

Origin of Dark Energy in the Universe: Can D-instanton Source a Quintessence?

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ABSTRACT: Can a D -instanton provide a clue to the origin of dark energy in universe? In the context we briefly review our construction for a string-brane model which underlies a vacuum created gravitational pair of $(3\bar{3})$ -brane by a Kalb-Ramond (KR) field on a D_4 -brane. Obtained results reveal that a dynamical D -instanton could be quintessential to incorporate a non-perturbative quantum correction to $(3+1)$ -dimensional brane universe. It provokes thought to believe that an extra fifth spatial dimension to the brane universe can be sourced by a D -instanton which could be a potential candidate to source the enormous dark energy.

KEYWORDS: Cosmological Pair Production, Kalb-Ramond Field, Quantum Gravity, String Theory, D-instanton

I. INTRODUCTION: STRINGY APPROACHES TO QUANTUM GRAVITY

Black holes are described in Einstein gravity which underlies an intrinsic metric dynamics on a Riemannian manifold. Interestingly the stringy versions of these macroscopic black holes have been obtained in a low energy limit of a string effective action in the past [1, 2, 3, 4, 5]. In fact, a nontrivial background metric on a string world-sheet is known to incorporate vertex operators in a path integral and hence naturally introduces a string coupling at each interaction vertex. A weak coupling consistently incorporates perturbative geometric (higher genus) corrections to the string world-sheet at tree level and leads to a theory of quantum gravity.

On the other hand the quantum effects to Einstein gravity can also be explored addressed non-perturbatively using the strong-weak coupling duality in ten dimensional superstring theories [6]. A non-perturbative quantum effect is believed to be sourced by compactified extra space dimension(s) to various stringy vacua. In particular, the type IIA superstring theory in a strong coupling limit is known to incorporate an extra spatial dimension on S^1 and has been identified with the non-perturbative M -theory in eleven dimensions. Generically M -theory has been shown to be identified with the stringy vacua in various dimensions [7]. In a low energy limit M -theory is known to describe an eleven dimensional supergravity. However a complete non-perturbative formulation of M -theory is not known.

II. PAIR CREATION OF $(3\bar{3})$ -BRANE UNIVERSE AT BIG BANG

PERSPECTIVES: We begin by briefly revisiting the Schwinger pair production mechanism [8] established in quantum field theory (QFT). The novel idea elegantly describes a positron and electron pair production at a QFT vacuum by electromagnetic quanta, i.e. photon. The pair production mechanism is an emergent non-perturbative phenomenon. It is believed to be instrumental to describe diverse quantum phenomenon in gravitation and cosmology. In fact the tool was explored to explain the Hawking radiation phenomenon [9], where an incident photon generates a pair of charged particle/anti-particle at the event horizon of a black hole. Furthermore the idea was applied to the open strings pair production by Bachas and Poratti [10]. Majumdar and Davis have exploited the underlying mechanism to investigate the production of a higher dimensional pair of $(D\bar{D})_9$ at the cosmological horizon [11].

An extra spatial dimension compactified on S^1 has been argued to unfold in the ten dimensional type IIA superstring theory when the string coupling becomes large. As a result the strong coupling string theory has been conjectured to describe an eleven dimensional non-perturbative M -theory. Interestingly the emergent curvature on a pair of brane/anti-

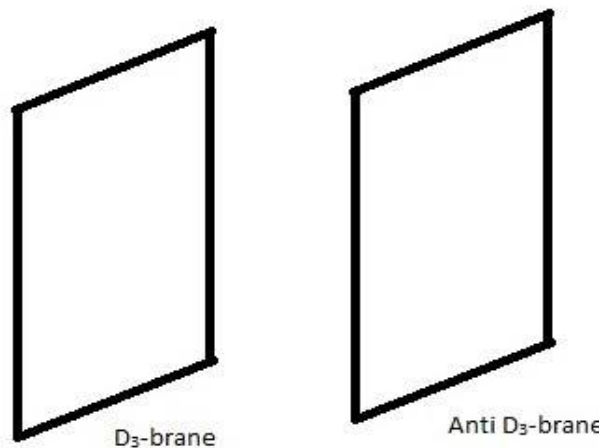
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brane was shown to be described by a geometric torsion in a string-brane model [12, 13, 14]. The model may be viewed as an attempt to explore the non-perturbative domain in quantum gravity underlying a string theoretic setup. Importantly the torsion geometry underlying a (4+1)-dimensional world-volume gauge theory was generalized to (5+1)-dimensional CFT to describe a gravitational pair of de Sitter ($4\bar{4}$)-brane universe [15, 16]. In principle the mechanism may be explored on a pair of $(D\bar{D})_9$ -brane at a strong coupling to gain insight into the conjectured M -theory. A preliminary investigation, using the brane/anti-brane production tool by a higher form, in an appropriate p-brane world-volume theory has been performed [17] to enhance our knowledge on the M-theory.

STRING-BRANE MODEL: DYNAMICAL NS FIELD: In the recent past the string-brane model underlying a geometric torsion was constructed to address a non-perturbative [18] quantum correction to the low energy string vacuum [12, 13, 14]. It was shown that non-BPS brane may well be described by a non-perturbative phenomenon leading to a vacuum created gravitational pair of $(D\bar{D})_3$ -brane by the KR quanta on a D_4 -brane at the cosmological horizon of a background de Sitter brane geometry. The absorption of the KR field in the five dimensional $U(1)$ gauge theory was shown to modify the covariant derivative, which in turn describes an emergent torsion curvature on a pair. Alternately, KR field local degrees have been transformed to project a dynamical NS field on a vacuum created non-BPS pair of $(D\bar{D})_3$ -brane which presumably defines our early universe. The momentum conservation ensures that the vacuum created gravitational 3-brane and $\bar{3}$ -brane cannot annihilate each other and defines a stable pair of (3+1)-dimensional brane/anti-brane universe. In fact, the cosmological creation of a pair of non-BPS $(D\bar{D})_9$ -brane in a different context was discussed by Majumdar and Davis [11]. Their work was primarily motivated to address the strong coupling regime in type IIA superstring leading to the M -theory. A brief outline to exploit the strength of a string-brane model for an enhanced understanding of the M -theory has been discussed in ref. [17]. It is worth mentioning that a pair of brane and anti-brane is known to break the supersymmetry and hence is described by a non-BPS brane. Past analysis has revealed that some of the non-BPS states are stable in superstring theories [19]. It was shown that the (open string) tachyon condenses on a non-BPS brane to describe a stable pair of $(D\bar{D})$ -brane [20].



In the context the vacuum refers to an open string background black hole on a D_4 -brane which is known to be sourced by a constant NS field [21] in the string bulk. The KR field quanta is believed to vacuum create a pair of $(1\bar{1})$ -brane instead of a charged pair of particle and anti-particle. Their stability favours an increase in the number of their spatial dimensions. Finally, they describe a space filling gravitational pair of $(3\bar{3})$ -brane underlying the (4+1)-dimensional world-volume gauge theory. The KR field dynamics is given by

$$S = -\frac{1}{12C_2^2} \int d^5x \sqrt{-G} {}^{(NS)}H_{\mu\nu\lambda} H^{\mu\nu\lambda}, \quad \text{where } C_2^2 = (8\pi^3 g_s) \alpha'^{3/2} \quad (1)$$

The significance of the constant NS field in addition to the local KR field has been addressed in an effective curvature formalism on a D_4 -brane [22, 23, 24, 12, 13, 14]. Importantly H_3 has been identified with a connection which in turn

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modifies the covariant derivative to \mathcal{D}_μ on a D_4 -brane. The mathematical construction implies an absorption of KR field quanta and hence the \mathcal{D}_μ describes a “fat” brane or a string-brane model. In other words the model evolves with a dynamical NS field at the expense of the KR field on a D_4 -brane. As a result the emergent pair of brane-universe is governed by a geometrical torsion:

$$H_{\mu\nu\lambda} = \mathcal{D}_\mu B_{\nu\lambda}^{NS} + \text{cyclic} = (H_{\mu\nu\alpha} B_{\lambda}^{(NS)\alpha} + \text{cyclic}) + H_{\mu\nu\beta} B_{\alpha}^{(NS)\beta} B_{\lambda}^{(NS)\alpha}$$

$$\text{Where } \mathcal{D}_\lambda B_{\mu\nu}^{NS} = \frac{1}{2} H_{\lambda\mu}^\rho B_{\rho\nu}^{NS} - \frac{1}{2} H_{\lambda\nu}^\rho B_{\rho\mu}^{NS}, \quad \nabla_\lambda B_{\rho\nu}^{NS} = 0. \quad (2)$$

It shows that the geometric torsion underlies a fat brane which breaks the supersymmetry. Thus it describes a non-BPS pair of emergent gravitational (33̄)-brane. The presence of string bulk due to the dynamical NS field ensures the closed string modes coupling to the otherwise BPS brane. Importantly, the geometric torsion in the string-brane model is exact and hence is non-perturbative. In addition, the $U(1)$ gauge invariance of a geometric torsion under a two form transformation has been realized in an effective space-time curvature formalism. A dynamical space-time without a torsion in 4-Dimensions has been argued to begin at a Big Bang singularity defined at a cosmological horizon. It is noteworthy to remark that the space-time curvature sourced by a geometric torsion in 5D naturally incorporates an intrinsic angular momentum on a vacuum created pair of $(D\bar{D})_3$ -brane. The world-volumes of a brane and an anti-brane are separated by an extra fifth dimension transverse to each other. It may imply that an observer in a D_3 -brane universe is inaccessible to an anti D_3 -brane universe or vice-versa. Nevertheless, the hidden effect of an anti D_3 -brane space-time via an extra dimension is indeed compelling on a 3-brane universe. Analysis may reveal that a brane universe geometry appears to be influenced by an axion which is a potential candidate to source the dark energy.

NON-PERTURBATIVE QUANTUM GRAVITY: EMERGENT METRIC

The commutator $[\mathcal{D}_\mu, \mathcal{D}_\nu]$ is worked out to yield a fourth order reducible torsion curvature tensor in a second order formalism [12] underlying a vacuum created gravitational pair of (33̄)-brane [13]. With an appropriate rescaling of $\frac{1}{2}\mathcal{H} \rightarrow \mathcal{H}$, the emergent torsion curvature tensor takes a form:

$$\tilde{K}_{\mu\nu\lambda}^\rho = \partial_\mu \mathcal{H}_{\nu\lambda}^\rho - \partial_\nu \mathcal{H}_{\mu\lambda}^\rho + \mathcal{H}_{\mu\lambda}^\sigma \mathcal{H}_{\nu\sigma}^\rho - \mathcal{H}_{\nu\lambda}^\sigma \mathcal{H}_{\mu\sigma}^\rho \quad (3)$$

The fourth order tensor is antisymmetric under an exchange of indices within a pair and is not sym-metric under an exchange of its first pair of indices with the second. It differs from the Riemannian tensor $R_{\mu\nu\lambda\rho}$. However for a non-propagating torsion $\tilde{K}_{\mu\nu\lambda\rho} \rightarrow R_{\mu\nu\lambda\rho}$. The irreducible torsion curvature scalar \tilde{K} is worked out on S^1 to describe a vacuum created gravitational pair of (33̄)-brane. Then, the local dynamics is approximated by two independent 4-Dim curvatures and is given by

$$S_{(3-\bar{3})} = \frac{1}{12\kappa^2} \int d^4x \sqrt{-g} K - 3 \bar{\mathcal{F}}_{\mu\nu} \mathcal{F}^{\mu\nu} \quad (4)$$

where $\mathcal{F}_{\mu\nu} = (\mathcal{D}_\mu A_\nu - \mathcal{D}_\nu A_\mu) = F_{\mu\nu} + \mathcal{H}_{\mu\nu}^\alpha A_\alpha$. The $U(1)$ gauge invariance of the Lorentz scalar \mathcal{H}^2 has been shown to incorporate a metric fluctuation $f_{\mu\nu}^a = C (2\pi\alpha') H_{\alpha\beta}^\mu \mathcal{H}_\nu^{\alpha\beta}$ to the background open string metric. It takes a form:

$$G_{\mu\nu} = (G_{\mu\nu}^{(NS)} + C \overline{\mathcal{H}}_{\mu\lambda\rho} \mathcal{H}_\nu^{\lambda\rho}) \quad (5)$$

where $B_{\mu\nu}$ signifies a constant NS field and appropriately couples to an electromagnetic field $F_{\mu\nu}^{linear}$ to retain the $U(1)$ gauge invariance. Thus $f_{\mu\nu}^a$ incorporates a non-perturbative correction to the open string metric established on a D -brane [21]. Interestingly a low energy limit in the string- brane model corresponds to a non-propagating geometric torsion and hence the emergent scenario on a pair of (33̄)-brane is described with a large extra dimension. Then a D -brane or an anti D -brane correction, sourced by a geometric torsion, may be ignored to describe Einstein vacuum in the string-brane model. A fact that a torsion is dual to an axion on a gravitational 3-brane ensures one degree of freedom. In addition $\mathcal{F}_{\mu\nu}$ describes a geometric one form field with two local degrees on a gravitational 3-brane. A precise match among the (three) local degrees of torsion in \tilde{K} on S^1 with that in K and $\mathcal{F}_{\mu\nu}$ reassure the absence of a dynamical dilaton field in the emergent metric scenario under S^1 compactification.

III. QUINTESSENCE

SCALAR DYNAMICS IN HIGHER DIMENSIONAL EINSTEIN GRAVITY: We revisit the domain of observational cosmology to reiterate a variable vacuum energy density in our universe. A time variation of

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cosmological vacuum energy density in the early epoch leading to a de Sitter geometry has been argued in the inflationary models [25, 26, 27]. Remarkably a hidden fifth essence, i.e. a quintessence, is known to describe a time varying spatially homogeneous cosmic density with a negative pressure and a positive energy density. Quintessence is indeed a potential candidate to describe the dark energy in our universe. In the recent past a slowly rolling time dependent scalar field is believed to describe the quintessence presumably due to its simplest form as a tensor field which couples minimally to Einstein gravity [28, 29]. The acceleration of universe is known to be parameterized by the cosmological equation of state: $\omega = P/\rho$, where $P = -T^i_i < 0$ and $\rho = T^0_0 > 0$ respectively define the pressure and energy density sourced by a scalar field. In the recent years the observational cosmology primarily focuses on the measurement of ω sourced by a quintessence. Its value is known to be bounded, i.e. $-1 < \omega < -1/3$.

AXIONIC SCALAR IN A GRAVITATIONAL PAIR: In the context the quintessence energy density underlying a five dimensional geometric torsion on S^1 has been explored in a string-brane model [12, 13, 14]. It was shown that the non-trivial torsion curvature scalar K has been shown to be sourced by a mass-less axion on an anti D_3 -brane. In particular, the action (5) underlying a vacuum created gravitational pair of $(3\bar{3})$ -brane reveals that the emergent 3-brane can be governed by a geometric Lorentz scalar F^2 while an anti 3-brane can be described by the curvature scalar K or vice-versa. Then the two within the three local degrees of the five dimensional NS field would like to describe an emergent metric fluctuation on a 3-brane. The remaining local degree underlying an axionic scalar on an anti-3-brane becomes hidden to the emergent (3+1)-dimensional brane universe. Thus a dynamical axion on an anti-brane indeed influences our brane-world. In other words, an axion may naturally be identified with a quintessence scalar in a string-brane model which describes a vacuum created gravitational pair of $(3\bar{3})$ -brane.

An extra fifth spatial dimension is transverse to the vacuum created gravitational pair of $(3\bar{3})$ -brane universe. It is known to be sourced by a higher dimensional gauge field and in the case it is a KR field on a D_4 -brane in a string-brane setup. An axion is Poincare dual to a torsion on a gravitational anti 3-brane and hence is inaccessible to an observer on a vacuum created 3-brane. The idea of a quintessence energy density sourced by an axion field on an anti-brane is remarkable. The dynamical aspects of an axion on a 3-brane universe may also be viewed via an extra fifth dimension in between the gravitational pair, which in turn is known to describe a Liouville scalar in string theory.

A fact that the dark energy permeates all the space and tends to enhance the rate of expansion of universe may be understood via an extra dimension between a vacuum created pair of $(3\bar{3})$ -brane. Hubble's law may be revisited to explain the receding of a brane universe from an anti-brane. The law states that the recessional speeds of a brane and anti-brane universes are proportional to the transverse distance between them. Since a vacuum created brane universe moves away from its an anti-brane in an opposite direction, it implies a repulsive gravity between them. The notion of repulsive gravity has been argued to be sourced by a quintessence scalar field in cosmology. It provokes thought to believe that an axion in a hidden anti-brane is realized through a geometric torsion which in turn is responsible for the repulsive gravity. In fact a repulsive gravity underlying a quintessence has been conjectured between a matter and anti-matter which may seem to be in conformity with the notion of a vacuum created pair of $(D\bar{D})_3$ -brane by a KR field quanta on a D_4 -brane. Interestingly an effective Schwarzschild de Sitter black hole obtained in a gauge choice for a non-propagating torsion in ref.[30] has been shown to describe a varying positive curvature scalar $R = 12/r^4$.

It further strengthens the presence of quintessence axion in a string-brane model. It may imply that the brane/anti-brane universe(s) at its vacuum creation, i.e. at the past horizon radius b with a Big Bang, was described by a constant curvature $R = 12/b^4 > 0$. Computations [31] have been performed to show that the quintessence kinetic energy can be ignored at the Big Bang and hence the equation of state reduces to $\omega = -1$. The result is in agreement with the value of ω known for a constant vacuum energy density [28, 29].

D-INSTANTON AS A QUINTESENCE: An axion in the Ramond-Ramond (RR) sector of type II superstring ensures the significance of a D -instanton in the string-brane model. Importantly a D -instanton is known to incorporate a non-perturbative correction in a perturbative string theory. In fact the universe was argued to begin at a past horizon with a Big Bang on a pair of $(D\bar{D})$ -instanton at an early epoch in de Sitter underlying a geometric torsion [12]. The hot de Sitter is believed to expand and the notion of a real time was incorporated subsequently into the geometry. The expansion of a pair of brane (or anti-brane) universe from its origin at the Big Bang singularity was argued to pass through a series of nucleation of a pair of D -instanton followed by higher dimensional pairs such as D -particle, D -string

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and D -membrane. The nucleation process stops when a pair of $(3\bar{3})$ -brane is created as the pair with a transverse fifth dimension completely fills the D_4 -brane world-volume.

In other words an instanton local degree on an anti D_3 -brane influences the world-volume of a D_3 -brane within a pair. Arguably the instantaneous effect of a D -instanton on a D_3 -brane is in agreement with the non-perturbative universe in $4D$. A quintessence axion, presumably on a vacuum created 3-brane, is argued to source an extra fifth dimension to our brane universe on a 3-brane with a vacuum pair. The curvature scalar K on a gravitational anti 3-brane may describe a quintessence axion and a geometric \mathcal{F}_2 governs the torsion curvature on a gravitational 3-brane. An accelerated and expanding universe in the present day cosmology may seem to be influenced by a growth in extra dimension between a brane and an anti-brane universes. The high energy torsion modes have been argued to decouple with a large fifth dimension and eventually a low energy brane universe may appear to decouple from the anti-brane in the limit. The decoupling of non-perturbative quantum effects may lead to describe Einstein vacuum in the string-brane model.

Furthermore the brane geometries have been shown to be sourced by an axionic scalar underlying a vacuum created gravitational pair of $(3\bar{3})$ -brane. They were argued to describe the degenerate vacua and the degeneracy is sourced by a string charge underlying a NS field in the string bulk [32, 33, 34]. In principle the degeneracy may seem to be sourced by a lower form obtained from a higher form on S^1 or on $S^1 \times S^1$. The degenerate brane vacua at string scale may intuitively be identified with the notion of lower dimensional D -brane within a higher dimensional brane. The quantum effects have been worked out to show that the low energy perturbative string vacuum receives a non-perturbative $5D$ -brane world-volume correction in the string-brane model. Axionic sourced quantum geometries are further analyzed for two larger length scales to qualitatively describe a laboratory black hole in a medium energy regime and a semi-classical brane universe in a low energy regime [34]. Analysis under the emergent metric scalings have been performed to explore the effective (Anti) de Sitter brane vacua in presence of non-perturbative correction(s). A quantum correction has been shown to be approximated by a varying energy density underlying an axionic quintessence.

Thus an axion quanta can vacuum create a pair of $(D\bar{D})$ -instanton which is the fundamental building block to describe a natural pair of $(D\bar{D})$ -string by the KR field quanta. The nucleation of a higher dimensional pair of brane/anti-brane ceases with a stable pair of $(D\bar{D})_3$ -brane underlying a five dimensional gauge theory.

IV. CONCLUDING REMARKS AND RESULTS

We have briefly reviewed a geometric construction underlying a string-brane model to address an unresolved puzzle in quantum cosmology. In particular the model has been known to incorporate a non-perturbative quantum correction to the low energy string vacuum. Schwinger pair production mechanism was invoked to argue for a vacuum created gravitational pair of $(3\bar{3})$ -brane at the cosmological horizon by a KR field quanta in the world-volume gauge theory on a D_4 -brane. A stable pair of brane and anti-brane universe has been known to be separated by extra transverse dimension(s) in a ten dimensional superstring theory. They are believed describe the transverse scalars hidden to our brane-universe. One such hidden scalar in a string-brane toy model has been identified with a dynamical axion on an anti 3-brane within a vacuum created pair. The axion was argued to describe the quintessence in the model which is believed to be a potential candidate for dark energy in our universe. However the quintessence axion in the string-brane model is known to source a D -instanton which in turn incorporates non-perturbative correction to our present day universe. At an early epoch, i.e. right after a Big Bang, our universe is believed to be influenced significantly by a non-perturbative quantum correction sourced by an axion in the string-brane model. Primarily the quantum corrections have been known to be described by a geometric torsion which forms a condensate in a low energy regime such as Einstein vacuum.

Furthermore the brane-world models have been successful to address the issues related to the cosmological inflation [25, 26, 27]. These models have been explored to describe the inflationary cosmology underlying a rapid accelerated expansion of our universe [30, 31]. Interestingly a quintessence axionic scalar dynamics is hidden or outside the $4D$ brane or anti-brane universe in the proposed string-brane model. The axion was argued to source a D -instanton which in turn incorporates a non-perturbative quantum correction to Einstein vacuum. An emergent pair of gravitational brane and anti-brane universe are non-BPS and they may be viewed via a spontaneous supersymmetry breaking phenomenon as they possess their origin in a supersymmetric or BPS D_4 -brane. Thus the massless KR field regains mass, and renamed as a NS field, in an emergent supersymmetry broken phase underlying the gravitational dynamics. The massive NS field further reassures Newtonian gravity which is indeed a non-relativistic limit in Einstein gravity.

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Intuitively, the dark energy sourced by boson(s) and the dark matter sourced by fermion(s) are intimately related by a plausible supersymmetry in a higher dimensional gauge theory. It was shown that a geometric torsion dynamics in a second order formalism leads to an effective space-time curvature scalar K on S^1 [12, 13, 14] which may ensure an underlying T-duality symmetry between the gauge theory and the emergent gravity dynamics. Nevertheless the novel idea leading to our proposition for an emergent, non-BPS, stable pair of gravitational 3-brane and anti 3-brane universe inspires thought and possibly sheds light to a non-perturbative formulation such as M -theory [17] and needs further attention in current literature. Our analysis signifying an emergent geometric torsion curvature, underlying a vacuum created gravitational pair of $(3\bar{3})$ -brane by a KR field quanta, appears to be an insightful tool to explore the cosmological domain related to the accelerated expansion of our universe.

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