

## NATURAL DYNAMICAL GENERATION OF ELECTRO-WEAK SPONTANEOUS SYMMETRY BREAKING IN THE POST-INFLATIONARY UNIVERSE

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In a remarkable paper from 1986 J. Bekenstein proposed the intriguing idea about a gravity-assisted spontaneous symmetry breaking of electro-weak (Higgs) type without invoking unnatural (according to Bekenstein's opinion) ingredients like negative mass squared and a quartic self-interaction for the Higgs field.

Motivated by Bekenstein's idea, in the present talk we will discuss a new non-standard model of gravity coupled to a neutral scalar "inflaton", as well as to a  $U(1)$ -charged  $SU(2)$  iso-doublet scalar field with a standard positive mass squared and no self-interaction, and to  $SU(2) \times U(1)$  gauge fields. Recall that the  $SU(2) \times U(1)$  scalar and gauge fields constitute the bosonic part of the electro-weak particle sector. The essential non-standard feature of our model is employing the formalism of non-Riemannian space-time volume forms – alternative generally covariant integration measure densities defined in terms of auxiliary antisymmetric tensor gauge fields independent of the pertinent Riemannian metric.

Although being pure-gauge degrees of freedom, the non-Riemannian space-time volume forms trigger a series of important features unavailable in ordinary gravity-matter models with the standard Riemannian volume-form (given by the square-root of the determinant of the Riemannian metric): (i) The "inflaton" develops a remarkable effective scalar potential in the Einstein frame possessing an infinitely large flat region for large negative values describing the "early" universe evolution; (ii) In the absence of the  $SU(2) \times U(1)$  iso-doublet scalar field, the "inflaton" effective potential has another infinitely large flat region for large positive values describing the "late" (post-inflationary) universe; (iii) Inclusion of the  $SU(2) \times U(1)$  iso-doublet scalar field introduces a drastic change in the total effective scalar potential in the post-inflationary universe – the total effective scalar field potential acquires exactly the celebrated electro-weak Higgs-type spontaneous symmetry breaking form.

The talk is based on an essay <http://arxiv.org/abs/1603.06231>, which received a *honorable mention* in *2016 Gravity Research Foundation Competition for Essays on Gravitation* ([http://www.gravityresearchfoundation.org/pdf/2016\\_Awards.pdf](http://www.gravityresearchfoundation.org/pdf/2016_Awards.pdf)).

**POSITIVE ENERGY UNITARY IRREDUCIBLE REPRESENTATIONS OF  
THE SUPERALGEBRAS  $osp(1|2n, R)$**

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We continue the study of positive energy (lowest weight) unitary irreducible representations of the superalgebras  $osp(1|2n, R)$ .

We update previous results and present the full list of these unitary irreducible representations.

## A COMPUTER TEST OF HOLOGRAPHIC FLAVOUR DYNAMICS

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Gauge/gravity duality is among the most important theoretical developments coming from string theory. In the original formulation of Maldacena, the duality relates string theory in the  $AdS_5 \times S^5$  background space-time to the large  $N$  limit of  $3 + 1$  dimensional  $N = 4$  Super-symmetric Yang-Mill theory living on the asymptotic boundary of the  $AdS_5$  space-time. This idea has inspired numerous extensions of the duality with ever increasing phenomenological relevance, currently ranging from heavy ion collisions to condensed matter physics. In this work we are interested in holographic flavour dynamics—the generalisation of the AdS/CFT correspondence to flavoured gauge theories.

The first such generalisation was proposed by Karch and Katz, who introduced a probe  $D7$ -brane to the  $AdS_5 \times S^5$  supergravity background. On the field theory side this corresponds to introducing an  $N = 2$  fundamental hypermultiplet in the quenched approximation. The classical dynamics of the probe brane is governed by an effective Dirac-Born-Infeld action. Remarkably the AdS/CFT dictionary relates the classical properties of the brane to quantum vacuum expectation values in the dual flavoured gauge theory. One such quantity is the fundamental condensate of the theory, which is encoded in the classical profile of the probe brane near the asymptotic boundary.

Testing the AdS/CFT correspondence requires an alternative nonperturbative approach and for a four dimensional gauge theory lattice simulations on a computer seem a natural approach. We perform computer simulations of the Berkooz-Douglas (BD) matrix model, holographically dual to the  $D0/D4$ -brane intersection. We generate the fundamental condensate versus bare mass curve of the theory both holographically and from simulations of the BD model. Our studies show excellent agreement of the two approaches in the deconfined phase of the theory and significant deviations in the confined phase. We argue the discrepancy in the confined phase is explained by the embedding of the  $D4$ -brane which yields stronger  $\alpha'$  corrections to the condensate in this phase.

## BLACK HOLE MICROSTATES IN STRING THEORY

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This talk addresses the problem of counting the black hole microstates within the framework of string theory. The particular example we take are super symmetric asymptotically AdS black holes in four dimensions and our description is in terms of a holographically dual field theory. We focus on a class of asymptotically AdS<sub>4</sub> static black holes preserving two real supercharges which are dual to a topologically twisted deformation of the ABJM theory. We evaluate in the large N limit the topologically twisted index of the ABJM theory and show that it correctly reproduces the entropy of the AdS<sub>4</sub> black holes. An extremization of the index with respect to a set of chemical potentials is required. We interpret it as the selection of the exact Rsymmetry of the superconformal quantum mechanics describing the horizon of the black hole.

## БАЗИС НА ГЕЛФАНД-ЦЕТЛИН ЗА КЛАС ОТ ПРЕДСТАВЯНИЯ НА СУПЕРАЛГЕБРАТА НА ЛИ $gl(n|n)$

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Нов, така наречен, нечетен базис на Гелфанд-Цетлин е въведен за неприводимите ковариантни тензорни представяния на супералгебрата на Ли  $gl(n|n)$ . Свързаните с това таблици на Гелфанд-Цетлин се базират на разложението по отношение на определена верига от подалгебри на  $gl(n|n)$ . Тази верига съдържа само супералгебри на Ли от вида  $gl(k|l)$  с  $k$  и  $l$  различни от нула (с изключение на крайния елемент на веригата, който е  $gl(1|0) = gl(1)$ ). Намерени са точни изрази за действието на множество от генератори на алгебрата върху този базис.

## ARE THE ELEMENTARY PARTICLES REALLY ELEMENTARY: OPE ALGEBRAS IN QUANTUM FIELD THEORY

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In Quantum Field theory (QFT) and in the theory of elementary particles two closely related notions are considered: composite fields and composite particles, respectively. In the field picture the compositeness is conceptually fully understood by the notion of Operator Product Expansion (OPE), which has been introduced by Nobel laureate Kenneth Wilson in 1964. Intuitively, the OPE describes the product of quantum fields at short distances in terms of other (composite) quantum fields. Afterwards, it has been realized that the OPE is a new algebraic structure, which itself can provide an alternative definition of QFT. In this talk I shall make a popular level review of the above mentioned basic notions, and in conclusion I shall briefly present a result of mine on this topic.

## QUINTESSENCE AND UNIFIED DARK ENERGY AND DARK MATTER

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Dark energy and dark matter, occupying around 70% and 25% of the matter content of the Universe, respectively, continue to be the two most unexplained “mysteries” in cosmology and astrophysics. In most loose terms dark energy is responsible for the accelerated expansion of today’s Universe, i.e., dark energy acts effectively as repulsion force among the galaxies – a phenomenon completely counterintuitive w.r.t. naïve notion about gravity as an attractive force. And vice versa, dark matter holds together the matter objects inside the galaxies. The adjective “dark” is due to the fact that both these fundamental matter components of the Universe interact only gravitationally, and they do not directly interact with ordinary (baryonic) matter, in particular, they do not interact electromagnetically and thus they remain “dark”.

There exist a multitude of proposals for an adequate description of dark energy’s and dark matter’s dynamics within the framework of standard general relativity or its modern extensions. On this topic our collaborative group has already certain non-trivial contribution through few joint publications in leading European physics journals. In the present talk we will briefly describe and further extend the basic features of our approach.

Using the method of non-Riemannian spacetime volume-forms (metric-independent generally-covariant integration measure densities) we first construct a new non-canonical cosmological model of gravity interacting with a single scalar field (“darkon”), which explicitly yields a self-consistent unified description of “dark energy” as a dynamically generated cosmological constant, and “dark matter” as a dust fluid flowing along spacetime geodesics, by unifying them as an exact sum of two separate contributions to the pertinent scalar field energy-momentum tensor. In other words, this unified description shows that “dark energy” and “dark matter” may be viewed as two different manifestations of one single matter source – the scalar “darkon” field.

Next, extending our formalism of non-Riemannian spacetime volume-forms, we couple the above non-canonical gravity-matter system to a second scalar field – the “inflaton” - in such a way that the “inflaton” dynamics provides a unified description of the evolution of both the “early” and “late” Universe – this is a model of “quintessence”. We exhibit in some detail the interplay between the “inflaton” and the “darkon” in the “early” (inflationary) and the “late” (dark energy dominated) epochs of the Universe.

## EINSTEIN-ROSEN “BRIDGE” REVISITED AND LIGHTLIKE THIN-SHELL WORMHOLES

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The celebrated Einstein-Rosen “bridge” in its original formulation from 1935 is historically the first example of a traversable gravitational wormhole spacetime. However, the traditional presentation of the Einstein-Rosen “bridge” in modern textbooks in general relativity *does not* correspond to its original formulation. The “textbook” version of the Einstein-Rosen “bridge” is physically inequivalent to the original 1935 construction as it represents both a non-static spacetime geometry as well as it is *non-traversable*.

Based on earlier works of ours we revisit the original Einstein-Rosen formulation from 1935. We find that the originally used local spacetime coordinates suffer from a serious problem – the pertinent spacetime metric in these coordinates possesses an essential unphysical singularity at the wormhole “throat” – the boundary between the two “universes” of the Einstein-Rosen “bridge” manifold.

We propose instead a different set of local coordinates for the Einstein-Rosen “bridge” such that its spacetime geometry becomes well-defined everywhere, including on the wormhole “throat”.

On the other hand, this reveals a very important *new feature of the correctly defined* Einstein-Rosen “bridge”, which was *overlooked in the original* Einstein-Rosen paper. Namely, we show that the correct construction of the Einstein-Rosen “bridge” as self-consistent solution of the corresponding Einstein equations requires the presence of a “thin-shell” “exotic” matter on the wormhole “throat” – a special particular member of the (originally introduced in other papers of ours) class of *lightlike membranes*.

In the present talk we will discuss briefly several crucial properties of the correct formulation of the original Einstein-Rosen “bridge” as a specific well-defined solution of wormhole type of gravity interacting self-consistently with a lightlike membrane matter: Lagrangian action principle; traversability of the Einstein-Rosen wormhole w.r.t. proper-time of travelling observers; Kruskal-Penrose formalism and maximal analytic extension of the Einstein-Rosen “bridge” manifold.

Finally, we will briefly illustrate the application of the above formalism to more complex physically interesting lightlike thin-shell wormholes with more than one wormhole “throat”, in particular – QCD-like electric flux confinement in “tube-like” wormholes.



## **COSMOLOGICAL ASPECTS OF A UNIFIED DARK ENERGY AND DUST DARK MATTER MODEL DUAL TO QUADRATIC PURELY KINETIC K-ESSENCE**

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Recently, a model of modified gravity plus single-scalar-field model was proposed by Guendelman et al., in which the scalar Lagrangian couples symmetrically both to the standard Riemannian volume-form given by the square-root of the determinant of the Riemannian metric, as well as to another non-Riemannian volume-form given in terms of an auxiliary maximal-rank antisymmetric tensor gauge field. This model provides an exact unified description of both dark energy and dark matter, because on the one hand, it dynamically generates a cosmological constant, and on the other – it features a “dust” fluid with geodesic flow as a result of a hidden Noether symmetry, which can be interpreted as a dark matter candidate. Here we apply this  $f(R)$  theory with two measures to cosmology and we report our first results.

## W4 TODA CFT EXAMPLE AND SOME APPLICATIONS

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There are few explicit results for the basic structures of the 2d conformal field theories (CFT) based on higher rank algebras. We construct some new examples of 3- and 4-point correlators for the W4 Toda CFT and use them to compute a class of braiding/fusing matrices. Possible applications of these results to the 4d models with superconformal symmetry  $sl(2, 2|4)$  in the context of the AdS5/CFT4 correspondence are discussed in the heavy and light charge classical limits. The 4-point Toda correlator admits an explicit integral representation which reveals a surprising relation to a correlator in the Liouville CFT with different central charge.

## QUANTUM ENTANGLEMENT OF PAIS-UHLENBECK OSCILLATORS

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We study the quantum entanglement of coupled Pais-Uhlenbeck oscillators using the formalism of thermo-field dynamics. The entanglement entropy is computed for the specific cases of two and a ring of  $N$  coupled Pais-Uhlenbeck oscillators of fourth order. It is shown that the entanglement entropy depends on the temperatures, frequencies and coupling parameters of the different degrees of freedom corresponding to harmonic oscillators. Finally, we advert to the information geometry theory by calculating the Fisher information metric for the considered system of coupled oscillators.

## META-CONFORMAL INVARIANCE AND THE BOUNDEDNESS OF TWO-POINT CORRELATION FUNCTIONS

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The covariant two-point functions, derived from Ward identities in direct space, can be affected by consistency problems and can become unbounded for large time- or space-separations. This difficulty arises for several extensions of dynamical scaling, for example Schrödinger-invariance, conformal Galilei invariance or meta-conformal invariance, but not for standard ortho-conformal invariance.

For meta-conformal invariance in  $(1 + 1)$  dimensions, these difficulties can be cured by going over to a dual space and an extension of these dynamical symmetries through the construction of a new generator in the Cartan sub-algebra. This provides a canonical interpretation of meta-conformally covariant two-point functions as correlators. Galilei-conformal correlators can be obtained from meta-conformal invariance through a simple contraction. In contrast, by an analogous construction, Schrödinger-covariant two-point functions are causal response functions. All these two-point functions are bounded at large separations, for sufficiently positive values of the scaling exponents.

## КОМПАКТНА КАРТИНА ЗА ПОЛЕВИ ТЕОРИИ С РАЗШИРЕНА СУПЕРКОНФОРМНА СИМЕТРИЯ

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За конформните теории на полето съществува удобно координатно описание, известно като компактна картина. То се осигурява от комплексна конформна трансформация (обобщение на изображението на Кейли), която изобразява реалното  $D$ -мерно пространство на Минковски в ограничено подмножество в  $D$ -мерното комплексно векторно пространство. В този доклад ще представим разширение на компактната картина за полеви теории със суперконформна симетрия.

## ON THE RENORMALIZATION GROUP FLOW IN GENERAL $su(2)$ COSET MODELS

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We consider a RG flow in a general  $su(2)$  coset model perturbed by the least relevant field. This is done using two different approaches. We first compute the mixing coefficients of certain fields in the UV and IR theories using a conformal perturbation theory. The perturbing field as well as some particular fields of dimension close to one are constructed recursively in terms of lower level fields. Using this construction we obtain the structure constants and the four-point correlation functions up to the desired order. This allows us to compute the anomalous dimensions and the aforementioned mixing coefficients. The same coefficients can be calculated using the RG domain wall construction proposed by Gaiotto. We compute the corresponding one-point functions and show that the two approaches give the same result in the leading order.

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Недановски, Д., 16  
Benini, F., 7  
Dimov, H., 14  
Dobrev, V., 5  
Filev, V., 6  
Furlan, P., 13, 18  
Guendelman, E., 4, 10, 11  
Hristov, K., 7  
Mladenov, S., 14  
Nikolov, N.M., 9  
Nissimov, E., 4, 10, 11  
O'Connor, D., 6  
Pacheva, S., 4, 10, 11  
Petkova, V.B., 13, 18  
Rashkov, R.C., 14  
Staicova, D., 12  
Stanishkov, M., 17  
Stoilov, M., 11, 12  
Stoilova, N.I., 8  
Stoimenov, S., 15  
Van der Jeugt, J., 8  
Vetsov, T., 14  
Zaffaroni, A., 7