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A New Approach to the Dark Matter/Dark Energy Puzzle

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Abstract

The dilemmas posed by dark matter and dark energy have been with us for decades without a satisfactory resolution. We propose that both DM and DE can be explained by the existence of long-lived topological gravitational vortices that were produced in the quark-gluon epoch of cosmic inflation due to the misalignment of the gravitational and strong forces. This is analogous to the misalignment mechanism proposed for the production of axions in the early universe. The masses of these topological vortices are expected to be on the order of the nucleon mass. Possible means for their detection are discussed.

Keywords

Dark Matter, Dark Energy, Topological Defects, Cosmic Inflation, Quark-Gluon Plasma

1. Introduction

The existence of dark energy has been known for at least 20 years ([1], p: 499) and for dark matter even longer ([1], p: 483). Despite many experimental searches, no convincing explanations for the nature of DM or DE have been found [1]. The leading contender for the nature of DE is that it is due to the cosmological constant. However, this leads to predictions that are ~60 orders of magnitude too large [2].

In view of the present dilemma, it is an appropriate time to consider other paradigms to explain (hopefully) both DM and DE. We propose that both DM and DE can be explained by the existence of long-lived topological vortices that were produced as strong interactions emerged in the quark-gluon epoch of cosmic inflation ~10^{-10} seconds after the Big Bang. There is no theory of quantum gravity so we here consider a semi-classical approach. It is convenient to use vector terminology.

Vortex formation is familiar in fluid mechanics. Vortices are formed in water by ship propellers and in the atmosphere behind airplane wings and automobiles. Long-lived vortices in the atmosphere, such as tornadoes and the Great Red Spot on Jupiter, are well-known. Spiral galaxies are ubiquitous. In an optical vortex, light is twisted like a corkscrew around its axis of travel [3]. Localized optical vortices, *i.e.*, vortex solitons, have drawn much attention as physical objects of fundamental interest and also because of their potential applications to optical information processing [4].

A vortex can be generated whenever two vector fields are misaligned, for example, a pressure gradient and a density gradient. The resulting vector cross product or torque generates an angular momentum $\Delta L = \tau \Delta t$ where τ is the torque. In the ship propeller example, the vectors are the pressure on the propeller blades and the velocity of the water going past them.

A similar scenario for generating a nonzero energy density for light scalar fields is through the misalignment mechanism proposed for axions [5] [6] [7]. Co *et al.* [8] propose a misalignment scenario where the axion field has a nonzero initial velocity that can be generated from the explicit breaking of the axion shift symmetry in the early universe. In the scenario proposed here, the breakdown occurs much later, in the quark-gluon epoch.

2. Background

Edery [9] has studied vortex solutions in Einstein gravity and found numerically static solutions in which a complex scalar field φ and a gauge field A_μ have a non-singular profile in an anti-deSitter (2 + 1)-dimensional space-time background. Vortices with different winding numbers n, vacuum expectation value v, and cosmological constant Λ were obtained. These vortices have positive mass and are not black holes as they have no event horizon. The works of Edery and others show that it is plausible that gravitational vortices are produced late in inflation but they give no real insight as to their masses, mass density, and lifetimes.

There is a significant literature on cosmological gravitational particle production (CGPP) in an expanding universe. A review by Ford [10] gives estimates for particle creation rates by gravitational fields in specific inflationary cosmology models, including some exactly soluble models. He concludes that particle creation by the gravitational field could play a significant role in cosmological evolution and that gravitational particle creation could be a promising model for the origin of the dark matter.

Recently Kolb *et al.* [11] discuss CGPP which is expected to occur during the period of inflation and the transition into a hot big bang cosmology. Particles may be produced even if they only couple directly to gravity, and so CGPP provides a natural explanation for the origin of dark matter. They study the gravitational production of massive spin-2 particles assuming two different couplings to matter and calculate the spectrum and abundance of massive spin-2 particles that result from inflation on a hilltop potential. They conclude that CGPP might provide a viable mechanism for the generation of massive spin-2 particle dark matter during inflation and identify the favorable region of parameter space in terms of the spin-2 particle's mass and the reheating temperature.

These CGPP models generally assume the particles are produced during inflation and the exponential expansion acts as a gravitational amplifier. They are focused mainly on production and detection of thermal relics with mass typically in the range a few GeV to a hundred GeV or nonthermal WIMPs with masses in the range 10^{12} to 10^{16} GeV. The gyrons discussed here are produced in the quark-gluon epoch when gravitational forces are comparable to strong interaction forces, so that gyron masses would be comparable to baryon masses as discussed below.

3. Formation of Long-Lived Topological Vortices in the Quark-Gluon Plasma

Vector misalignments, as discussed above, are inevitable in the quark-gluon epoch of cosmic evolution due to the local misalignment between the gravitational force vectors and the strong and electromagnetic forces between the emerging quarks and gluons. This generates spatial vortices in the evolving universe. (They might also be produced in the earlier electroweak epoch.) The vortices acquire a mass due to their coupling to the strong/electromagnetic fields. These vortices should be long-lived and may grow in size as the universe expands [9]. Further torques can only spin their angular momentum up or down. Unlike other topological defects, such as strings and walls [12], they are produced late in inflation and so are not "inflated" out. Just as for other topological defects they carry energy and thus experience gravitational forces. Their creation is analogous to the formation of a gravitational singularity–a black hole–when two neutron stars collide. The latter happens much later in inflation on a much grander scale.

I shall refer to the gravitational solitons as *gyrons*. Without a rigorous quantum gravity treatment, it is not possible to predict the characteristics of gyrons, in particular their masses and mass density. However, it is possible to make plausible arguments for their general properties. Like neutrinos, they decouple and move through space freely. They carry angular momentum and mass energy. The unification of the electroweak force and the strong force with the gravitational force in the so-called "Theory of Everything" requires an energy level which is generally assumed to be close to the Planck scale of 10^{19} GeV. The unification of the electroweak force and the strong force with the gravitational force is, in turn, related to the Planck mass as $G_N = \hbar c / M_p^2$ where G_N is the gravitational constant and the Planck mass M_p = 1.22 × 10^{19} GeV/c^2. The final symmetry breaking, that of chiral symmetry in the quark sector, occurs ~10^{-10} seconds after the Big Bang. Gravitational forces are then comparable to strong interaction forces as quarks and baryons emerge. In this epoch, the effective coupling was on the order of the strong coupling constant $\alpha_s \sim 0.11$ [13]. Therefore, the effective gravitational constant at this epoch is $G_g \sim \hbar c / M_n^2$ where M_n is the nucleon mass. Thus, the mass scale for gyron production is on the order of baryon masses so that the expected gyron mass is ~1 GeV/c^2.

Since they are fundamentally quantum objects, it is reasonable to assume that their angular momentum is quantized in half-integer multiples of $\hbar$, as for other elementary particles. They could carry electric and/or magnetic charges. Their total mass density could be greater than the mass density of baryons in the universe.

4. Discussion

Gyrons would interact with each other and interact gravitationally with baryonic matter. Winding number is conserved so they are long-lived, though gyrons with opposite winding numbers could annihilate each other. Dark matter causes an attractive gravitational force while dark energy appears as a repulsive force or negative energy. To explain both dark matter and dark energy would require two varieties of gyrons. Vortex solitons will repel or attract depending on their topological charge [14] [15]. The observed baryon, cold dark matter, and dark energy densities normalized to the critical density $\rho_{\text{critical}} = 9.47 \times 10^{-27}$ kg·m^{-3} are respectively, $\Omega_b = 0.0223h^{-2}$, $\Omega_c = 0.105h^{-2}$, and $\Omega_L = 0.73h^{-2}$ ([1], p: 134). Without a theory there is no way to predict the gyron mass density. A density about 5 times the baryon density for the attractive component would explain the dark matter. A density for the repulsive component about 7 times that of the attractive component would account for the dark energy. Edery [9] found that the cases with $n = 2$ and $\nu = 2$ differed from their $n = 1$ and $\nu = 1$ counterparts in that they had significantly higher masses, reflecting the approximate dependence of the integral mass formula on $n^2\nu^2$, so that a repulsive component that is 7 times the attractive component is plausible.

In this picture the "attractive" vortices are the dark matter and along with the ordinary matter cause structure formation. The repulsive component accounts for the repulsive force that is the only known attribute of dark energy which causes the acceleration of the expansion that is observed in the present universe. This picture is similar to that of quintessence [16]. However, quintessence is driven by an evolving scalar field which is present from the beginning of inflation, while the topological vortices posited here are elementary objects that are produced much later in the quark-gluon phase. Gyron masses ~1 GeV/c^2, as discussed in Section 2, would explain the observed clustering. Gyrons could also have appeared earlier in the weak interaction dominated universe and would likely cause a CP violation that led to an excess of right- or left-handed gyrons. This would propagate the CP violation into the later universe.

Theoretical considerations aside, there are some possibilities for detecting gyrons. Gyrons with electric charge would behave like cosmic ray electrons or muons depending on their mass (but, unlike muons, they would not decay). They would undergo the same acceleration mechanisms as other cosmic rays, so their energy spectrum would be similar to that of other cosmic rays. Cosmic muons, because of their short lifetimes, must be produced locally in the Earth or atmosphere by decays of hadrons that are produced by cosmic rays or by cosmic neutrino interactions. The IceCube detector at the South Pole has detected hundreds of muon-like events produced by cosmic neutrinos [17]. Some of these could be due to gyrons whose electromagnetic interactions would closely resemble those of muons. A careful study of the ionization profiles in the detector, which would be different from that of muons because of their different mass, could establish whether two components were in the data. Cosmic gyrons could also masquerade as cosmic electrons. Data from the Alpha Magnetic Spectrometer on the International Space Station exhibit a significant excess of electrons starting above ~42 GeV and an excess of positrons above ~25 GeV [18]. These excesses have not been explained. They could reflect a previously unrecognized component in the data that mimics electrons. This could be revealed by a study of the ionization profiles in the detector.

Gyrons without electric or magnetic charge would only interact gravitationally with matter. In passing through a torsion balance or near a gravitational wave detector such as LIGO, they would leave a characteristic signal unlike the compression/expansion caused by a gravitational wave [19]. Another possibility is that they would contribute to the stochastic noise in pulsar timing arrays [20] [21]. The technique used by Dixit *et al.* [22] using a superconducting qubit to make repeated quantum nondemolition measurements of cavity photons could also be applied in searching for the passage of topological vortices.

The possibility that new fundamental particles are produced in the quark-gluon era is intriguing. The ingredients for their production—the final symmetry breaking in the quark sector together with the misalignment of the gravitational and strong and electromagnetic forces in the quark-gluon plasma–were there. We won't find them if we don't look for them.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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