Appendix 1

New paradigms for fundamental structure of matter
Description of the project and the research programme

1. Status of research in Bulgaria in the relevant research field (1 page)

The main motivation of this interdisciplinary and inter-institutional project comes from modern string theory as a unified theory of the interactions between elementary particles at superhigh energies. The two main pillars on which is based string theory are quantum field theory and relativistic gravity and cosmology (Einstein's theory of relativity and its modern generalizations), which in turn are closely intertwined with the research at the forefront of almost all branches of modern mathematics (algebraic and differential geometry, topology, functional analysis, group theory, number theory, etc.)..

Senior members of the staff of this project are leading Bulgarian scientists of international reputation in the field of theoretical and mathematical physics. They have major contributions in several actively developed worldwide scientific fields such as quantum conformal field theories in two or more space-time dimensions, study of nonperturbative properties of string theory of the fundamental interactions at ultrahigh energies - gauge-gravity duality and integrable structures, mathematical structures of string theory, the latter implications in cosmology and astrophysics, the role of conformal symmetry in the physics of condensed media, algebraic aspects and geometric structure of integrable dynamical systems.

The scientific papers (more than 1500 in number) of the members of the team cover the whole range of issues related to this project and were published mainly in the world's leading international scientific journals with high impact factor in the field of physics and mathematics. The results have been reported (some in plenary talks) at hundred prestigious international conferences and have been cited more than 12,000 times in the papers of foreign scholars, including - from leading experts.

2. Relevance of the scientific problems in Bulgaria and Europe (1 page)

The most significant event in the development of string theory in the last 15-16 years is the concept / hypothesis "holographic" duality between gauge theories and gravitation (gauge/gravity duality). In this context, string theory at strong coupling appears to be dually equivalent to field theory at weak coupling and vice versa, which means that the gauge-gravity "holography" is a crucial tool for understanding the physics of quantum gauge systems at strong coupling, where perturbation theory is not applicable. Particularly impressing are the new developments - deep connection between string dynamics and integrable systems (solitons), its applications to study quantum chromodynamics (highly correlated quarks, collisions of ultrarelativistic heavy ions, quark-gluon plasma), relativistic hydrodynamics (fluid dynamics as dynamics black holes horizons), and condensed matter physics ("holographic" superconductors, quantum Hall effect). The mathematical aspects are an important bond of our interdisciplinary team. This reflects the global trend of the use of the latest achievements of mathematics in quantum field theory and string theory in particular. Conversely, the development of modern branches of mathematics constantly receives fresh ideas from the development of string theory. This global trend is present in Bulgaria long time ago, it is represented here by the project participants.

Recent developments in quantum field theory and especially in string theory led to the discovery of unsuspected deep connections with modern information theory, which dramatically transformed the latter theory into a new fundamental scientific field called "relativistic quantum information", with huge potential for physics and technology of the future. One of the main objects that arises in studies of quantum theory in the postmodern period, reflecting its inherent non-locality, is the so-called entanglement of quantum states. Such states occur in a very wide range of physical models arising in various areas of physics. The investigation of possible relativistic effects concerning entangled states may have potential applications in many different areas of physics, including condensed matter physics, high energy processes in atomic and nuclear physics, physics of elementary particles, gravity and cosmology. Entangled states could serve as a natural explanation for the mysterious fact that space-time manifolds with horizons have physical entropy. Among such space-time manifolds are black hole. Along with these cutting-edge research, quantum theory is the tool for the study of current problems of particle physics, such as the internal spin structure of nucleons at high energies.

3. Description of the coordinator organization INRNE and the partner organization the Faculty of Physics of Sofia University (2 pages)

Institute for Nuclear Research and Nuclear Energy (INRNE) at BAS was founded in 1972. It is the leading research institute in Bulgaria in the field of fundamental and applied research in particle physics, nuclear physics, high energy physics, nuclear radiochemistry, radio ecology, environmental monitoring, nuclear instrumentation and many other areas related to applications of nuclear physics and its methods. The institute employs about 270 people, of whom 135 are researchers working in seven scientific fields, 16 laboratories, two scientific experimental facilities and 8 joint institute departments. Teams of INRNE scientists work together with scientists from leading research centers like CERN, JINR Dubna, the Joint Research Centre of the European Commission (EC), laboratories and universities around the world. INRNE scientists have participated in projects under the Fifth, Sixth and currently under the Seventh Framework Programme of the EC. INRNE is sought and respected partner in major projects funded by the EC. By the number of contracts and current European projects INRNE ranks among the first in the Academy. The successful integration of INRNE scientists in the international research area is due to their competence and adequate support from the Institute. There is a fast internet connection, as well as opportunities for numerical calculations - along with modern PCs access is provided to a computer cluster and the network GRID. The Institute has the administrative capacity to support many local and international research projects. Much of the scientists who will work on the proposed project are employees of the Laboratory "Theory of elementary particles" in INRNE. It is the undisputed leader in Bulgaria in theoretical research in elementary particle physics at high and ultrahigh energies. The intellectual capacity of the Laboratory and INRNE infrastructure guarantee the successful implementation of the work program of the proposed project.

Sofia University "St. Kliment Ohridski "is the first Bulgarian university. Today Sofia University is the largest and most prestigious educational and scientific center in the country. The University educates students in all three levels of education and performs research in the natural, mathematical and social sciences and humanities. Its structure comprises 16 faculties, 3 Departments and numerous research centers and laboratories. In Sofia University work much of the best Bulgarian specialists in all areas of natural and mathematical sciences and humanities. By the number of teachers and students, theoretical and practical achievements, national influence, international contacts, library and information services, facilities and equipment and opportunities, as well as the success of graduates, Sofia University is comparable to the best universities in Europe and is one of the leaders in Southeastern Europe. The intellectual potential of the people of the Department "Theoretical Physics" and the infrastructure of the Physics Department are sufficient guarantee for the implementation of the program for this project.

4. Description of the work programme of the project

This project is designed as a comprehensive and multidisciplinary, offering basic research in a wide range of fields of modern theoretical physics. The project is aimed at priority "3. New materials and technologies, including research in chemistry, physics and engineering sciences ", and more specifically - fundamental research in particle physics and astrophysics with a focus on contemporary aspects of quantum field theory and relativistic gravity in the context of string theory.

There are several main objectives:

(A) significant expansion of current knowledge of the nature of the fundamental forces in nature and the structure of matter, both in the world of elementary particles and at the galactic scale, with rigorous scientific description based on modern quantum field theory, relativistic gravity and several branches at the forefront of mathematics.

(B) Contribution to solving the cardinal problems of modern physics with a global ideological significance – the issues of "supersymmetry", "extra space-time dimensions," "dark matter" and "dark energy" of the Universe.

(C) Along to the purely scientific goals, an important goal is the development of young professionals. The project is focused enough to act as a basis for fruitful education of young scientists and to contribute to the preparation of highly qualified professional realization in such important innovation of science and technology of the future as "relativistic quantum informatics" and "new energy sources based of subnuclear and relativistic-gravitational processes. "

4.1. Research objectives

Due to the wide-ranging character of the planned research we plan its implementation to be organized in four working groups operating in close cooperation and exchange of expertise.

4.1.1 Working Group "Duality between quantum gauge field theories and gravity"

The conceptually new ideas of gauge-gravity duality lead to the following questions in the focus of the scientific community: What are the relations between the main characteristics of the two fundamentally different theories defined in spaces of different dimensions? How to build a gravity dual description of a gauge theory that has phenomenological meaning? Of main interest is the example of quantum chromodynamics (QCD), in which it is impossible to find analytically the spectrum of mesons and hadrons using the standard methods of field theory. To what extent is it possible to use the duality in the opposite direction, i.e., to study strongly-interacting gravitational system via a dual weakly-interacting gauge theory? Progress in this direction could revolutionize our understanding of black holes, which present are known to be widespread in the universe. Important for the applications is the study of holographic models of field theories allowing dynamic symmetry breaking, for example of chiral symmetry. This topic is important for understanding how to generate the mass of elementary particles in the Standard Model. Other types of important issues that currently can be studied only by holographic methods are the properties of quark-gluon plasma and high-temperature superconductors.

Two-dimensional conformal field theories (CTP) are among the main technical tools of string theories. However, the actual applicability of these theories, that are based on the representation theory of infinite-dimensional algebras, to the detailed description of strings on curved spaces as AdS_5 (5-dimensional anti-de Sitter space) remains an open question. In this respect it is important to develop CTP of algebras of higher rank, and their supersymmetric analogues.

The above mentioned important issues motivate several key objectives in this working group:

a) To find and investigate string solutions holographically dual to gauge operators. This includes finding anomalous dimensions and correlation functions in the dual theories in four, three and two dimensions. To this end will be developed some new methods and approaches to calculate the holographic characteristics of the theories;

b) Investigation of the holographic dual theories in the presence of topological defects (vortex type, etc..) and gauge theories with borders.

c) qualitative and quantitative study of the so-called. S-duality relating theories with inverse coupling constants via two-dimensional conformal theories, the so-called membrane engineering and string theory.

d) To develop methods for building and investigating gravitational duals of theories exhibiting spontaneous chiral symmetry breaking. Especially interesting for phenomenology are duals of gauge theories with two dynamical scales. Such duals can also play an important role in building models of Inflationary Cosmology, which predict non-negligible primordial gravity waves.

From here follow the following specific research objectives:

(1) Calculation of correlation functions in gauge theories at strong coupling via the holographic correspondence;

(2) Developing method(s) to calculate the holographic features as anomalous dimensions and correlation functions based on integrable models.

(3) Study of the holographic duality in the case of gauge theories with boundary and topological defects, incl. calculating the entropy of the holographically entangled states, study of the encoding of the information for the theory of higher dimensionality in the theory of lower dimensionality.

(4) Studies of duality in 3 - and 4-dimensional Yang-Mills theories embedded in spaces of higher-dimensionality from the viewpoint of the two-dimensional conformal theories.

(5) Development and application of (super) conformal theories to the description of the vertex operators and their correlators.

(6) Study of the relationship between modular invariance of two-dimensional theories

and the transformation strong/weak coupling in the generating functional of Nekrasov.

(7) To develop a systematic method for investigating the stability of gravitational duals of spontaneous chiral symmetry breaking.

(8) To build models of Inflationary Cosmology that produce non-negligible primordial gravity waves, by using gravitational duals with two dynamical scales.

String theory is conceived as an all-embracing theory, ("theory of everything"), and therefore it incorporates elements of nonrelativistic quantum mechanics. Thus, naturally is occurring the direction "nonrelativic holography", where the symmetry is the Schrödinger group - the largest group of symmetry of the Schrodinger equation. The role of the group in the nonrelativistic Schrödinger holography has a natural mathematical framework – either as contraction of the conformal group to the Schrödinger group or by embedding of the Schrödinger group in the conformal group of higher dimension. The latter approach provides a direct relation of the nonrelativisic holography with Einstein's theory, as the properties of the Schrödinger group are encoded in the metric of the corresponding curved space. This is used to connect the black holes of the Kerr-AdS with nonrelativistic quantum mechanics, to consider nonrelativisic conformal field theory, of the "AdS / cold atoms" correspondence, there variants of supersymmetric IIB string with Schrödinger symmetry, supersymmetric nonrelativisic geometries in M-theory, and others are considered.

4.1.2 Working Group "Physics of black holes and space-time portals - thermo-dynamics, entropy and quantum entanglement; gravity and supersymmetry"

In recent years the theory of black holes is undergoing rapid development and has obtained unexpected results. There were constructed multidimensional solutions (background geometries) having the horizon of events which exhibit qualitatively new properties compared to the known black holes in usual 4-dimensional space-time. In five dimensions there is the possibility for diverse topologies of the horizon. The latter changes the notion of sufficient set of physical data that fully define a black object.

The basic idea here is to investigate quantum fields in the presence of horizons and cosmological horizon, to find the density matrix and hence to calculate the entropy of the entangled states comparing it with the entropy calculated by the methods of quasi-quantum gravity.

Other no less important gravitational objects are so-called space-time portals ("wormholes") connecting by "short-cut" two or more universes with different space-time geometry or “short-cutting” two very distant regions of the same universe with non-trivial topology. In some solutions of type "wormholes" spacetime contains closed time-like curves, which means "traveling back in time" - one of the most spectacular outstanding paradoxes in the history of science. From information- theoretic point of view the existence of closed time-like curves would violate the Church-Turing thesis.

In this project we shall examine a wide range of interesting physical space-time portals – so-called "thin-shell wormholes", whose "mouths" (or "tunnel") between the various universes are realized by a special kind of matter called "light-like membranes." It is known that light-like membranes are of fundamental interest in general relativity, where they describe light-like impulse signals arising from catastrophic astrophysical events. They play an essential role in a number of other important cosmological and astrophysical phenomena, including - in the "membrane paradigm" of the physics of black holes and in the membrane approach to the problem of gravitational domain walls. Recently light-like membranes began to play an important role in the context of modern string theory of fundamental forces of nature. Here it is important to note that for every static observer in a particular universe in the global space-time manifold with one or more membrane light-like portals, a portal to the next universe looks exactly like the horizon of a black hole. This gives grounds to apply approaches analogous to the above-mentioned to study the thermodynamic properties and quantum entropy in the case of entangled light-like "thin-shell wormholes".

Another important issue is the shock gravitational waves mainly because of their key role in the description of impulsive ultrarelativistic signals in general relativity, in the high-energy scattering of matter at the Planck scale and in energetic collisions of ultrarelativistic heavy ions. Members of the team already have interesting results in this area - new type electro-vacuum gravitational shock wave confining electro-charged matter at finite distance from the wave front.

One of the main paradigms of modern elementary particle physics and cosmology is the spontaneous breaking of supersymmetry – a fundamental symmetry unifying the building blocks of matter with integral spin (bosons) and half-integral spin (fermions). Team members already have interesting results in this area – they proposed qualitatively new mechanism of dynamical spontaneous breaking of supersymmetry in the context of supergravity, in which is realized a prototype of expected physically significant properties of matter in today's era of evolution of the universe – a very small observable cosmological constant and at the same time – a very large mass of the gravitino - the supersymmetric partner of the graviton. Further studies on the subject, especially having in mind the strong international competition require non-trivial concentration of efforts and expertise of the team members.

There is the possibility that these theoretical considerations will be supported by experimental data in the near future, as the tasks of the Large Hadron Collider (LHC) at CERN includes both the discovery of extra space-time dimensions and the observation of microscopic black holes and space-time portals.

The main scientific goals of this working group can be formulated compactly as follows:

(a) Analytic construction of black lens solutions and study of their properties, Hawking radiation and thermodynamics.

(b) Obtaining the spectrum of quasinormal modes of different physically important and interesting solutions describing black holes, and on the basis of the obtained results conclusions to be drawn about the stability of the studied objects. Study of the relation of quasinormal modes with quantum properties of space-time.

(c) Study of entangled quantum states occurring in quantum dynamics of scalar, vector, spinor fields and of Yang-Mills fields in non-trivial space-times - in the vicinity of black holes, in cosmological models, and in spacetimes with light-like membrane portals .

(d) Investigation of the potential applications of light-like membrane matter to modern cosmological scenarios of type "membrane universes".

(e) Exploring new types of shock gravitational waves, incl. collisions between such waves and possible processes of creation and annihilation of pairs of particles, analogous to the Schwinger mechanism.

(f) Development and testing of a cardinal new mechanisms for dynamic spontaneous breaking of supersymmetry corresponding to the modern understanding of the structure and evolution of the Universe.

4.1.3 Working Group "Quantum field theory and quantum computers"

Research will be focused on the study of different (space-time and internal) symmetries and statistics, naturally occurring in modern quantum field theory, as well as on general theoretical problems as quantization and renormalization. This area provides interesting possibilities for practical applications such as (topological) quantum computers or powerful renormalization methods as those due to Connes and Kreimer.

The main efforts will be focused on the ultimate determination of the braid statistics of the experimentally observed Hall state with filling factor $\nu_H = 5/2$ which is the best candidate for the physical realization of a topological quantum computer. To this end the methods of conformal quantum field theory will be used to determine the conductivity and the Seebeck coefficient in the regime of sequentially tunneling electrons in the single-electron transistor geometry. Research will show whether this Hall state is in the universality class of the Pfaff model, the anti-Pfaff model or the 331 model. During the second stage we shall use the methods of quantum information theory to study the algorithms for the error correction in topological quantum computers realized on the basis of stabilizer codes, Kitaev's toric code and surface codes. Research will establish the thresholds for error correction for Abelian anions in case of information loss. A problem that will be tackled will be to estimate the dependence of the Seebeck coefficient for the Hall state with $\nu_H = 5/2$ from the temperature, the Aharonov-Bohm flow and the potential of the gate of single-electron transistor formed by two quantum point contacts.

In quantum information theory quantum systems consisting of chains of interacting qubits (particles with spin 1/2) are studied. Such systems will be discussed and proposed as communication channels for the transmission of quantum states. In this context we shall examine the question of transfer of perfect states.

Certain physical problems related to generalized statistics lead to interesting algebraic relations between (quantum-group) symmetry and combinatorical objects. Quantizing the $SU(n)_k$ Wess-Zumino-Novikov-Witten (WZNW) model naturally arises an (associative) algebra of so-called zero modes responsible for the "internal" symmetry of the model which is of quantum group type. When the deformation parameter q is not a root of unity, the Fock representation of this algebra defines a model (i.e., a direct sum of all irreducible representations with multiplicity one) of $U_q(sl_n)$. In the WZNW case, however, $q^{2(k+n)} = 1$ and the structure of the Fock representation is a complex combinatorial problem which we plan to attack.

The causal approach of Epstein and Glaser is the most rigorous and conceptually complete approach to the construction of perturbative models of interacting quantum fields. Many well-known models like e.g. conformal invariant supersymmetric ones, are not formulated in this approach. Using the method of Epstein-Glaser we plan to study first a simplified model of massless Wess-Zumino with a self-interacting supersymmetric chiral field, and later the very topical N = 4 supersymmetric gauge model. At the second stage we plan to build Batalin-Vilkoviski models in the causal approach in conjunction with the operator realization. Another aspect are the methods for calculating Feynman diagrams of massless theories in the configuration space. In the recent years special interest has been assigned to the calculation of the renormalization invariant of Feynman diagrams called residuum. In the first phase of the project methods for calculating residua of primitively divergent diagrams will be developed, and in the second we shall work on methods for calculating residua of nonprimitively divergent diagrams.

4.1.4. Working Group "Mathematical aspects - group-theoretical and geometric approaches to quantum field theory and string theory"

Currently, the leading edge of the group-theoretic approach is expressed both in the development of the representation theory of different symmetry objects and in the continuous expansion of the spectrum of these objects. In representation theory the important tasks are explicit description of the representations of the known symmetry objects, especially of superalgebras and quantum groups , of intertwining operators between these representations, the relationship of representation theory to the problems of integrability, etc. These tasks are closely related to applications in string theory and can be formulated as follows:

(i) Obtaining explicitly the characters of superconformnata algebra, especially in the case of N = 4, where we consider the integrable supersymmetric Yang-Mills theory.

(ii) Description of the intertwining differential operators, especially at the points of the holomorphic representations of the so-called Euclidean Jordan groups of which so far only the conformal group is studied in detail.

The natural connection of the Hamiltonian of a quantum system with Lie superalgebras (LSs) leads to the important fact that the state space of the system is an irreducible representation of the corresponding LS. So far, only rather simple unitary representations of LSs (namely Fock type representations) have been constructed and studied in this context. In the frame of this project, we plan to construct other classes of unitary representations, and study the physical properties of the corresponding systems - energy spectra, spectrum of position and momentum operators, classical limits of solutions, including the deformed case.

Since parastatistic Fock spaces are related to combinatorial algebra, by the Kadeishvili theorem of homotopy transfer, the ring of cohomologies of the algebra of parastatistical creation operators is enriched with higher priducts and acquires the structure of homotopy (commutative associative) algebra. Will be attacked the problems of finding explicit formulas for higher products of the homotopy algebra and of using the crystal limit of quantum deformation of this construction to derive the combinatorial algebra of (selfconjugated) Young tableaux.

4.1.5 Methodology

The interdisciplinary nature of the proposed research defines the great variety and range of arsenal of powerful methods and approaches from the leading edge of modern theoretical physics and mathematics: nonperturbative approaches in quantum field theory; renormalization theory of ultraviolet divergences; nonperturbative methods in string theory; modern mathematical concepts and approaches in general relativity; methods from the theory of integrable systems (soliton theory) and Hamiltonian dynamical systems with constraints; methods of differential geometry and topology; algebraic geometry; methods from group theory - representation theory, incl. representations of infinite-dimensional Lie algebras; abstract algebra and number theory; methods of the theory of special functions.

More specifically, the methodology of the research project includes the following:

(a) Construction of exact analytical solutions of black objects in multi-dimensional space-time will be performed with the aid of methods for generating the exact solutions developed by S. Yazadzjiev and methods of the theory of integrable systems. For cases where analytical solutions can not be constructed the field equations will be solved numerically.

(b) For the examination of quasinormal modes will be used mainly direct methods for integrating a time independent wave equations for the field perturbations.

(c) For treatment of systems of gravity and gauge-field matter, interacting self-consistent with a light-like membrane matter, we shall use methods from the theory of dynamical systems with constraints in order to explore extended objects with world-volume reparametrization invariance.

(d) Entangled states and entropy will be studied with the methods and techniques of local quantum field theory in curved space-time.

(e) In the study of gauge-gravity duality will be used the methods developed by team members, and also by leading scientists in the field, including methods of string theory, integrable systems, algebraic and differential geometry, Lie groups and algebras and their representations, techniques and methods of gauge theories and of two-dimensional conformal models.

(f) For the calculation of the characters of superconformal algebras will be used the most recent developments in the theory of representations, incl. ones developed by team members.

4.2 Types of activities

The main types of activities of the team will be in several main directions:

(A) Research on expert level on the scientific tasks detailed above, both within individual workgroups, and taking advantage of the already established close and fruitful collaborations with scientists from prestigious universities and other academic institutions abroad;

(B) Preparing and publishing the research results obtained under the work program in prestigious refereed international journals with impact factor;

(B) Preparing and delivering reports, incl. invited plenary talks, presenting the results of the project in different international scientific events - conferences, workshops and schools for young scientists;

(D) Preparation and publication of the full text of the talks at international conferences in the corresponding Proceedings;

(D) Delivery of seminar reports on the results obtained and on the current progress in the scientific objectives of the project, regular research seminars at INRNE, at the Faculty of Physics of Sofia University "St. Kl. Ohridski", at other academic institutions, which will further contribute to the development of the young professionals of the team;

(E) Preparation and delivering courses of lectures for MSc and PhD on contemporary aspects of quantum field theory, relativistic gravity and their mathematical apparatus, focusing on the problems and achievements in this project with a view to their application in high energy physics and relativistic quantum informatics.

(G) Organization of the 11-th issue of the already internationally prestigious international workshop (school for young scientists) "Lie Theory and Its Applications in Physics", Varna, June 2015.

4.3 Expected Results

The results of the planned basic research will contribute to the long-term programme of the international community of researchers in the field of particle physics and high energy, astrophysics and cosmology searching for **answers to such important conceptual scientific problems** as the nature of "dark matter" and "dark energy "in the Universe, the existence of extra dimensions of space-time, supersymmetry, microscopic black holes and space-time portals, solving the ubiquitous "information paradox", in controlling the powerful energy processes at subnuclear level. In particular, we expecte contributions to the rigorous proof of the validity of the hypothesis of a holographic duality between quantum gravity and gauge theories, which in turn, particularly through a new fundamental concept of holographic entanglement entropy, has a huge impact on the development of relativistic quantum informatics. The full proof of the hypothesis of gravity-gauge duality in its impact on all areas of physics will be far beyond the context of high energy physics and will be similar to the revolution in physics in the beginning of the last century with the establishment of the theory of relativity and quantum mechanics.

We expect the following essential results:

(1) New classes of exact solutions describing rotating black holes with different topology, "membrane" universes with space-time portals in more than four dimensions, and new types of shock gravitational waves.

(2) New significant physically mechanisms for dynamic spontaneous violation of supersymmetry - the modern theoretical models of the structure and evolution of the Universe.

(3) Spectrum of the quasinormal modes of static asymptotically non-flat black holes and determination of their stability.

(4) Spectrum and other characteristics of the quantum Hawking radiation for asymptotically non-flat black holes, deeper understanding of the relationship of entangled states with the entropy of black holes and the problem of "data loss".

(5) Obtaining new correlation functions in gauge theories with different supersymmetry at strong coupling constant.

(6) Study of the holographic correspondence in spaces of non anti-de Siter type.

(7) Study of holographic correspondence related to Schrödinger (super) algebras.

(8) Obtaining of correlation functions in systems with boundaries and calculating basic characteristics such as "holographic entropy of entanglement".

(9) Obtaining explicit formulas for the characters of superconformal algebra in the case of supersymmetric Yang-Mills theory.

(10) Study of chains of interacting qubits which will lead to the provision of communication channels for the transmission of (perfect) quantum states.

4.4 Potential for further development of the scientific group executing the project

The research related to the project will expand existing knowledge with new significant results in the described areas. Professional experience and the results will be used in future fundamental research of the group since project topics in quantum field theory, relativistic gravity and the fundamental mathematics will be hot also in the next decade.

In this context, to illustrate the cardinal importance of fundamental theoretical research in science, it must be noted that the recent discovery at CERN of the elusive until recently scalar Higgs boson – besides the fact that it is a spectacular and impressive achievements of genius creativity and ingenuity of experimental physicists and high technology, it is, after all, just a brilliant confirmation of the predictions of theoretical physicists from nearly 50 years ago!

Another important aspect concerning the further development of the group, is the fact that this project will give the younger members of the research team valuable international experience in science, which is crucial for their future development as researchers. After completion, the young scientists will have acquired the skills to adapt to the highly competitive and creative environment typical of European and global research area.

An important consequence of the successful completion of the project will be the consolidation of the fruitful cooperation of the scientific team with leading scientists and groups in the world working in similar research areas.

Success of the project will surely increase the interest among students to the subject of the research team, which will allow us to attract the most talented of them to choose careers in the fundamental areas of physics and mathematics, where recently there has been a dangerous outflow of young people - to the risk of collapse of the genetic link between scientific generations and loss of positions and gained international prestige of the Bulgarian school in theoretical physics and fundamental mathematics.

Younger members of the team will develop their research potential and teaching ability to train future scientists. By recruiting, training and developing of new scientists the project will be a valuable contribution to the core mission of the Sofia University "St. Kliment Ohridski" and INRNE BAS.

4.5 Potential for transfer of knowledge and applicability of the results

4.5.1. Let us remind here the astronomical observations widely discussed in recent years, incl. studies of over 200 000 galaxies, which reaffirm the accelerated expansion of the Universe - in 2011 the Nobel Prize in Physics was awarded for the experimental confirmation of this acceleration. But the reason for this – the unknown mysterious dark energy" is still awaiting its theoretical explanation.

Let us also recall that the standard model of fundamental interactions between elementary particles at high energies, although until now with brilliant experimental confirmation of its predictions, describes only about 4% of the matter in the known universe, and leaves a significant number of unsolved problems of the universe fundamental structure - including the so-called grand unification of forces of nature, supersymmetry, "why gravity is so weak."

The main value of the expected new results is to acquire new knowledge about the structure and behavior of matter at ultramicroscopic and galactic distances. These results will be a significant contribution to the efforts of the world scientific community in the field of particle physics and high energy, astrophysics and cosmology to decipher "mystery" of the cardinal problems of modern physics with a global worldview significance - "supersymmetry", "extra space-time dimensions", "black holes and space-time portals (" time travel"), "dark matter" and "dark energy" in the Universe.

4.5.2 Transfer of knowledge - application in the educational sphere

Relativistic quantum informatics is one of the most important areas of science and technology of the future. Since (the transmission of) information is a physical process of interaction between the detectors and the physical systems, the contemporary information theory, not only must describe quantum detectors, but also those moving at velocities near the speed of light, and more generally - in curved space-time due to gravitational effects. From this it becomes obvious the extreme topicality of the building of modern courses competitive at European level for masters and doctoral students, taking into account recent developments in quantum field theory and relativistic gravity.

In particular, we plan the following courses for students and doctoral candidates:

1) Course on holographic duality between strings and gauge theories ;
2) Course in supersymmetric gauge theories and Seiberg-Witten theories;
3) Courses on mathematical methods used in the planned research;
4) Courses on quantum information, quantum calculus and quantum logic;

5. Plans for dissemination of results

These studies will be conducted within a broad international cooperation with world renowned and leading institutes and universities around the world, which is an excellent habitat for the wide dissemination of the results of this project. In particular, it provides part of the project participants to visit established foreign groups working in similar areas. During these visits they will deliver talks presenting the research results of the project, and thus will be carried out valuable exchang of expertise. Such events are crucial not only for raising the prestige of Bulgarian science in the world, but are also essential elements in building up the international reputation of our young scientists.

Incomplete list of active or recently completed international collaborations of team members through bilateral or multilateral research agreements, at the European level: :

(a) COST Action MP-1210 "The String Theory Universe" (2013-2017);

(b) COST Action MP-1304 "Exploring Fundamental Physics with Compact Stars" (2013-2017);

and at institutional and/or international level:

(1) Austria - Erwin Schrödinger Institute for Mathematical Physics (ESI), Vienna; Institut für Hochenergiephysik der Universität Wien;

(2) Belgium - University of Ghent;

(3) France - C.E.A. Saclay (Gif-sur-Yvette), Institut des Hautes Etudes Scientifiques (Bur-
sur-Yvette); Université de Paris-Sud (Orsay), Ecole Polytechnique (Palaiseau), LAPP (Annecy); Université Paul Sabatier (Toulouse); Université Henri Poincaré (Nancy); Institut de Recherche Mathematique Avancée CNRS et Université de Strasbourg; Centre de Physique Théorique (Marseille);

(4) Germany - Institut für Theoretische Physik der Universität Göttingen; Technische Universität Clausthal; Max-Planck Institut für Mathematik in den Naturwissenschaften, Leipzig; Institut für Theoretische Physik der Justus-Liebig-Universität, Giessen; Institut für Theoretische Physik der Universität Hamburg; Eberhard Karls Universität Tübingen, Carl von Ossietzky
Universität Oldenburg

(5) Greece - Aristotle University of Thessaloniki;

(6) Ireland - Dublin Institute of Technology;

(7) Israel - Ben-Gurion University (Beer-Sheva);

(8) Italy - I.C.T.P. and S.I.S.S.A. (Trieste), University of Trieste; Rome University "Tor Vergata" & INFN;

(9) Japan - Osaka Prefecture University;
(10) Republic of Korea - Ewha University (Seoul);
(11) Russia - J.I.N.R. (Dubna);
(12) Switzerland - Theory Group of C.E.R.N. (Geneva); University of Geneva;
(13) United Kingdom - Imperial College, London;
(14) United States of America - Pennsylvania State University (Abington).

We expected that all results obtained within the project will be published in the most prestigious international refereed journals with impact factor such as Physical Review D, Physical Review Letters, Journal of High Energy Physics, Nuclear Physics B, Physics Letters B, Communications in Mathematical Physics, Journal of Mathematical Physics, International Journal of Modern Physics A, Classical and Quantum Gravity, General Relativity and Gravitation, and/or Proceedings of prestigious international scientific events.

Another important opportunity for the dissemination of research results on the topic of the project is their reporting at prestigious international scientific events (conferences, workshops, schools). It is here that the financial support of the project from the Fund will be crucial. In addition, members of our team have extensive experience in organizing numerous international conferences, workshops and schools in quantum field theory, mathematical physics, group theoretical methods, including quantum groups, superstrings, supergravity, integrable systems, which meetings have always been on very high level and were attended by a large number of world-renowned specialists. We expect the same high scientific level to be maintained at the planned for June 2015 in Varna International Conference and School on the subject of this project, of which the organizing committee will include a significant number of members of our team.

6. Project management.

The proposed project will have highly effective management and organizational structure similar to those that have already successfully functioned for previous projects with NSF and other (international) cooperations with the participation of almost all members of this team.

Project members have extensive experience in various scientific and organizational activities; they have been organizing many international conferences, members of the Standing Committee of the existing European networks and the scientific committees of international conferences.

Organization implementing the project will include:

(A) Management Board which will be responsible for the scientific strategy of the project, the organization of conferences in the proposed areas for research and for making important decisions regarding the implementation of the project in the financial part.
Project Manager: Corresponding member of BAS, Prof., Dr.Sci. Valentina Petkova (INRNE-BAS);
Team Coordinator INRNE-BAS: Corresponding member of BAS, Prof., Dr.Sci. Emil Nisimov;
Coordinators team Faculty of Physics of Sofia University: Prof. Dr.Sci.. Stoytcho Yazadjiev and Prof. Dr.Sci. Radoslav Rashkov;
Team coordinator responsible for organizing international events on the subject of the

project: Prof. Dr.Sci. Vladimir Dobrev (INRNE BAS);
Techn. Secretary: Virginia Doseva (INRNE-BAS)

(B) Meetings of members of the project. In addition to regular meetings of the members of each of the 5 working groups, it is planned once in 2 or 3 months all project members to hold joint meetings where they can discuss current problems in the performance of specific tasks, and coordinate the cooperation and interaction between the different working groups.

(C) Weekly seminars: The partners of the project have traditional regular scientific seminars, which will be extended to all participants, so that they can report the results obtained so far on the project.

(D) Lectures: We plan lecture courses for master and doctoral students in the Faculty of Physics of Sofia University. Their goal is the training of students and young scientists at the highest level, to enter the forefront of research in the proposed project areas.

(E) Visits of prominent foreign scientists in the participating organizations shall be used for informal meetings that would allow direct contact between the guests and students and young scientists.

(F) Website: We plan maintenance of a website with regular updates to inform partners of seminars, lectures, defense of dissertations and other events and activities related to the project.

(G) International Workshop series "Lie Theory and Its Applications in Physics": V. Dobrev plans to organize 11th Workshop in June 2015. This series of international scientific events has already gained considerable popularity in many leading scientific countries. The goal is for students and young scientists to come into direct contact with prominent members of the international scientific community in the proposed areas of research. Among other benefits of such a prestigious international event is the organization of a poster session for the young scientists.

(H) We plan to conduct regular open meetings of the Board once or twice a month, at which will be discussed progress in the work of each member of the team, as well as problems encountered in the course of work. At these meetings will be resolved ongoing organizational issues such as travel, participation in conferences of team members, financial management and others.