Bulgarian Academy of Sciences
Institute for Nuclear Research and Nuclear Energy
Report for scientific and applied activities for 2014

Project Title	New Aspects in String Theory and Gravity
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Summary of activities and results for **2014**

During 2014 altogether **17 scientific papers with total impact-factor 40.37** have been published or accepted for publication, containing research on the topic of the current project.

Extended objects (strings and p-branes) are of primary importance for the construction of self-consistent unified modern theory of fundamental forces in Nature. In a series of previous papers we have proposed a new class of brane theories which are qualitatively distinct from the standard Nambu-Goto type brane models and provide a systematic lagrangian description of ***lightlike*** branes. As it is well known lightlike branes are of substantial interest in general relativity as they describe impulsive lightlike signals arising in various violent astrophysical events, e.g., final explosion in cataclysmic processes such as supernovae and collision of neutron stars. Lightlike branes also play important role in the description of various other physically important cosmological and astrophysical phenomena such as the "membrane paradigm" of black hole physics and the thin-wall approach to domain walls coupled to gravity. More recently they became significant also in the context of modern non-

perturbative string theory.

Another closely related and actively developed topic is the study of gravity, including its higher nonlinear extensions (the so called f(R)-gravity models), interacting with a special brand of nonlinear electrodynamics containing the square-root of standard Maxwell Lagrangian. It is known that in flat spacetime (i.e., in the absence of gravity) the latter describes charge confinement analogous of quark confinement in quantum chromodynamics.

In our recent papers [1-6] devoted to the above topics we have obtained a variety of physically interesting results:

(a) In our paper [1] we have obtained a new physically interesting solution describing an electrovacuum gravitational shock wave. Specifically, we study the ultra-relativistic limit (Aichelburg-Sexl-type ultra-relativistic boost) of the previously obtained by us new non-standard Reissner-Nordström-type black hole solution which is non-asymptotically flat and carries a non-trivial constant vacuum radial electric field apart from the standard Coulomb piece (such electric fields do not exist in ordinary charged black holes). We show that unlike the standard Reisnner- Nordström black hole, where the Coulumb electric field does not contribute in the ultra-relativistic limit, in the present case the constant radial vacuum component persists in the ultra-relativistic limit and as a result it generates a new type of electrovacuum gravitational shock wave confining charged test particles (both massive and massless) within a finite distance from its front.

(b) In paper [2] we study a new type of system containing "nonlinear" R^2 gravity generalizing the standard Einstein's general relativity, which is coupled to a special kind of a non-canonical nonlinear electrodynamics known to produce in flat space-time a QCD-like confining potential between charged fermions. We find the following new physically interesting features: (i) appearance of a constant vacuum radial electric field in charged black holes within Reissner-Nordstroem-de-Sitter-type and/or Reissner-Nordstroem-anti-de-Sitter-type space-times, in particular, in electrically neutral black holes with Schwarzschild-de-Sitter and/or Schwarzschild-anti-de-Sitter geometry (let us stress that constant vacuum radial electric fields do not exist in standard Maxwell electrodynamics); (ii) novel mechanism of dynamical generation of cosmological constant through the nonlinear gauge field; (iii) appearance of a QCD-like confining effective potential in charged test particle dynamics in the above black hole backgrounds. We also obtained new solutions for compactified "tube-like" universes of Levi-Civita-Bertotti-Robinson type. Furthermore, in paper [2] by deriving the effective "Einstein frame" reformulation of the original "nonlinear" R^2 gravity system (within first-order Palatini formalism) we succeeded to obtain further physically relevant effects: (i) phase transition "confinement-deconfinement" triggered by the appearance of a "flat region" in the pertinent effective scalar dilaton potential leading to deconfinement, whereas in other complementary regions of the effective dilaton potential charge confinement remains intact; (ii) we obtain effective variable gauge coupling constants (in particular - a variable strength of confinement) as well as effective variable cosmological constant, both depending on the strength of the dynamically generated dilaton vacuum expectation value; (iii) we obtain a dynamical generation of conventional Maxwell kinetic term for the gauge field even if absent in the original theory, i.e., we find a dynamical appearance of physical photon particles

as a commulative effect of the special type of gravity and gauge field nonlinearities.

(c) The principal result in paper [3] is the proposed qualitatively new mechanism for dynamical spontaneous breakdown of supersymmetry. Specifically, we consider a modified formulation of standard minimal N=1 supergravity. The modification is based on an idea worked out in detail in previous papers by our Israeli collaborators, where they propose a new formulation of (non-supersymmetric) gravity theories employing an alternative volume form (volume element, or generally-covariant integration measure) in the pertinent Lagrangian action, defined in terms of auxiliary (pure-gauge) fields instead of the standard Riemannian volume form. Invariance under supersymmetry of the new modified N=1 supergravity action is preserved due to the addition of an appropriate compensating antisymmetric tensor gauge field. We find as a result of the above modification, that a non-zero cosmological constant is naturally produced as an integration constant when solving some of the relevant (supersymmetric) equations of motion. It is this dynamically generated cosmological constant which signifies a dynamical spontaneous breakdown of supersymmetry in the supergravity context.

(d) In papers [4-6] we have proposed a new model of gravity plus matter defined in terms of two independent non-Riemannian volume forms on the pertinent spacetime manifold. The initial Lagrangian action is constructed in such a way that is invariant under global Weyl-scale transformations. As a result of spontaneous breakdown of global Weyl-scale symmetry and upon passing to the physical "Einstein-frame" we find the following remarkable effects: (i) We obtain an effective potential for the cosmological scalar field possessing two infinitely large flat regions, which allows for an unified description of both the "inflationary" phase of the early Universe as well as the current "dark energy"-dominated epoche; (ii) For a specific range of the parameters of the model we find a non-singular solution of an "emergent" universe, which describes an initial phase of a non-singular (no "Big-Bang") beginning/creation of the Universe preceding the era of "inflation". One of the main features of the new approach in the theory of cosmological evolution proposedin [4-6] is the prediction (under minimal plausible assumptions) for the values of some fundamental magnitudes such as the energy scale of "inflation" and the scale of the cosmological energy density in the current "dark energy"-dominated epoche, which match the recent much talked about experimental data of Planck Collaboration.

An investigation of collapsing spheres of anisotropic fluids with heat flow, representing models of collapsing and radiating stars in astrophysics, has been initiated. The main equations are the junction conditions at the surface of the star. The collapse of anisotropic fluid spheres towards black holes or naked singularities and Minkowski spacetime has been studied in the most general situation – when there is shear, expansion and acceleration and the metric has 3 different components, functions of time and distance from the centre of the sphere. Different solutions have been found.

In paper [7] we study how rapid rotation influences the relation between the normalized moment of inertia I and quadrupole moment Q for scalarized neutron stars. The questions one has to answer are whether the equation of state universality is preserved in this regime and what the deviations from general relativity are. Our results show that the $I - Q$ relation is nearly equation of state independent for scalarized rapidly rotating stars, but the differences with pure Einstein's theory increase compared to the slowly rotating case. An important remark is that although

the normalized I − Q relation may not differ much between scalar-tensor theories and general relativity, the unnormalized moment of inertia and quadrupole moment can be very different in the two theories.

In papers [8] and [10] we investigate non-perturbatively and self-consistently the structure of both static and slowly rotating neutron stars in R-squared gravity by simultaneously solving the interior and exterior problem. The mass-radius relations are obtained for several equations of state and for wide range of the R-squared gravity parameter *a*. Even though the deviation from general relativity for nonzero values of a can be large, they are still comparable with the variations due to different modern realistic equations of state. That is why the current observations of the neutron star masses and radii alone cannot put constraints on the value of the parameter *a*. On the other hand the neutron star moment of inertia can be up to 30% larger compared to the corresponding general relativistic models. This is much higher than the change in the maximum mass induced by R-squared gravity and is beyond the EOS uncertainty. In this way the future observations of the moment of inertia of compact stars could allow us to distinguish between general relativity and f (R) gravity, and more generally to test the strong field regime of gravity.

In paper [9] the orbital and epicyclic frequencies of particles orbiting around rapidly rotating neutron and strange stars are studied in a particular scalar-tensor theory of gravity. We find very large deviations of these frequencies, when compared to their corresponding values in general relativity, for the maximum-mass rotating models. In principle, such deviations could become important in models of quasi-periodic oscillations in low-mass x-ray binaries and could serve as a test of strong gravity (if other parameters are well constraint). In addition rapidly rotating scalarized equilibrium compact stars with realistic hadronic and strange matter equations of state are presented for the first time. We also provide analytical expressions for the exterior spacetime of scalarized neutron stars and their epicyclic frequencies in the nonrotating limit.

It was shown recently, that normalized relations between the moment of inertia (I), the quadrupole moment (Q) and the tidal deformability (Love number) exist and for slowly-rotating neutron stars they are almost independent of equation of state (EOS). In paper [11] we extend the computation of the I-Q relation to models rotating up to the mass-shedding limit and show that the universality of the relations is lost. With increasing rotation rate, the normalized I-Q relation departs significantly from its slow-rotation limit deviating by about 40% for neutron stars and up to 75% for strange stars. The deviation is also EOS dependent and for a broad set of hadronic and strange matter EOS the spread due to rotation is comparable to the spread due to the EOS if one considers sequences with fixed rotational frequency. Still, for a restricted sample of modern realistic EOS one can parametrize the deviations from universality as a function of rotation only. In astrophysical situations involving compact objects rotating faster than a few hundred Hz, the previously proposed I-Love-Q relations should thus be used with care.

In paper [12] we develop an approach for solving the string equations of motion and Virasoro constraints in any background which has some (unfixed) number of commuting Killing vector fields. It is based on a specific ansatz for the string embedding. We apply the above mentioned approach for strings moving in AdS_3 x S^3 x T^4 with 2-form NS-NS B-field. We succeeded to find solutions for a large

class of string configurations on this background. In particular, we derive dyonic giant magnon solutions in the R_t x S^3 subspace, and obtain the leading finite-size correction to the dispersion relation.

In paper [13] we consider strings moving in the R_t x S^3_eta subspace of the \eta-deformed AdS_5 x S^5 and obtain a class of solutions depending on several parameters. They are characterized by the string energy and two angular momenta. Finite-size dyonic giant magnon belongs to this class of solutions. Further on, we restrict ourselves to the case of giant magnon with one non-zero angular momentum, and obtain the leading finite-size correction to the dispersion relation.

In paper [14] we derive the 3-point correlation function between two giant magnons heavy string states and the light dilaton operator with zero momentum in the \eta-deformed AdS_5 x S^5 valid for any J_1 and eta in the semiclassical limit. We show that this result satisfies a consistency relation between the 3-point correlation function and the conformal dimension of the giant magnon. We also provide a leading finite J_1 correction explicitly.

Modeling of singularities that represent distributions or non-differentiable functions by means of generalized functions of Colombeau has proved useful in attacking a series of physical problems such as geodesic gravitational waves, hyperbolic systems with discontinuous functions as boundary conditions and others. That algebra of generalized functions allows both such modeling and algebraic operations with singularities; moreover the so called ‘association process’ allows us to obtain results for singular products of Schwartz distributions.

In paper [15] the method described above is applied to studying series of singular distributional products in multidimensional case in the framework of Colombeau algebra. The results are obtained for discontinuous functions and derivatives of Dirac δ-function that exist as Schwarz distributions.

Paper [16] deals with products of generalized functions of Colombeau that model distributions with singular support in a point on the real line. Applying the idea of balanced products, the results are obtained as regular Schwarz distributions.

The compact massive objects (black holes, neutron stars, white dwarfs and exotic objects) are of extreme importance to the modern astrophysics, because of their role in the one of the most powerful processes in the Universe -- the astrophysical jets. For the complete description of such violent processes one needs to solve the complete equations of Einstein -- a system of 10, strongly non-linear partial differential equations -- for which one needs the use of supercomputers and dedicated numerical codes, for which the static case is usually used as an initial condition. The minimal dilatonic gravity is an alternative theory of gravity in which one introduce a scalar field (the dilaton) and a scalar potential, a function of the dilaton. Trough the introduction of the dilaton, one can vary the gravitational constant and also the cosmological constant. This way, one gets a theory which is locally equivalent to the well-known f(R) theories, but globally has different properties. Using the MDG, we solve the field equations in the case of perfect fluid with a polytropic equation of state, in order to describe non-rotating neutron stars and white dwarfs. The work in this case has been done in collaboration with prof. Plamen Fiziev from JINR, Russia and Dr. Antionios Tsokaros and prof. Luciano Rezzolla from ITP, Germany. It is planned the publication of an article on the white dwarfs case, as well as continuation of the

collaboration in the next year.

We also continue the study of the quasinormal modes -- complex frequencies describing the perturbation of the Kerr metric in late times, which is a still very popular subject due to its relevance to the physics of the gravitational waves. We are preparing 2 articles on this subject, one of which already published as a preprint [17] to be submitted to a journal, and the second one is currently in preparation.

[iR1]

Publications for **2014**:

1. E.I. Guendelman, **E. Nissimov** and **S. Pacheva,** *"Charge-Confining Gravitational Electrovacuum Shock Wave",* Mod. Phys. Lett. A 29 (2014) 1450020 [ISSN: 0217-7323, IF=1.11].

2. E.I. Guendelman, A. Kaganovich, **E. Nissimov** and **S. Pacheva,** *"f(R)-Gravity: Einstein Frame Lagrangian Formulation, Non-Standard Black Holes and QCD-like Confinement/Deconfinement",* to appear in Proceedings of the X International Workshop "Lie Theory and Its Applications in Physics", ed. V. Dobrev, "Springer Proceedings in Mathematics and Statistics", Vol. 111 (Springer, Tokyo, Heidelberg) [ISSN 2194-1009, ISBN 978-4-431-55284-0].

3. E.I. Guendelman, **E. Nissimov**, **S. Pacheva** and M. Vasihoun**,** "*A New Mechanism of Dynamical Spontaneous Breaking of Supersymmetry",* Bulg. J. Phys. 41 (2014) 123-129 [ISSN: 1310-0157] .

4. E.I. Guendelman, **E. Nissimov** and **S. Pacheva,** *"Unification of Inflation and Dark Energy from Spontaneous Breaking of Scale Invariance"*, arxiv:1407.6281 [hep-th], to appear in *"Eighth Mathematical Physics Meeting"*, B. Dragovic and Z. Rakic (eds.), Belgrade Inst. Phys. Press, 2015 [ISBN 978-86-82441-30-4].

5. E.I. Guendelman, A.Kaganovich, **E. Nissimov** and **S. Pacheva,** *"Emergent Cosmology, Inflation and Dark Energy from Spontaneous Breaking of Scale Invariance"*, arxiv:1408.5344v2 [gr-qc], talk at *Miami 2014 Topical Conference on Elementary Particles, Astrophysics and Cosmology.*

6. E.I. Guendelman, R. Herrera, P. Labrana, **E. Nissimov** and **S. Pacheva,** *"Emergent Cosmology, Inflation and Dark Energy from Gravity-Matter Model with Two Non-Riemannian Spacetime Volume Forms"*, arxiv:1408.5344v4 [gr-qc], to appear in General Relativity and Gravitation, [ISSN: 0001-7701, IF 1.902]

7. Doneva, D. D., Yazadjiev, S. S., Staykov, K. V., and Kokkotas, K. D., "*Universal I-Q relations for rapidly rotating neutron and strange stars in scalar-tensor theories*", **Phys. Rev. D 90, 104021 (2014) , ISSN: 1550-7998, IF: 4.864.**

8. Staykov, K. V., **Doneva, D. D.,** Yazadjiev, S. S., and Kokkotas, K. D., "*Slowly rotating neutron and strange stars in R^2 gravity"*, **J. Cosmology Astropart. Phys. 10, 006 (2014), ISSN 1475-7516, IF: 5.877.**

9. Doneva, D. D., Yazadjiev, S. S., Stergioulas, N., Kokkotas, K. D., and

Athanasiadis, T. M., "*Orbital and epicyclic frequencies around rapidly rotating compact stars in scalar-tensor theories of gravity"*, **Phys. Rev. D 90, 044004 (2014) , ISSN: 1550-7998, IF: 4.864.**

10. Yazadjiev, S. S., **Doneva, D. D.**, Kokkotas, K. D., and Staykov, K. V., "*Non-perturbative and self-consistent models of neutron stars in R-squared gravity*" , **J. Cosmology Astropart. Phys. 6, 003 (2014), ISSN 1475-7516, IF: 5.877.**

11. Doneva, D. D., Yazadjiev, S. S., Stergioulas, N., and Kokkotas, K. D., "*Breakdown of I-Love-Q Universality in Rapidly Rotating Relativistic Stars"*, **ApJ 781, LL6 (2014)** , **ISSN: 0004-637X, IF: 6.405.**

12. Changrim Ahn, **Plamen Bozhilov**, *String solutions in AdS_3 x S^3 x T^4 with NS-NS B-field ,* **Phys. Rev. D90 , 066010 (2014), ISSN 1550-7998, IF 4.691.**

13. Changrim Ahn, **Plamen Bozhilov**, *Finite-size giant magnons on eta-defrmed AdS_5 x S^5,* **Phys. Lett. B737 293-297 (2014), ISSN 0370-2693, IF 4.569.**

14. Changrim Ahn**, Plamen Bozhilov,** *A HHL 3-point correlation function in the eta-deformed AdS_5 x S^5,* arXiv:1412.6668 [hep-th].

15. B. Damyanov, *"Results on balanced products of the distributions x^a in Colombeau algebra G(Rm)",* C. R. Acad. Bulg. Sci. **67** (2014) 1310-1331 [ISSN 1045-1052, IF 0.211]

16. B. Damyanov, *"Results on generalized models and singular products of distributions in Colombeau algebra G(R)",* Comment. Math. Univ. Carolinae., [ISSN 0010-2628]. /letter by editor/ FA: arXiv:1007.1568

17. D. Staicova, P. Fiziev, "New results for electromagnetic quasinormal and quasibound modes of Kerr black holes", arxiv:1412.4111 [astro-ph.HE]

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