Milgrom[20–22] developed a modification of Newton's universal law of gravitation, known as the modified Newtonian dynamics (MOND) theory, as a possible alternative to dark matter.

The MOND theory postulates that gravity varies from the prediction of Newtonian dynamics for low accelerations. In order to explain both the flat rotation curves of spiral galaxies and the Tully–Fisher relation:[23]

$$L \propto v_f^4, \tag{4}$$

where L is the intrinsic luminosity of a galaxy and v_f is the orbital velocity of matter circulating in the flat region of the corresponding velocity curve, the transition to $1/r$ gravity should occur below a 'critical acceleration' a_0, which is assumed to be fixed from one galaxy to the next.

It should be noted that the MOND theory of gravity, based upon a critical acceleration a_0, implies that the modified gravitational interaction is associated with a different radial parameter for each galaxy, unlike the corresponding modified law of gravity in terms of a critical length scale.[2] This is the fundamental reason why the MOND theory satisfies the Tully–Fisher relation and the critical length scale theory does not.

As indicated above, the GM expression, Eq. (2), for a modified gravitational interaction is also associated with a radial parameter, r_S, which varies from galaxy to galaxy. Indeed, one can relate[2] the modified terms in the gravitational acceleration expressions to obtain:

$$a_0 = GM\epsilon^2/r_S^2. \tag{5}$$

Thus the scale factor r_S may be regarded as the radial parameter beyond which the acceleration takes the value a_0 or less, and the value of r_S will depend upon the radial mass distribution of the galaxy. Equation (5) implies that the physical basis of the critical weak acceleration a_0 of the MOND theory is the existence of a radial parameter r_S, which defines a region beyond which the gravitational field behaves essentially as $1/r$. This occurs in the GM as a consequence of the universal nature of the weak residual color interaction identified as the universal gravitational interaction.

To summarize: The nature of the gravitational interaction in the GM leads to a modified law of gravity given by Eq. (2), which defines a scale factor r_S beyond which weak acceleration takes place and the gravitational field behaves essentially as $1/r$. Equation (2) describes both the flat velocity rotation curves of spiral galaxies and also the correlation of their asymptotic orbital velocity with their luminosity (the Tully–Fisher relation).[2] This modification of Newton's universal law of gravitation is very similar to that used in Milgrom's MOND theory, with the GM modification providing a physical understanding.

The continuing success[24,25] of MOND theory in describing extragalactic mass discrepancy problems constitutes a strong argument against the existence of undetected dark matter haloes, consisting of unknown nonatomic matter, surrounding spiral galaxies.

The property of 'asymptotic freedom', arising from the self-interactions of the hypergluons, mediating the residual color interaction corresponding to the gravitational interaction of the GM, also argues against the existence of nonatomic dark matter.

We shall now indicate how the second property of 'color confinement', which also arises from the self-interactions of the hypergluons of the GM, leads to an understanding of dark energy.

As we have seen, the main effect arising from the self-interactions of the hypergluons is to modify Newton's universal law of gravitation so that there is additional gravity at large galactic distances than that predicted by Newtonian mechanics.

However, the self-interactions of the hypergluons are expected to cease at a sufficiently large distance. This finite range arises from the color confinement property, which causes the residual color gravitational interaction to produce colorless particles rather than continuing to modify Newton's universal law of gravitation by producing additional gravity at larger distances. This process takes place when the gravitational field energy is sufficient to produce the mass of a particle–antiparticle colorless pair. It is completely analogous to the 'hadronization process', involving the formation of hadrons out of quarks and gluons, which leads to the finite range ($\approx 10^{-15}$ m) of the strong color interaction in the SM.

In the gravitational case, the relative intrinsic strength is about 10^{-41} times weaker than the strong color interaction at 10^{-15} m.[26] This suggests that the equivalent process to hadronization in the gravitational case should occur at a cosmological distance of about 10^{26} m, i.e., roughly 10 billion light years (one light year is $\approx 10^{16}$ m). This result agrees well with the observations[4,5] of distant Type Ia supernovae, which indicate that the onset of the accelerating expansion of the universe occurs at about 6 billion light years.

In the GM, dark energy-like dark matter may be understood as an effect arising from the nature of the gravitational interaction. For cosmological distances exceeding several billion light years, gravity essentially ceases to exist so that galaxies will experience less gravitational acceleration than for smaller cosmological distances. Eventually, the galaxies will experience a speeding up (i.e., less rapid slowing down) of their expansion rate as the lack of gravity for larger cosmological distances overcomes the gravitational pull experienced for smaller cosmological distances.

4. Conclusion

In the GM, gravity is identified[7,10] with the very weak universal and attractive residual interfermion color interactions acting between the colorless particles of ordinary matter (electrons, neutrons and protons). This gravitational interaction is mediated by massless vector bosons (hypergluons), which self-interact so that the interaction has two additional properties compared with Newtonian gravitation: (i) asymptotic freedom and (ii) color confinement. These two additional features of the interfermion color interactions provide an understanding of both dark matter and dark energy.

The self-interactions of the hypergluons, which are associated with asymptotic freedom, cause antiscreening effects,[17,18] which lead to a modification of Newton's universal law of gravitation such that the gravitational field behaves as $1/r$ rather than $1/r^2$ at galactic distances. This modified gravitational field describes both the flat rotation curves of spiral galaxies and also the Tully–Fisher relation, which correlates their asymptotic orbital velocity with their intrinsic luminosity.[2]

This modification of Newton's universal law of gravitation agrees with that of the MOND theory, with the GM modification providing a physical basis. The continuing success[24,25] of MOND theory in describing the extragalactic mass discrepancy, together with the GM modification, constitutes a strong argument against the existence of nonatomic dark matter.

The color confinement property of the residual interfermion color interactions, identified with gravity, leads to a finite range of the self-interactions of the hypergluons. This process takes place when the gravitational field energy is sufficient to produce the mass of a particle–antiparticle colorless pair. An estimate of the cosmological distance at which gravity ceases to act is in good agreement with observations[4,5] of distant Type Ia supernovae.

In the GM, dark energy, like dark matter, may be understood as an effect arising from the nature of the gravitational interaction. In the case of dark energy, the rate of expansion of the galaxies will change rather suddenly once the cosmological distances of separation exceed a critical value, estimated to be several billion light years. Eventually, the galaxies will experience a speeding up of their expansion rate as the lack of gravity for larger cosmological distances overcomes the gravitational pull experienced for smaller cosmological distances.

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