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ABSTRACTS

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Plenary Session

B. Allen

Max Planck Institute for Gravitational Physics, Hannover, Germany

Direct observation of gravitational waves from the merger and inspiral of two black holes

This talk describes the advanced LIGO observations of gravitational waves emitted by the final few orbits and merger of two black holes. I present our main results, as well as some of the "behind the scenes"details of the 14 September 2015 discovery, and briefly describe our 26 December 2015 detection of somewhat weaker gravitational waves from a similar system. The consistency of these observations with the predictions of General Relativity, and our expectations for the second observing run O2 (which began at the end of 2016) and for future observing runs are also discussed. [B.P. Abbott et al., Phys. Rev. Lett. 116, 061102 (2016); Phys. Rev. Lett. 116, 241103 (2016); Phys. Rev. Lett. 116, 22110; Ann. der Physik 529, No. 1-2, 1600209 (2017)]

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R. Blandford

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On the formation of relativistic jets: observation, simulation and theory

Recent and forthcoming observations using mm VLBI of M87 and other AGN confirm that jet formation and collimation happens on scales smaller than 10 gravitational radii. Numerical simulations using 4D relativistic MHD show how this may happen at the fluid level when the power is extracted electromagnetically from a spinning massive black hole. However, we do not have a good understanding of how the emitting electrons and positrons are accelerated and where. Simulations using a variety of simple prescriptions for the particle acceleration and transporty are “observed” and compared with the observations. Further application of this approach to 3C279 is also described.

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Nonlinear dynamics of shock and detonation waves in gases

Detonations are supersonic combustion waves composed of an inert shock followed by an exothermal reaction zone. They were discovered in laboratory experiments about 150 years ago. They concern safety (especially of nuclear power plants), future propulsion (detonation engine) and the explosion of stars (supernovae SN I) that is not yet well understood. The internal structure of the planar wave was understood mid of the last century. Since that time, experiments have shown that typical detonations are not plane and that, most of the time, their dynamics is very complex, involving strongly transient phenomena and multidimensional structures of the shock front. Even though they are extensively studied experimentally and numerically since more than half a century, these phenomena remained poorly understood. Nonlinear analyses explaining the complex dynamics of detonation waves are very recent. I shall present in this lecture the theoretical results of the last few years, focusing the attention on the physical aspect, skipping the mathematical details. I am very pleased to give this lecture at the Ginzburg Conference 2017 in Moscow, particularly because pioneering researches in detonations were performed in this city.

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Yu. Gefen

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Physics at the Edge: Quantum Phase Transitions at the Edge of Topological Materials

Much of the non-trivial low energy dynamics of topological systems takes place at the edge. Here we will focus on the edge of two-dimensional materials and show how quantum phase transitions at the edge may give rise to spontaneous symmetry breaking and the emergence of non-trivial textures at the edge. We will discuss this broad topic vis-à-vis two examples.

Our first example concerns with time reversal invariant topological insulators. They epitomize the concept of "topological protection". The latter is responsible for a host of observable phenomena, and represents a class of materials that could be employed to design quantum computing devices. Wang, Meir, and Gefen have recently shown that such topological protection could be spontaneously broken, raising severe questions on the robustness of such systems.

The second example (Khanna, Murthy, Rao, Gefen) concerns two-dimensional electron gas in the regime of the integer quantum Hall effect ($\nu = 3$). Varying the electrostatic potential at the edge may lead to a new type of quantum phase transitions: spin switching transitions, and the formation of novel spin textures at the edge.

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RG flows as dynamical systems

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Asymptotic symmetries in gravity: the Hamiltonian approach

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I. Khriplovich

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Positron production in collision of heavy nuclei

We consider the electromagnetic production of positron in collision of slow heavy nuclei, with the simultaneously produced electron captured by one of the nuclei. The cross-section of the discussed process exceeds essentially the cross-section of e^+ e^- production.

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E. Peik

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Testing invariance of the fine structure constant with atomic clocks

Optical clocks based on different atoms and ions are now reported with systematic uncertainties in the low $10^{-}18$ range, and experiments based on frequency comparisons and precise measurements of frequency ratios allow for improved tests of fundamental physics, especially quantitative tests of relativity and searches for violations of the equivalence principle. The 171Yb+ optical clock that is based on the extremely narrow S-F electric octupole transition possesses a favorable combination of small systematic uncertainty and high sensitivity for such tests because of the strongly relativistic character of the excited state. In comparisons of the 171Yb+ single-ion clock and a 87Sr optical lattice clock at PTB we have performed improved tests for temporal variations of the fine structure constant and for its coupling to the solar gravitational potential. In both cases, previous limits from clock-based experiments could be made more stringent by more than an order of magnitude. A future nuclear clock based on the low-energy transition in Th-229 that is investigated in our group may further increase the sensitivity of such tests.

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Towards an accurate and efficient description of cosmic Large-Scale Structure

Statistical properties of the matter distribution at cosmological scales carry a wealth of information about the constituents of the universe, its expansion history and primordial state. However, this information is concealed by the complicated non-linear dynamics of the structure formation. Extracting it requires development of accurate and efficient theoretical methods for the description of the gravitational clustering in the standard LambdaCDM cosmology and its extensions.

I will present a novel analytic approach to this problem called “Time-Sliced Perturbation Theory”. The central object of the method is the time-dependent probability distribution function generating correlators of the cosmological observables at a given moment of time. Its perturbative expansion leads to a diagrammatic technique similar to that of quantum field theory. The formalism is manifestly free from spurious infrared divergences plaguing traditional approaches and allows a systematic resummation of infrared contributions that are important for the accurate description of the baryon acoustic feature in the galaxy correlation function. The impact of short-scale perturbations that evolve in deeply non-linear regime on the large scale structure of the universe is taken into account using the ideas of the renormalization group and effective field theory. In addition, this approach provides a link between the cosmological perturbation theory and the statistics of large non-perturbative deviation through a kind of "semiclassical" expansion.

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A. Starobinsky

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Inflation: present status and future perspectives

Present knowledge about physical properties of the simplest models of an inflationary stage in the early Universe in GR and f(R) gravity (curvature, its rate of change, inflaton mass, etc.) which follow from the latest observational data is reviewed and possibilities to find out anything new about it are discussed. Existing data on the primordial spectrum of scalar (density) perturbations suggest to go further and to reconstruct slow-roll inflationary models phenomenologically using some additional assumptions, mainly aesthetic ones, about the form of the spectrum in the region of smaller scales and its smooth behaviour at low space-time curvature. I remind an old result on the reconstruction of the inflaton potential in GR, obtained without expanding the power spectrum in a power series at some scale, and generalize it to the case of f(R) gravity. From what can be discovered in the future, the most fundamental are primordial quantum gravitational waves generated during inflation. It is argued that the measured value of the slope $n_s - 1$ of the primordial scalar power spectrum, under natural additional assumptions, implies small, but not too small tensor-to-scalar ratio of powers of the perturbations $r \sim 3(1-n_s)^2 \sim 0.0004$ or more, similar to that in the original $R + R^2$ inflationary model (1980). Another possible discovery is related to small local features in the CMB temperature anisotropy power spectrum in the multipole range $l = (20 - 40)$ beyond which new physics during inflation may be hidden. Also discussed is the question how generic is the onset of inflation from generic curvature singularity preceding it in GR and f(R) gravity, and which conditions are needed for it. It seems that, for inflation to begin inside a patch including the observable part of the Universe, causal connection inside the whole patch is not necessary. However, it becomes obligatory for a graceful exit from inflation in order to have practically the same number of e-folds during inflation inside this patch. Thus, the fact that inflation does not "solve"the singularity problem, i.e. that it does not prohibit a less symmetric stage with even higher curvature preceding it, can be an advantage, not a weakness.

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V. Volpert

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Nonlinear dynamics of reaction-diffusion waves

We will present in this lecture the classical theory of reaction-diffusion waves and its recent developments. It will be illustrated by various examples from combustion theory, population dynamics and biomedical applications.

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High Energy and Plasma Astrophysics

M. Avillez

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Ionization structure and emission due to non-thermal particles in regions of particle acceleration

In general the ionization structure and emission of plasmas is calculated assuming that the particles involved in the processes have a Maxwellian distribution. However, this may not be the case in the regions where particle acceleration occurs. Therefore, the determination of the ionization structure and the emission of the plasma requires the calculation of all the rates associated to ionization, recombination, charge exchange, and excitation/deexcitation processes using non-thermal distributions and the cross sections of the different processes. The excitation/deexcitation by proton and electron impact requires the use of the collision strengths available in the literature (a small number) or newly calculated for the purpose. A summary of this work and of results obtained thus far is presented.

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The origin of the X-ray-emitting object moving away from PSR B1259-63

A mysterious X-ray-emitting object has been detected moving away from the high-mass gamma-ray binary PSR B1259-63, which contains a non-accreting pulsar and a Be star whose winds collide forming a complex interaction structure. Given the strong eccentricity of this binary, the interaction structure should be strongly anisotropic, which together with the complex evolution of the shocked winds, could explain the origin of the observed moving X-ray feature. We propose here that a fast outflow made of a pulsar-stellar wind mixture is always present moving away from the binary in the apastron direction, with the injection of stellar wind occurring at orbital phases close to periastron passage. This outflow periodically loaded with stellar wind would move with a high speed, and likely host non-thermal activity due to shocks, on scales similar to those of the observed moving X-ray object. Such an outflow is thus a very good candidate to explain this X-ray feature. This, if confirmed, would

imply pulsar-to-stellar wind thrust ratios of ~ 0.1, and the presence of a jet-like structure on the larger scales, up to its termination in the interstellar medium.

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V. Berezinsky

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UHECR: Problems and Solutions

Ultra High Energy Cosmic Rays at the observed energies $10^{18} - 3.10^{20}$ eV is the field with great achievements and with great disappointments. Energy of particles are measured with unprecedented accuracy, but nature of primary particles (protons? nuclei?) remains contradictory. The nature of the observed spectral signatures, dip at energy $1.10^{18} - 3.10^{19}$ eV and cutoff at higher energy can be explained due to interaction of protons with CMB photons, but mixed nuclei composition can also explain it. Acceleration of particles up to energy 3.10^{20} eV is suggested in many models, but most conservative model of shock acceleration meets the serious problems. In this talk some possible solutions are presented.

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D. Bisikalo

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Gaseous envelopes of hot Jupiter exoplanets and their changes due to CME

Hot Jupiter exoplanets, have a number of outstanding features, caused mostly by their proximity to the host star, e.g.: gas outflowing from the planet's atmosphere to the star, as it happens in close binary stars. In addition, the short distance between the planet and the star results in a large planet's orbital velocity. If this velocity exceeds the local sound speed a bow-shock forms ahead of the planet. Gas-dynamical and MHD modeling shows that, if the dynamical pressure of the stellar-wind is high enough to stop the outflow from the vicinity of the inner Lagrangian point, a quasi-closed non-spherical envelope, bounded by the bow-shock of a complex shape, forms in the system. In this report we discuss possible types of gaseous envelopes of hot Jupiters. We also consider the variations of flow patterns in the gaseous envelopes, occurring under the action of coronal mass ejections.

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G. Bisnovatyi-Kogan

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(with M.V. Glushikhina)

Kinetic theory of the heat conductivity in the crust of a magnetized neutron star

The solution of Boltzmann equation for plasma in magnetic field, with arbitrarily degenerate electrons and non-degenerate nuclei, is obtained by Chapman-Enskog method. Fully ionized plasma is considered. The tensor of the heat conductivity coefficients in non-quantized magnetic field is calculated. The Lorentz approximation, with neglecting of electron-electron encounters, is asymptotically exact for strongly degenerate plasma. For strongly degenerate electrons we obtain, an asymptotically exact analytical solution for the heat conductivity tensor in presence of a magnetic field. This solution has considerably more complicated dependence on the magnetic field than those in previous publications, and gives several times smaller relative value of a thermal conductivity across the magnetic field at $\omega\tau >\sim 0.8$ [G.S. Bisnovatyi-Kogan, M.V. Glushikhina, arXiv 0616.05226 (2016)].

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E. Blackman

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Transport, non-locality, magnetorotational instability, and dynamos: clues and challenges for next generation accretion theory

Accretion disc theory is less developed than stellar evolution theory although a similarly mature phenomenological picture is ultimately desired. While the interplay of theory and numerical simulations highlights the importance magnetic fields in angular momentum transport, there remains a challenge to incorporate the insights gained from simulations into improving mean field accretion models for comparison with observations. I discuss how observations of coronae and jets, combined with the interpretation of simulations, of the magnetorotational instability (MRI) suggest

that a significant fraction of disc transport is indeed non-local. Mean field accretion theory and mean field dynamo theory should be unified into a single theory that predicts the time evolution of spectra and luminosity from separate disc, corona and outflow contributions.

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S. Bogovalov

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(with I.V Tronin)

Physics of "cold" disk accretion due wind from the disk

In the conventional models of disk accretion the accreted material losses the angular momentum due to turbulent viscous tensions, while the energy is carried out by electromagnetic radiation or is convected to the gravitation center. There is a general consensus that at least a part of the angular momentum and energy can be carried out by magnetized wind from the disk. We consider limiting case when all the angular momentum and energy are carried out by the wind. In this type of accretion the disk remains cold because the wind efficiently cools the disk. The results of numerical simulations of such a type of accretion and application of this model to the interpretation of the observations of the jets from AGNs with high ratio of the kinetic luminosity of the jets to the luminosity of the disks are presented.

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D. Breitschwerdt

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(with J. Feige, M.A. de Avillez, C. Dettbarn)

Tracing recent supernova explosion times and sites near Earth by modeling deep-sea 60Fe signatures

Recently several groups have found 60Fe from late AGB stellar and explosive nucleosynthesis in ocean crusts and sediments, as well as in magnetotactic bacteria and even in lunar samples. Due to a half-life time of 2.6 million years, no terrestrial contamination is expected, opening the possibility to study nearby supernova explosions during the last 15 million years. All measurements point to a significant peak in the 60Fe fluence at about 2.2 million years ago. We present a model, in which the radioactive isotope is incorporated in dust grains, and travels as a passive scalar through turbulent interstellar space. We have performed analytical and numerical hydrodynamical high resolution simulations on parallel computers that can explain both the 60Fe fluence as well as the formation and evolution of the Local Bubble (surrounding the solar system), as the result of supernovae exploding in a nearby moving group, whose still surviving members are now in the neighbouring Sco-Cen association. We deduce the number of explosions, as well as their most probable explosion times and sites. The consequences of nearby supernovae will be briefly discussed.

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O. Bromberg

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Magnetic energy dissipation and stability properties of relativistic AGN jets

It is commonly accepted that the relativistic jets observed in radio galaxies are launched magnetically and are powered by the rotational energy of the central supermassive black hole. Such jets carry most of their energy in the form of electromagnetic Poynting flux. However by the time the ejecta reach the emission zone most of that energy is transferred to relativistic motions of the jet material with a sizable fraction given to non-thermal particles. This calls for an efficient dissipation mechanism to work within the jets without compromising their integrity. Understanding how Poynting flux dominated jets can dissipate their energy is therefore crucial for modeling these astrophysical objects. In this talk I will present self-consistent 3D simulations of the formation and propagation of highly magnetized ($\sigma \sim 25$), relativistic jets in a medium. I will show how the jets magnetic energy is efficiently dissipated, reaching a state of equipartition between the magnetic and thermal energies. I will also show how the equilibrium state stabilizes the jets from being disrupted by magnetic instabilities. I will present interesting implications on Blazar flairs and on the well-known Fanaroff-Riley Dichotomy. I will also discuss how this affects the energy transport to the medium surrounding the jets.

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G. Brunetti

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Acceleration and transport of cosmic rays in galaxy clusters: constraints from radio and gamma-ray observation

Observations in the radio band prove the existence of non-thermal components, cosmic rays and magnetic fields, in galaxy clusters and a connection between the origin of these components and the hierarchical process of formation of galaxy clusters. This observational evidence suggests that a fraction of the energy that is injected in the form of large scale motions and shocks in the intra-cluster-medium during mergers between massive clusters is transported at smaller scales into magnetic fluctuations and particle acceleration. This scenario suggests that a complex hierarchy of mechanisms, based on collisionless and plasma effects, is active in the intra-cluster-medium and -in fact- it requires a major change of our modelling of the micro-physics of the intra-cluster-medium. In this talk I will briefly review the most relevant observational facts, based on radio and gamma-ray observations, and focus on the current theoretical understanding of these phenomena. I will discuss ongoing theoretical efforts to understand particle acceleration and propagation in the intra-cluster-medium and future directions. Future observational facilities are expected to produce a breakthrough in the field. In particular, I will show first results from the LOFAR radio telescope that is providing fundamental information and tests of theoretical models. I will also mention the potential impact in the field –on longer times- from the synergies between SKA (and its precursors) and X-ray observatories such as the eRosita and the Athena.

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R. Buehler

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The variable gamma-ray sky: observing astrophysical accelerators in real time

Particle acceleration to relativistic energies is common in the Universe. A wealth of astrophysical accelerators have been identified over the past decades using gamma-ray observations. Particularly interesting are variable sources, where the acceleration and radiation processes can be observed over time. In this presentation, I will review the different classes of variable gamma-ray sources known today. I will discuss the proposed acceleration mechanisms and end with an outlook on future observational and theoretical developments.

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A. Bykov

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Energetic particle acceleration and magnetic field amplification in supernova remnants

Astrophysical plasma flows carrying magnetic fluctuations of a broad dynamical range of scales are interacting with relativistic particles. The interaction results in particle acceleration, a modification of the plasma flows and specific mechanisms of magnetic field amplification in collisionless shocks. We present non-linear models of collisionless shocks in supernova remnants with dynamically significant relativistic components with account for the ponderomotive forces due to momentum exchange between the anisotropic distribution of relativistic particle population and the turbulent background plasmas. We discuss the observational appearance of the highly non-linear turbulent shells in multi-wavelength imaging and spectral observations of supernova remnants including the X-ray polarimetry.

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V. Chechetkin

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Mechanism of the explosion of the collapsing supernovae

Most of energy generated in the gravitational collapse of a supernova is radiated in neutrinos, hence the role of these particles in supernova explosions is crucial. At present time models of core collapse supernovae (SNe) are based on multidimensional hydrodynamics and nuclear burning, still the treatment of neutrino transport is often performed in a simplified manner. We are developing the hydrodynamic models with taking into account the neutrino transport. Models include the accurate neutrino treatment in the frame Bolzmann equations in a spherically symmetric collapse, while for the multidimensional case we proposed the original method based on the multi-temperature hydrodynamics with the heat conduction and the flux limiters. The role of multidimensional effects is discussed. These results are important for multi-dimensional models with large-scale convection development as the result of non-equilibrium neutronization in a stellar core. Also energetic neutrinos arising with large-scale convection are important for registration of a neutrino signal from SNe in future experiments. Also we discuss the applications of the developing multidimensional models to the thermonuclear SNe. If for SNe type II the convection plays a key-effect, the convection in SNe I changes nucleosynthesis dramatically.

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K.-S. Cheng

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Inverse Compton processes in gamma-ray binaries

In this talk I will discuss the contribution of inverse Compton processes between the relativistic electrons/positrons of pulsar wind and various of soft photon sources in two type of gamma-ray binaries, i.e. low mass binaries and high mass binaries. The first type of soft photons comes the companion star which can produce an orbital modulated gamma-ray component. The second type of soft photons is emitted by the accretion disk surrounding the pulsar. This inverse Compton component should not depend on the orbital phase. However in particular for long orbital binaries if the accretion disk around the pulsar is formed during the passage of pulsar passing through the companion stellar disk, then the disk can only survive for short period of time and consequently an orbital modulated gamma-ray component occur.

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A. Cherepashchuk

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Binary Stars, Black Holes and Gravitational wave astronomy

Gravitational wave radiation from binary black hole coalescence has been discovered recently by LIGO. At the last time, massive O+O, WR+O and WR+WR binary systems have been discovered (M>50-80Msun) which can be progenitors of black hole binary systems. To provide gravitational wave signal from merging black holes during Hubble time binary black hole system should be sufficiently compact (separation between the components <40-50Rsun). However, due to strong stellar wind from massive stars evolution of a massive close binary system goes with increasing separation between the components. Thus, massive stars with low metallicity and weak stellar winds should be considered. Also, some additional mechanisms of angular momentum loss are needed for description of evolution of massive close binary systems, leading to formation of compact black hole binary systems. In our talk, analysis of different evolutionary scenario of massive close binary systems will be presented, in connection with recent achievements in gravitational wave astronomy.

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A. Chernin

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Prediction, discovery and studies of local dark energy effects

It is proposed that Einstein's antigravity produced by omnipresent dark energy may dominate the dynamics of flows of galaxies on the local spatial scales of $1-10$ Mpc. As a result, the flows may be accelerating and self-similar with the linear velocity-distance relation. The prediction is confirmed by the recent observations of more than 300 nearby galaxies with the Hubble Space Telescope and 6-m BTA SAO. In combination with the cosmological data on the spatial scales of $1-10$ Gpc, the local data provides clear evidence for antigravity as a universal phenomenon of nature.

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(with K.S. Cheng, V.A. Dogiel, A.V. Ivlev, C.M. Ko)

Non-linear effects of interaction of cosmic rays with molecular clouds

We analyze interaction of fast charged particles with Galactic molecular clouds. As a results of energy losses inside the clouds, a particle flux, converging to the cloud, is formed in the cloud vicinity. This flux, in its turn, excites there an MHD-turbulence by the streaming instability, which scatter the primary particles. Therefore the CR/cloud interaction is a complex problem described by a system of non-linear equations. We suggested a model of CR penetration into the dense cloud interior through their diffuse outer envelope. Three different regimes of CR propagation are realized in the envelope depending of CR energy: 1) Low energy particles with energies of tens of MeV are almost frozen into the MHD waves and propagate by convection with Alfven velocity. These particle do not reach the dense interior because of energy losses; 2) High energy particles with energies above ten GeV do not experience any scattering and propagate freely with luminal velocities. 3) In the intermediate energy range a "mirroring shield" is formed between the diffuse envelope and the dense interior which prevents free CR penetration into the interior from outside. This effect is a function of the hydrogen density in the diffuse envelope and the spectrum of CRs in the intracloud medium.

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(with I. Khabibullin, R. Sunyaev, G. Ponti)

Synergy of molecular clouds and a supermassive black hole in our Galactic Center

While the supermassive black hole Sgr A* at the center of the Milky Way is currently very dim, we believe that it experienced a powerful outburst of X-ray radiation hundreds of years ago. The historical records of this outburst are revealed by reflection/reprocessed radiation coming from dense molecular clouds. The imprints left by the outburst in spatial and time variations of the reflected emission suggest that the outburst happened some hundred years ago. It lasted less than several years and Sgr A* was more than million times brighter than today. These characteristics are consistent with a relatively modest tidal disruption event. Thus, molecular clouds offer us a convenient tool to study Sgr A*'s past history. At the same time, the outburst serves as an extremely powerful probe of molecular gas. Essentially, this is the only opportunity to reconstruct a full 3D structure of molecular clouds and their mass distribution. Future X-ray observatories, including cryogenic bolometers and polarimeters, will further boost our ability to conduct in-depth studies of molecular gas and outbursts of Sgr A*.

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Study of extragalactic objects with Pushchino low-frequency radio telescopes

There are 2 meter-wavelengths radio telescopes at Pushchino Radio Astronomy Observatory: E-W arm of One-kilometer Wide-band Cross-type radio telescope and around 200 meters (in EW direction) and 400 meters (in NS direction) Large Phased Array. The first of these two radio telescopes is used for observations at wide range of meter wavelengths - from 2.5 till to 10 meters. The second one has relatively narrow frequency band – about 2% at 111 MHz. Today the both radio telescopes are used for observations of different kind objects: solar super corona and solar wind, super novae remnants and pulsars, radio galaxies and quasars, etc.. Some outstanding results obtained for extragalactic radio sources with these two radio telescopes in the past, as well as several relatively new results in this field will be presented in the report. Serious upgrade of the Large Phased Array made during the last few years and corresponding new prospects for extragalactic radio astronomy will be discussed, too.

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Forward to automatic forecasting of radiation hazards from solar cosmic rays for aircrafts and spacecrafts

In the last years became possible to have on-line through Internet one-minute cosmic ray (CR) data from many neutron monitors and muon telescopes (in high energy region) as well as from several spacecrafts (in very low energy region). To avoid damage of electronics and negative effects for people health is necessary in time forecast expected fluency of energetic particles and radiation hazards. It was shown by myself and colleagues that this possible to do by using the first 20-30 minutes of CR data on the basis of coupling functions, spectrographic method, and by solving inverse problem, and then calculate expected results on radiation hazards for many hours of Solar Energetic Particle (SEP) event. But all this must be made automatically, including the formation of corresponding alerts on the expected level of radiation hazard for different objects. We describe several automatically worked stages and obtain corresponding algorithms. The first's stage works continue, collecting from Internet all available one minute data on CR variations (corrected on meteorological and geomagnetic effects). The seconds stage also works continue according to automatically working program "SEP-Start supposed, developed and checked in the Israel Cosmic Ray and Space Weather Centre. Using of this program on many CR stations and on satellites allowed to determine automatically the beginning of SEP event (it can be different at different stations caused to anisotropy at beginning of SEP). If the seconds stage gives positive result, starts to work automatically the thirds stage according to program "SEP-Coupling"– using method of coupling functions and spectrographic method for transformation obtained at different altitudes and cutoff rigidities data on CR intensity variations to the space and calculation CR energy spectrum and angle distribution out of the Earth's atmosphere and magnetosphere, directly in the interplanetary space near the Earth. After obtaining results by thirds stage starts to work automatically the fourths stage according to program "SEP-Inverse Problem and it is determined source function, time of ejection SEP into interplanetary space, and diffusion coefficient of propagation in dependence of SEP energy and distance from the Sun. After obtaining results by fourths stage starts to work automatically the fifths stage according to program

"SEP-Direct Problem and it is determined by found at fourths stage parameters the time variations of primary SEP in dependence of particles energy in interplanetary space near the Earth for many hours ahead, up to few days (on the basis of only 20-30 minutes of SEP beginning). On the basis of information, obtained in the fifths stage, it is easy to calculate by known coupling functions and cutoff rigidities expected time variations of SEP intensity in atmosphere and in magnetosphere at different altitudes, and compare the beginning part with available observations and estimate the quality of forecasting (sixths stage, program "SEP-Forecasting"). If the forecasted radiation hazard is expected dangerous for different objects, will be immediately send corresponding Alerts (sevenths stage, program "SEP-Alerts"). By obtaining new data, forecasting Alerts became more and more exactly.

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The origin of cosmic rays - fifty years on

Just over fifty years ago Ginzburg and Syrovatskii published their great monograph "The Origin of Cosmic Rays"which has had enormous influence on the field and helped to establish cosmic ray physics as part of astrophysics rather than just the poor relation of particle physics. I will review our current thinking on the subject and argue that in fact we need to distinguish at least three "origins"for the cosmic rays. Despite the great advances in the intervening half century, there are still many open questions surrounding the origins of the cosmic rays.

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Electroweak mechanism for the generation of strong magnetic fields in quark matter and the problem of magnetars

The origin of strong magnetic fields with $B > 10^{15}$ G in some compact stars, called magnetars, is the open problem for modern astrophysics. I propose the new model for the generation of such magnetic fields based on the magnetic field instability driven by the parity violating electroweak interaction between background fermions. I study the quark matter in the core of a hybrid star or in a quark star with unbroken chiral symmetry. In this case the chiral magnetic effect in the presence of the electroweak interaction between quarks can take place. In this model, I predict the amplification of a seed magnetic $B_0 = 10^{12}$ G, typical for a pulsar, to the strengths $10^{14} - 10^{15}$ G, observed in magnetars. These fields are large scale with the typical scale comparable with the star radius. If I consider the generation of smaller scale magnetic fields and take into account the turbulent effects in quark matter, I can also explain the magnetar bursts within this model.

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(with A.W. Wolfendale)

Puzzles of the cosmic ray anisotropy

It is known that cosmic rays are highly isotropic. The level of anisotropy is very small ($< 1\%$) and has several puzzling features. We tell about cosmic rays at and below the knee at PeV energies: the so called inverse anisotropy, the dip in the amplitude at sub-PeV energies and the possible role of the Single Source in the anisotropy and formation of the knee.

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Ultraluminous X-ray sources

The origin of Ultraluminous X-ray Sources (ULXs) in external galaxies whose X-ray luminosities exceed those of the brightest black holes in our Galaxy by hundreds and thousands of times is mysterious. The most popular models for the ULXs involve either intermediate mass black holes (IMBHs) or stellar-mass black holes accreting at super-Eddington rates. Here we review the ULX properties. Their X-ray spectra indicate a presence of hot winds in their accretion disks supposing the supercritical accretion. In recent years, new surprising results were discovered in X-ray data, ULX-pulsars and high-velocity outflows up to 0.2c. They are also in accordance with the super-Eddington accretion. However, the strongest evidences come from optical spectroscopy. The spectra of the ULX counterparts are very similar to that of SS433, the only known supercritical accretor in our Galaxy. The spectra are apparently of WNL type (late nitrogen Wolf-Rayet stars) or LBV (luminous blue variables) in their hot state, which are very scarce stellar objects. We find that the spectra do not originate from WNL/LBV type donors but from very hot winds from the accretion disks, which have similar physical conditions as the stellar winds from these stars. The results suggest that bona-fide ULXs must constitute a homogeneous class of objects, which most likely have supercritical accretion disks.

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Extragalactic magnetic fields

The origin and evolution of magnetic fields in the Universe is one of the most fascinating and currently unsolved problems in astrophysics. The existence of large-scale fields in clusters of galaxies and beyond, in particular, raises several problems because of the need of amplification mechanisms acting with large efficiency on scales of hundreds kpc. A commonly accepted hypothesis is that these magnetic fields result from the amplification of much weaker pre-existing "seed" fields via shock/compression and/or turbulence/dynamo amplification during merger events. The origin of "seed" fields is unknown. They could be either primordial, i.e. generated in the early Universe prior to recombination, or produced locally at later epochs of the Universe, in early stars and/or (proto)galaxies, and then injected in the interstellar and intergalactic medium. The cosmic origin of magnetic seed fields and the subsequent processes through which they are amplified give us critical information on the growth of structure in the Universe. The history of these processes can be uncovered through accurate knowledge of the strength and structure of magnetic fields in clusters, in the intergalactic medium, at the boundary of galaxy clusters, in the bridges which join clusters, in the filamentary cosmic web, and in the relation of magnetic fields to gas flows in spiral galaxies, radio galaxies and active galactic nuclei. Extragalactic magnetic fields are investigated in the radio band through studies of the diffuse synchrotron emission and the Faraday effect of polarized radio sources. Current results and implications, as well as future prospects are presented.

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Synchrotron, Cherenkov and transition radiations from the Sun

Processes of electromagnetic emission and its transfer were always within the primary interests and highest priorities of Vitaly Ginzburg. He (along with Ilya Frank) theoretically discovered transition radiation and contributed a lot to development and interpretation of the Vavilov-Cherenkov radiation. He was among the very first scientists who recognized a fundamentally important role of the synchrotron radiation in astrophysics; moreover, he was the most enthusiastic 'promoter' of this emission mechanism during 50ies, which ensured that the synchrotron theory became commonly accepted in the radio astronomy and then well beyond that. His fundamental pioneering review paper 'Cosmic Magnetobremsstrahlung (Synchrotron Radiation)' published along with Sergei Syrovatskii in ARA&A in 1965 remains an up-to-date and actively used (and cited) paper on the topic.

Here I review these mentioned emission processes at the sun, where they occur mainly during solar flares and other transient events at the radio frequencies. The synchrotron (typically called gyrosynchrotron in the solar case given that non- and mildly relativistic electrons are involved) emission is the main emission mechanism responsible for the microwave bursts from solar flares in the range from 1 GHz up to, sometimes, a half of THz. Analysis of the gyrosynchrotron radiation from the sun enables studies of the solar energetic particles and coronal magnetic field. Transition radiation is a less common type of emission from the sun; it was reported to be responsible for a subclass of decimetric continuum radio bursts at 1—3 GHz; it provides information about small-scale inhomogeneities of the flaring plasma density. Vavilov-Cherenkov radiation requires a source moving faster than the phase velocity of the wave and so typically deemed irrelevant in the astrophysical context, where we often deal with hot ionized plasmas with the refractive index below one. However, at the sun, for example in a relatively cool chromosphere, the plasma is only weakly ionized with a lot of neutral atoms and molecules, which can result in the refractive index above one, particularly—in the submillimeter (and shorter) wavelengths. Vavilov-Cherenkov emission from the chromosphere is likely responsible for a strong sub-THz component observed from some strong solar flares.

In this talk I will show and discuss a few vivid contrasting examples of the corresponding emissions observed from compact magnetic flux tubes with a strong magnetic field, from elongated jets, and from large-scale coronal structures (a coronal plume, which is bright in the radio domain but undetectable by any other means). I will demonstrate the diagnostic potential of these radio emission and its importance in the context of most fundamental unanswered questions in solar physics.

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(with R. Stepanov, I. Mizeva)

Cascades and dynamo in helical MHD turbulence

MHD turbulence is an important part of astrophysical processes, which gives rise to global cosmic magnetic fields. Over the last few decades, the peculiarities of MHD turbulence have attracted the interest of researchers in astrophysics and fluid dynamics, significant attention has been paid to the role of magnetic helicity in fully developed MHD turbulence. Magnetic helicity, together with the energy and cross-helicity, is one of the three integrals of motion in ideal MHD. The purpose of the talk is to discuss the influence of magnetic helicity on the cascade properties of the developed MHD turbulence. To provide extended inertial range (4 decades in our case) we use helical shell model, which cannot take into account the spatial complexity of turbulent flows but reflect spectral distributions of real MHD turbulence [F. Plunian, R. Stepanov and P. Frick, Phys. Reports, 523, 1 (2013)]. Shell models are low-dimensional dynamic systems that are derived from the original MHD equations by a drastic reduction of the number of variables. First, we try to highlight the role of magnetic helicity by separating its source from the source of energy. We consider MHD turbulence that is stationary forced at the largest scale, with a source of magnetic helicity that is localized at a scale inside the pronounced inertial range. In our research, we focus on the possibility of a simultaneous direct cascade of energy and oncoming inverse cascade of magnetic helicity, and we examine the influence of the magnetic helicity on the standard Kolmogorov energy cascade. We demonstrate that in the inertial range in fully developed MHD turbulence with small-scale sources of magnetic helicity oppositely directed fluxes of energy and magnetic helicity coexist. Three inertial ranges with different scaling properties were obtained. in a short range of scales larger than the scale of magnetic helicity input, a bottleneck-like effect appears, which results in a local reduction of the spectral slope. The slope changes in a domain with a high level of relative magnetic helicity, which determines that part of the magnetic energy related to the helical modes at a given scale. In the infrared part of the spectra we observe simultaneous inverse cascade of energy and magnetic helicity. Our results indicate that a large-scale dynamo can be affected by the magnetic helicity generated at small scales [R. Stepanov, P. Frick and I. Mizeva, APJLV, 798, N 2 – L35 (2015)]. Second, we study the magnetic energy and magnetic helicity cascades, provided by the injection of magnetic helicity at different scales, paying attention to the infrared (relative to the scale of forcing) part of the spectra. In small scales the common Kolmogorov turbulence with a direct spectral energy flux is established. In the infrared part of spectrum the inverse cascade of magnetic helicity and magnetic energy provides an inertial range with a power law E(k)$\sim k^{a-1}$ with a depending on the magnetic helicity injection rate. Magnetic helicity and associated magnetic energy are accumulated at largest available scale. This scenario does not change if the magnetic helicity forcing is shifted to smaller scales. Our results indicate that a large-scale dynamo can be affected by the magnetic helicity generated at small scales. Particularly the magnetic helicity cascade is followed by a growth of kinetic helicity [P. Frick, I. Mizeva and R. Stepanov, Magnetohydrodynamics, V.53 (2017)].

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V.L. Ginzburg and gamma-ray astronomy: from GAMMA-1 to GAMMA-400

The role of V.L. Ginzburg in developing the extra-atmospheric gamma-ray astronomy in Russia and his determining role in the formulation of scientific problems in the GAMMA-1 space experiment for studying the gamma-ray emission in the energy range of 50 MeV – 5 GeV and in the GAMMA-400 project for solving the dark matter problem and studying the gamma-ray emission in the energy range of 20 MeV – 1000 GeV.

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Present and past high-energy activity of the Massive Black Hole at the Galactic Center

New results on the behavior of Sgr A*, the Massive Black Hole (MBH) at the Galactic Center (GC), are reported, including the simultaneous measurements in soft and hard X-rays and at infrared frequencies of one of the most bright flares detected so far from this source. These flares are originated close to the BH horizon and can tell us about the physical conditions present there. Our results confirm and that X-ray emission is due to synchrotron mechanism and set a number of constraints on the physical parameters of the emitting region. Also further properties of the X-ray diffuse emission in the Central Molecular Zone, indicating intense past activity of the MBH, have been obtained, thanks to the recent large surveys carried out with XMM-Newton and Chandra, and show that Sgr A* was indeed much more active in the past. In particular the observed variations of the continuum and the iron K emission line at 6.4 keV have been compared to simulations of X-ray reflection and fluorescence excitation of cold molecular material and they show that Sgr A* likely produced multiple outbursts of X-ray emission in the past, reaching luminosities 1 million times larger than its present luminosity. These and future observations along with the associated theoretical modelling will eventually lead to establish the Sgr A* X-ray light curve in the past 1000 yrs, which can then be linked to other indications of more ancient activity in the GC revealed by the GC hot gas shells and the extended gamma-ray Fermi bubbles.

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In synchrotron we trust: can it make happy both observers and theorists?

In this talk, I will focus on the current state of affairs in studies of radio emission from extragalactic sources (AGN of all kinds) and present the latest developments in this field, including results of the Space VLBI mission RadioAstron. I will attempt to connect these new results with the works of V.L. Ginzburg and other pioneers of the modern astrophysics.

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Accretion rings at the outermost part of accretion disks and their observational appearances

X-ray light curves of three X-ray pulsars, Her X-1, LMC X-4 and SMC X-1, folded with their respective super-orbital periods, can well be reproduced by a model that X-rays from a compact object towards us are periodically obscured by a precessing ring at the outermost part of an accretion disk around the central object. The best fir parameters of the model suggest that the optical depth of the accretion ring is around unity for Compton scattering and that the ring should suffer from a significant effect of X-ray heating from the central X-ray source. I will discuss important roles of accretion rings in several observational aspects of accretion flows onto compact objects.

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(with A.M. Kiselev)

Diffusion of charged particles in a stochastic force-free magnetic field

We study a diffusion of charged particles in stochastic magnetic field. We consider a random stationary magnetic field $\mathbf{B}$ with zero mean, $\langle \mathbf{B} \rangle = \mathbf{0}$. In the case when carriers of electric current are electrons, the field is force-free, $\mathrm{curl}\mathbf{B} = \alpha\mathbf{B}$. In a small region where the coefficient α and the magnitude $|\mathbf{B}|$ are approximately constant, magnetic field lines lie in parallel planes. But the direction of $\mathbf{B}$ varies with the coordinate perpendicular to these planes. The motion of charged particle in this field is described by the equation of mathematical pendulum and continuously traces the transition from magnetized motion, when the Larmor radius r_L is small, $r_L < l$ (trapped particles), to almost free motion, when $r_L > l$ (untrapped particles). Here $l = 2\pi/\alpha$ is the characteristic scale of magnetic field inhomogeneity. Averaging over magnetic field spectrum gives the diffusion coefficient of particles D as a function of Larmor radius r_L in the large-scale field and magnetic field correlation length L_0. The diffusion coefficient is proportional to Larmor radius, $D \propto r_L$, for $r_L < L_0/2\pi$, and proportional to the square of Larmor radius, $D \propto r_L^2$, for $r_L > L_0/2\pi$. We also discuss the diffusion of cosmic rays in the Galaxy. The Galaxy contains a large number of regions, their sizes L_0 and large-scale magnetic fields B_{LS} vary in a wide range. We average over L_0 and B_{LS} and obtain the diffusion coefficient as a function of the Larmor radius r_m in the maximum large-scale field, $D \propto r_m^{(1-\sigma)/(1+\beta)}$. Here β is the large-scale field spectral index, $B_{LS} \propto L_0^{\beta}$, and the distribution function $f(L_0)$ of region sizes has the form $f(L_0) \propto L_0^{-1+\sigma}$. For the Kolmogorov spectrum of the magnetic field, $\beta = 1/3$, and almost flat spectrum over scales, $\sigma = 1/15$, we have $D \propto r_m^{0.7}$, which consistent with observations of cosmic rays diffusion in the Galaxy.

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Mass discrepancy and acceleration in galaxies

Mass of a galaxy can be estimated by the amount of radiation it emits or the dynamics it exerts on itself or others. The estimated masses are called the luminous mass and dynamical mass, respectively. Observations show that dynamical mass is always larger than luminous mass, and this is known as the "missing mass problem". This mass discrepancy can be attributed to some form of dark matter or some form of modified gravity. Here we discuss recent developments on mass discrepancy (and other similar discrepancies, such as acceleration discrepancy and surface density discrepancy) in spiral and elliptical galaxies, in particular, its relation with the characteristic acceleration of the systems.

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(with V.V. Kocharovsky, V.Ju Martyanov, S.V. Tarasov)

The analytical theory of self-consistent current structures in a relativistic collisionless plasma

Using our recent review paper (Physics - Uspekhi 59 (12) 1165 - 1210 (2016)) we outline the most-studied classes of exact solutions to Vlasov-Maxwell equations for stationary neutral current structures in a collisionless relativistic plasma, which allow the particle distribution functions (PDFs) to be chosen at will. A general classification is presented of the current sheets and filaments described by the method of invariants of motion of particles whose PDF is symmetric in a certain way in coordinate and momentum spaces. A number of new analytical solutions of this type are given. The possibility is discussed of using these explicit solutions to model the observed and/or expected features of current structures in cosmic and laboratory plasmas. Also addressed is the analytical description of the so-called Weibel instability in a plasma with an arbitrary PDF.

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(with N.S. Kardashev)

Astrophysics at super-high angular resolution (missions RadioAstron and Millimetron)

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Magnetohydrodynamics of the Sun

Observations of our nearest star – the Sun – with a high spatial resolution carried out on board the recent space missions, such as SOHO, CORONAS-I, RHESSI, CORONAS-F, STEREO, HInode, SDO, Hi-C, EUNIS, IRIS etc., have revealed the diversity of MHD features and phenomena in the solar plasma. Simulation of these phenomena makes it possible to gain a better understanding of the inner structure and mechanisms working in the Sun, as well as the plasma astrophysics of distant stars. The differential rotation of the Sun, generation and emergence of magnetic fields to the upper solar atmosphere, magnetohydrodynamics of solar flares and mass ejections, heating of the solar corona, and acceleration of the solar wind are the key MHD processes that are discussed in this report based on the results of observations and theoretical modeling. Future observations of the Sun on board the Solar Orbiter, Solar Probe, Interhelioprobe, and other space missions will allow us to study in more detail the role of the solar magnetic fields and MHD processes in the origin of the solar periodicity, the mechanisms of triggering the most intensive phenomena of solar activity (flares and mass ejections), as well as the corona heating and solar wind acceleration mechanisms.

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Average value of the cosmic ray injection exponent at Galactic sources

We have performed the retrieval of the cosmic ray injection exponent at the Galactic sources from the spectrum observed at Earth taking into account the inhomogeneity of the turbulent interstellar medium. Two different transport models, based on anomalous and Ginzburg-Syrovatsky's normal diffusion equation, have been used to relate the spectrum injected by the source with that measured at Earth.
Using the normal diffusion model, we have shown that the variation of the interstellar medium properties leads to an anomalous spatial distribution of the particle density. Its asymptotic behavior practically coincides with result obtained in the framework of the anomalous diffusion model for $1 < \alpha < 2$. In other words, the cosmic rays observed at Earth collectively appear to display nondiffusive (superdiffusive) characteristics although an individual particle has moved in a diffusive manner.

We have shown that the average value of the injection index, obtained in the framework of both transport models, is about $(2.8 \div 3.0)$.

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Brighter than a billion suns: New physics at the synchrotron frontier

Astrophysical relevance of synchrotron radiation has been widely recognized since the early 1950-es, with a number of pioneering contributions from V.L. Ginzburg. Presently, the ubiquity and variety of cosmic synchrotron sources extends over essentially all astrophysical fields, from geosynchrotron emission generated by cosmic ray showers here on Earth to extragalactic jets generated by accretion of matter on supermassive black holes at cosmological distances. The latter ones in particular manifest one of the most spectacular properties of synchrotron radiation – its unparalleled brightness. These jets are many orders of magnitude brighter than the Sun and the synchrotron emission that can be generated in laboratory. It has been thought over decades that the brightness of cosmic synchrotron sources is ultimately determined by the energy losses due to inverse Compton scattering, limiting the effective (brightness) temperature of incoherent synchrotron radiation to about one trillion degrees. However, a number of recent measurements, particularly those made by the space radio interferometer "RadioAstron suggest strongly that cosmic synchrotron emitters may actually dramatically exceed this limit. These observations point toward new physics hidden in the synchrotron emission from relativistic jets – perhaps signaling the presence of significantly non-stationary processes and exceptionally strong and ordered magnetic fields in the vicinity of the supermassive black holes. A brief review of recent results in this field will be presented.

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Crab Nebula, pulsar winds and explosive reconnection in relativistic plasmas

We can probe observationally and reproduce theoretically the most detailed properties of the Crab Nebula nearest to the pulsar - The Inner Knot. The tiny knot is indeed a spot on the surface of relativistic shock, but The Inner Knot is not a site of Crab flares.

We develop a model of particle acceleration during explosive reconnection events in relativistic highly magnetized plasma and apply the model to explain the Crab gamma-ray flares. We argue that magnetic reconnection is an important (and dominant in some cases) process of particle acceleration in high energy astrophysical sources.

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Cosmological acceleration from gravitational waves

We show that gravitational waves (classical and quantum) produce the accelerated de Sitter expansion at the start and by the end of cosmological evolution of the Universe. We assume that the Universe was empty before the first matter was born. In these periods of time, the Universe contains no matter fields but contains classical and quantum metric fluctuations, i.e. it is filled with classical gravitational waves and gravitons. In such gravitational wave and graviton dominated eras of the evolution of the Universe, the de Sitter state is the exact solution to the self-consistent equations for gravitational waves and gravitons and background geometry for the empty (with no matter fields) space-time with FLRW metric. This solution is of the instanton origin since it can only be obtained by Wick rotation with the subsequent analytic continuation to real time. In the case of classical gravitational waves, the Wick rotation is only an option. In the case of quantum gravitons, this is also an option but not the only one. Gravitons can also produce the De Sitter expansion directly in real time due to "materialization" of fictitious particles (Feynman-Faddeev-Popov ghosts). The physical interpretation of this mathematical fact is unclear because of the lack of a quantum theory of gravity. There is no such problem in the instanton solutions for gravitons (obtained by Wick rotation). Thus, the exponentially fast accelerated expansion of the contemporary (almost empty) Universe, i.e. the dark energy effect, can be produced by gravitational waves and/or gravitons. This fact is consistent with the existing observational data. One of the great puzzles of the dark energy is the question why it has happened during the current epoch of the evolution of the Universe (coincidence problem)? The gravitational wave origin of dark energy provides a natural explanation of this fact. If the inflation is real, then the exponentially fast acceleration of Universe at the start of its evolution can be also produced by gravitational waves and/or gravitons. This fact is also consistent with the observational data on CMB anisotropy.

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Gravitational wave signatures generated by neutron star superfluids

A plausible path towards a predictive statistical theory of radio pulsar glitches is described, and it is argued that gravitational wave observations will enable quantitative tests of key aspects of the theory in the not-too-distant future. The long-term statistics of pulsar glitch sizes and waiting times are characterized using parametric and nonparametric approaches. Two classes of glitch activity are identified: Poissonian and quasiperiodic. It is shown that the observed behavior emerges naturally from Gross-Pitaevskii and N-body simulations of spin-down-driven superfluid vortex avalanches, where identifiable knock-on mechanisms drive correlated vortex dynamics reminiscent of a self-organized critical system. The absence of significant size-waiting-time correlations is explained in terms of a mean-field, compound Poisson model. The astrophysical implications for burst and continuous-wave gravitational radiation from glitching pulsars are explored.

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Current status of astrophysics of cosmic rays

I will review recent developments in astrophysics of cosmic rays and discuss their meaning and interpretation.

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The new concept of wormholes

The theoretical prediction of wormholes have been done about hundred years ago, almost at the same time as the prediction of black holes, but unlike black holes, wormholes in the Universe have not been discovered yet.

In this work the wormholes are divided into three types according to their properties:
1. Static wormholes,
2. Space-like wormholes,
3. Time-like wormholes.

We present the analysis of the wormholes properties for each type. The analysis of physical interconnections of wormholes and black holes is provided. The possible astrophysical manifestations of wormholes are investigated.

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Experimental study of Galactic and Extragalactic cosmic rays: for and against the theory

The report analyses recent experimental results in the study of galactic and extragalactic cosmic rays with ground-based and space instruments. A comparison of the most current models of acceleration and transport of cosmic rays in space the origin of which was Vitaly Ginzburg, is undertaken. The beginning of this century was marked by a breakthrough in terms of experimental studies of galactic, extragalactic cosmic rays. This was due to the development of experimental methods of measurements of Galactic Cosmic Rays, which by their physical characteristics closer to on ground accelerator instruments.Space experiments such as ATIC, CREAM, PAMELA, AMS-02, the NUCLEON has provided precision data on the energy spectrum and mass composition of galactic cosmic rays with energies less PeV, posmalaysia to rethink the nature of their origin. The same conclusion can be done about Ultra High Energy Cosmic Rays of extragalactic origin with energies in EeV and ZeV - interpretation of terrestrial plants is not yet fully fit into the framework of existing model's views. In the energy region characteristic of the transition region from galactic to extragalactic sources, one can also find new results to the proper understanding.

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(with A.P. Igoshev, J.G. Elfritz)

Post fall-back evolution of neutron stars

After a supernova explosion significant amount of matter can fall-back on a compact object. If it is a neutron star (NS) - then its properties can be significantly modified. Matter can screen magnetic field of a NS such that we observe an object with low surface magnetic field. It is believed that central compact objects in supernova remnants (CCOs) are examples of NSs which experienced a fall-back episode. Later, magnetic field diffuses out, and finally a radio pulsar can switch-on. Using numerical simulations we explore this possibility (MNRAS vol. 462, pp. 3689-3702, 2016; arXiv: 1608.08806). We distinguish three evolutionary epochs for the re-emergence process: the growth of internal toroidal field, the advection of buried poloidal field, and slow Ohmic diffusion. The efficiency of the first two stages can be enhanced when small-scale magnetic structure is present. The efficient re-emergence of high order harmonics might significantly affect the curvature of the magnetospheric field lines in the emission zone. So, only after few 10000yrs would the NS starts shining as a pulsar again, which is in correspondence with radio silence of CCOs. In addition, these results can explain the absence of good candidates for thermally emitting NSs with freshly re-emerged field among radio pulsars, as NSs have time to cool down, and supernova remnants can already dissipate.

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Between the disk and the star: boundary layers of astrophysical accretion disks

Disk accretion onto weakly magnetized astrophysical objects possessing a surface (such as planets, stars, white dwarfs, neutron stars) necessarily proceeds via a boundary layer that forms at the inner edge of the disk. In this layer the highly supersonic angular velocity of the disk material must drop from the Keplerian value in the disk to the rotation rate of the accreting object. Up to a half of all accretional energy is released in this layer, strongly affecting the spectra of such objects. How this happens and what physical processes mediate the angular momentum, mass, and energy transport inside the boundary layer has remained a mystery for decades. In this talk I will describe our recent discovery of a robust physical mechanism that naturally provides transport in the highly supersonic boundary layers of accretion disks, thus paving a way to understanding the properties of these disk regions. This mechanism relies on the excitation of large scale acoustic modes at the accretor-disk interface that propagate both into the star and in the disk. I will show that this transport mechanism is fully global in nature, can be understood analytically, and may affect not only the disk, but also the thermodynamical state of the accreting object. The implications of this finding for our understanding of the high- and low-energy accreting objects will be discussed.

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Tracing the gas composition of Titan´s atmosphere with Herschel : Advances and Discoveries

The nitrogen-dominated atmosphere of Titan, Saturn's largest moon, exhibits a great diversity and complexity of molecules and high organic material abundances. The origin of Titan atmosphere is poorly understood and its chemistry is rather complex. Here we will review key results and discoveries on the atmosphere of Titan obtained with the instruments onboard Herschel:
– an inventory of species detected including some isotopes from a survey between 51 and 671 microns.
– the determination of the abundance of trace constituents and comparisons with previous efforts
– the unexpectedly detection of hydrogen isocyanide (HNC), a specie not previously identified in Titan´s atmosphere, and the measurement of 16O/18O ratio in CO in Titan not previously published
– the determination of the vertical profile of water vapor over the 100–450 km

altitude range, distribution which does not follow previous predictions and allows to strength an Enceladus' activity as the source for the current water on Titan.

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The history of gamma-Ray astronomy from space

The history of gamma-ray astronomy from space can practically be subdivided into three time sections: In the first period from about 1960 to 1990 relatively small experiments with special scientific objectives were made, from which already fascinating results were obtained. From 1991 till 2000 NASA´ s Compton Gamma-Ray Observatory was in operation. It was the first mission performing comprehensive observations of the entire gamma-ray sky with broad capabilities, including low and high energies,full sky surveys ,study of time variability, and study of spectroscopy. Thanks to this Observatory gamma-ray astronomy became an integrated part of astronomy and astrophysics in general. Its discoveries were the foundations for current missions like INTEGRAL, SWIFT, AGILE and FERMI.

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Cosmic rays in intermittent magnetic fields

The propagation of cosmic rays in turbulent magnetic fields is a diffusive process driven by the scattering of the charged particles by random magnetic fluctuations. Random magnetic fields in the interstellar medium are highly intermittent, consisting of intense magnetic filaments and ribbons surrounded by weaker, unstructured fluctuations. Studies of cosmic ray propagation have largely overlooked intermittency, instead relying on Gaussian random magnetic fields. Using test particle simulations, we investigate cosmic ray diffusivity in intermittent, dynamo-generated magnetic fields. The results are compared with those obtained from non-intermittent magnetic fields having identical power spectra. The presence of magnetic intermittency significantly enhances cosmic ray diffusion over a wide range of particle energies. We demonstrate that the results can be interpreted in terms of a correlated random walk. We also explore the spatial distribution of cosmic rays and its relation to the topology of the random magnetic field that confines them.

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Violation of the Goldreich-Julian relation in a neutron star

The electromagnetic field in a magnetized neutron star and the underlying volume charges and currents are considered. It is shown that the charge density is not equal to and can exceed significantly the common Goldreich-Julian density. For a rotating neutron star, twisting magnetic field lines causes charge accumulation and current flows. This fact shows a possible link between changing internal magnetic field topology and observed activity of neutron stars.

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(with E. Yushkov)

Small-scale dynamo, helicity fluctuations and magnetic field generation in celestial bodies

Magnetic field of celestial bodies like the Earth, the Sun, Milky Way etc is believed to be excited by action of a dynamo based on differential rotation and mirror asymmetric convection or mirror asymmetric turbulence. Governing equation for large-scale magnetic field can be formulated in a closed form which do not includes explicit description of small scale magnetic fields or fluctuations of dynamo governing parameters.Underlying averaging is taken over the ensemble of turbulent (or convective) vortexes. The point however is that the number of vortexes in a given celestial body is as a rule quite moderate in comparison with, say, Avogadro number. As a result fluctuations in dynamo action play a much more substantial role rather in many other problems of statistical physics. We discuss several manifestations of fluctuations in particular problems of dynamo studies.

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eRosita X-ray and South Pole and Atacama Cosmology Telescopes microwave sky surveys: synergy and competition

Russia and Germany are planning to launch in 2018 the Spektr-RG (SRG) X-Ray observatory to the L2 point of the Sun-Earth system. The main goal of this observatory is to perform 8 all sky surveys in X-Rays during 4 years with 15"angular resolution and sensitivity 30 times higher than was achieved previously. There is a hope to discover more than 100 thousand clusters of galaxies: all clusters in the observable Universe more massive than 10^{14} Msun of dark matter and baryons. In addition we plan to detect at least 3 million of Active Galactic Nuclei (accreting supermassive black holes) and thousands of tidal disruption events due to disruption of stars by gravity of supermassive black holes. Many thousands of highly relativistic jets, tens of thousands gravitationally lensed extragalactic objects and a million of Galactic objects emitting in X-Rays like supernovae remnants, accreting neutron stars, black holes and white dwarfs in stellar binaries, young and coronal active stars will be detected. We plan to investigate the variability of these objects. These unique sky maps with millions of sources at significant redshifts will be used for the search of different cosmological effects to permit us to estimate the key properties of our Universe and of the dark energy and dark matter.

Very effective South Pole and Atacama Cosmology Telescopes with tens of thousands cryogenic bolometers in their focal planes will perform the competing sky survey in millimeter spectral band detecting clusters and groups of galaxies with comparable sensitivity using thermal and kinematic SZ-effects. In addition, they will detect a comparable amount of AGNs due to the presence of dusty tori around them. Synergy arising from the comparison of X-Ray and microwave sky maps will be enormous: it will provide a lot of beautiful physics of newly discovered objects and will permit to create the maps of the hot diffuse plasma distribution in the surrounding Universe.

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Photon momentum in a transparent insulator and stress-energy tensor in macroscopic electrodynamics (Импульс фотона в прозрачном диэлектрике и тензор энергии-импульса в макроскопической электродинамике)

Структура тензора энергии-импульса электромагнитного поля в макроскопической электродинамике, различная в записях Минковского и Абрагама, продолжает активно обсуждаться уже более ста лет. Настоящая работа касается этой же темы, но имеет два существенных отличия от предшествующих исследований: а)рассматривается только высокочастотное поперечное электромагнитное поле в виде квазимонохроматических волн (волновых пакетов) и не рассматриваются статические и квазистатические поля; б) используется квантовое описание макроскопического электромагнитного поля, впервые примененное В.Л. Гинзбургом в квантовой теории эффекта Вавилова-Черенкова. Приведем высказывания по затронутым вопросам этого выдающегося физика, который неоднократно возвращался в своих трудах к обсуждаемой проблематике: "Все сказанное позволяет считать тензор Абрагама "правильным"но, как нам представляется, объявить тензор Минковского "неправильным"можно, лишь подходя к проблеме несколько формально. Фактически же в большинстве ситуаций результаты, получаемые на основе использования тензоров Абрагама и Минковского, совершенно тождественны. Это дает возможность в соответствующих случаях не только пользоваться тензором Минковского, но даже делает это вполне целесообразным, если тем самым достигаются какие-то упрощения". И далее, говоря о силе Абрагама : "...учет действия этой силы в рамках классического подхода весьма прост (см. выше), но квантовомеханически он оказался бы, по-видимому, довольно громоздким делом. Так или иначе, насколько нам известно, такое квантовое рассмотрение еще не проведено". В настоящей работе произведен учет силы Абрагама на квантовом уровне, так как она включена в тензор натяжений $\sigma^A_{\alpha,\beta}$ Абрагама, и для всех компонент тензора энергии-импульса найдены квантовомеханические собственные значения. Но это сделано не для общего случая, который мог бы охватывать статические, квазистатические и быстропеременные поля, а для поперечного высокочастотного поля, для которого только и требуется квантовое рассмотрение. Статические и квазистатические поля полноценно описываются и классическими методами. При этом никаких противоречий не возникает. Но поперечное электромагнитное поле существенно отличается от поля, создаваемого неподвижными либо медленно движущимися заряженными частицами. Поэтому нет никаких априорных оснований считать, что формулы, описывающие плотности энергии и импульса поля, сохраняют свой вид во всем безграничном интервале частот и волновых чисел. Квантовые закономерности, свойственные высокочастотному поперечному полю, делают не только целесообразным, но и необходимым использование таких характеристик "фотонов в среде которые определяются плотностью импульса импульса по Минковскому $g^M = D \times B/4\pi c$ и связанной с ней формулой Гинзбурга $p^M = \hbar\omega\sqrt{\epsilon\mu}$ для импульса фотона (ϵ, μ - линейные отклики среды). Использование плотности импульса в форме Абрагама $g^A = E \times H/4\pi c$ и соответствующего импульса фотона $p^A = u\hbar\omega/c^2$, где u – групповая скорость, не согласуется с опытными данными и приводит к противоречиям. На основе проведенных расчетов можно сделать следующие выводы.

1. Для поперечных электромагнитных волн в прозрачной среде правильное значение плотности импульса дается формулой Минковского, а правильное значение импульса отдельного фотона дается формулой Минковского-Гинзбурга,

впервые использованной В.Л. Гинзбургом в 1940 г.
2. Достоверность этого вывода подтверждается принципом соответствия между классическим и квантовым значениями плотности импульса поперечных волн в среде, согласием с опытными значениями спина фотона в среде и правильным результатом для вероятности излучения фотона заряженной частицей (эффект Вавилова-Черенкова). Использование выражения Абрагама для этих целей ведет к противоречиям и не согласуется с экспериментальными данными. 3. Поскольку квантовое описание поперечного поля в среде включает как частный случай и его классическое описание с помощью уравнений макроскопической электродинамики, то сформулированный вывод, полученный из квантовой теории, сохраняет силу и в классической макроскопической электродинамике для случая высокочастотного поперечного поля. К статическим и квазистатическим полям этот вывод не относится.

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High energy neutrino astronomy: What have we learned?

The detection of high energy extra-terrestrial neutrinos by IceCube opens a new window for observations of the Universe. I will discuss the origin of these neutrinos, the clues that their detection provide towards the solution of the long standing question of the origin of cosmic-rays, and the prospects for identifying the cosmic-ray sources and for studying open questions in astro- and particle- physics using combined electromagnetic and neutrino observations.

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Two ways to weight graviton

In February 2016 the LIGO & VIRGO collaboration reported the discovery of gravitational waves in merging black holes, therefore, the team confirmed GR predictions about an existence of black holes and gravitational waves in the strong gravitational

field limit. Moreover, in their papers the joint LIGO & VIRGO team presented an upper limit on graviton mass such as $m_g < 1.2 \times 10^{-22}$ eV (Abbott et al. 2016) analyzing gravitational wave signal as it was suggested by C. Will (1998). So, the authors concluded that their observational data do not show any violation of classical general relativity. We show that an analysis of bright star trajectories could constrain graviton mass with a comparable accuracy with accuracy reached with gravitational wave interferometers and the estimate is consistent with the one obtained by the LIGO & VIRGO collaboration. This analysis gives an opportunity to treat observations of bright stars near the Galactic Center as a useful tool to obtain constraints on the fundamental gravity law such as modifications of the Newton gravity law in a weak field approximation. In that way, based on a potential reconstruction at the Galactic Center we obtain bounds on a graviton mass.

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Lunar dust – origin and dynamics

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(with V.S. Ptuskin)

Supernova remnants as sources of cosmic rays, gamma rays and neutrinos

Cosmic ray acceleration by astrophysical shocks in supernova remnants is briefly reviewed. Results of numerical modeling taking into account magnetic field amplification by streaming instability and shock modification are presented. Nonthermal emission produced by accelerated particles in young and old supernova remnants is compared with available data of modern radio, X-ray and gamma-ray astronomy. It is also shown that high energy neutrinos produced in supernova remnants of IIn extragalactic supernova can explain the recent IceCube detection of astrophysical neutrinos.

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Strong Correlation Effects and High-Tc Superconductors

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Fluctuations in quasi-1-dimensional superconductors

Superconducting properties of metallic nanowires can be entirely different from those of bulk superconductors because of the dominating role played by thermal and quantum fluctuations of the order parameter. For superconducting channels with diameters below ~ 50 nm fluctuations of the phase of the complex order parameter – the phase slippage – lead to non-zero resistance below the critical temperature. Fluctuations of the modulus of the complex order parameter broaden the gap edge of the quasiparticle energy spectrum and modify the density of states. In extreme case of very narrow channels imbedded in high-impedance environment (which fix the charge and, hence, enable strong fluctuations of the quantum-conjugated variable, the phase) the superconductor can be driven to insulating state – the Coulomb blockade. We review recent experimental activities in the field demonstrating rather unusual phenomena.

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(with N.S. Maslova)

Excitation of plasmons in planar tunnel junctions

Theory of plasmon excitation in planar tunnel junction based on nonequilibrium diagram technique in effective mass representation is presented. The theory shows that conditions for symmetric and asymmetric plasmonic modes excitation are quite different. Emission of low frequency asymmetric mode can be considerable only in planar structure with different metal banks of the junction. In the case of identical metal banks emission of low frequency asymmetric mode is negligible.

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(with P. Machon, M. Wolf and D. Beckmann)

Strongly spin-dependent effects at interfaces between superconductors and magnetic metals and insulators

First I will review the recent developments in the problem of spin-dependent boundary conditions for the quasiclassical Greens function. Those have implication for spin, charge and energy transport through interfaces between superconducting and magnetic materials. Second, I present a combined experimental and theoretical work that investigates the proximity effect of a ferromagnetic-insulator - superconductor (FI-S) interface. The experimentally found differential conductance of an EuS-Al heterostructure is compared with the theoretical one. The theoretical calculation is based on the recently developed boundary conditions, that treats arbitrarily strong spin-dependent effects. With the assumption of a uniform distribution of spin mixing angles that depend on the externally applied field, we already find good agreement between theory and experiment. The theory depends only on very few parameters, mostly specified by the experimental setup. As the main result, we observe that large spin mixing angles are possible, indicated by the highly nonlinear behaviour in dependence on an applied external field. We thus proof that it is not possible to generally assume weak spin-dependence, as it is usually done in theoretical treatments of ferromagnet-superconductor interfaces.

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(with M. Skvortsov)

Magnetic disorder in superconductors: Enhancement by mesoscopic fluctuations

We study the density of states (DOS) and the transition temperature T_c in a dirty superconducting film with rare classical magnetic impurities of an arbitrary strength described by the Poissonian statistics. We take into account that potential disorder is a source for mesoscopic fluctuations of the local DOS, and, consequently, for the effective strength of magnetic impurities. We find that these mesoscopic fluctuations result in a non-zero DOS for all energies in the region of the phase diagram where without this effect the DOS is zero within the standard mean-field theory. This mechanism can be more efficient in filling the mean-field superconducting gap than rare fluctuations of the potential disorder (instantons). Depending on the magnetic impurity strength, the suppression of T_c by spin-flip scattering can be faster or slower than in the standard mean-field theory.

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Coexistence of superconductivity and magnetism at the nanoscale

In the bulk magnetic superconductors the antagonism between ferromagnetism and singlet superconductivity leads to the spectacular effects such as a re-entrant superconductivity and the short period domain structure formation. With a decrease of the temperature this domain structure may be transformed into a self-induced vortex phase. Another interesting case of the coexistence of magnetism and superconductivity is realised in in superconductor-ferromagnet heterostructures, where the damped oscillatory behaviour of the Cooper pair wave function leads to the formation of the special Pi-Josephson junctions, with a spontaneous ground phase difference. The noncollinear magnetization of the ferromagnetic layer provides the conditions necessary to generate the triplet superconducting correlations. By tuning the Josephson current, one may manipulate the long-range induced magnetic moment. The induced magnetic moment controlled by the Josephson current may be used in spintronics devices instead of the spin-torque effect. The proposed mechanism seems to be attractive for superconducting spintronics devices with low dissipation because it provides a direct coupling between the superconducting current and magnetization.

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Quantum generalization of the Thomas – Fermi approach: exactly solvable example

Correct allowing for the interparticle interaction in many-body systems faces considerable mathematical difficulties. The most frequently used approximation in such problems is the mean field approximation (MFA) which neglects fluctuations and the particles are considered as a continuous medium of inhomogeneous density. If , moreover, the system is described by the classical distribution function (the statistics can be a quantum one) we obtain the well known Thomas - Fermi approach .However there are situations when at least some of the degrees of freedom of the system have to be treated in accord with quantum mechanics. Such examples are electrons in quantum wells or dipolar excitons in an electrostatic trap. In such cases the density of particles appearing in MFA is to be expressed via wave functions of a particle in the effective potential. The latter, in its turn, depends on the wave functions and occupation numbers, so one has to solve a self-consistent problem. In case of a short-range interparticle pair potential (2D gas of dipolar excitons) a nonlinear wave equation arises while for the long-range (Coulomb) pair interaction the corresponding equation becomes integro-differential (nonlocal effects).

The present talk deals with two different systems: bose –gas of dipolar excitons in a ring shape trap and fermi-gas of electrons in a quantum well of a MOS-structure. The trapped excitons are described by the Gross-Pitaevsky nonlinear equation and for the very simple case of the rectangular potential of the 'bare" trap the exact analytical solution is found. The most interesting result of this problem is criterion for existence of bound state in the effective potential (in the one particle problem a 1D symmetric potential well always contains at least one bound state) . In case of electrons in a quantum well one deals with nonlinear integro-differential equation for which the exact solution is unknown. The direct variational method was used to find the frequency of the intersubband transition. This frequency turned out to be scaled with the electron concentration N as $N^{2/3}$.

The work has been supported by RSF.

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(with A. Golubov, O. Dolgov)

Tracing the $s\pm$-symmetry in Fe-based superconductors by controlled disorder

Determining the symmetry of the superconducting order parameter is the most important but also the most complicated step in elucidating the mechanism of superconductivity. In the talk it will be shown that systematic study of the response of introduced disorder to a superconductor is a phase-sensitive tool to probe the order parameters of superconductors. The role of disorder in multiband superconductors (such as Fe-based pnictides) will be reviewed. It will be shown that impact of impurities in multiband superconductors is beyond of a common wisdom: the impurities in s+- superconductors suppress Tc in the same way as paramagnetic ones in common superconductors, and vice versa magnetic impurities act as nonmagnetic ones. Impurities (nonmagnetic as well as magnetic) themselves can give rise new phenomena like change of the symmetry of superconductive order parameter. As a result, intrinsically phase-insensitive experimental methods like tunneling, ARPES, terahertz spectroscopy may be used for revealing of information about the underlying order parameter symmetry. Finally we present an investigation of a Ba(Fe0.9Co0.1)2As2 thin film by THz spectroscopy and stepwise proton irradiation. With increase of the irradiation, the low-energy superconducting gap first vanishes but recovers at higher irradiation doses. At the same time, the decrease of the superfluid density with disorder comes to a halt. The behavior is explained by the change from sign-reversed (s±) to sign-preserved (s++) symmetry and consequently by s± symmetry in the pristine sample.

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Spintronics with spinpolarized Cooper pairs

In 1956, Vitaly Ginzburg was the first to formulate the problem of coexistence of ferromagnetism and superconductivity, following his stunning prediction in 1950 of a macroscopic quantum wavefunction in superconductors that provides the order parameter in Lev Landau's theory of second-order phase transitions. Since then, this problem has led to a multitude of new fruitful discoveries, predictions, and applications. In particular, the past 15 years have seen a series of pivotal experimental discoveries relating to spin physics in superconductor-ferromagnet heterostructures. This resulted into new synergies between the fields of superconductivity and spintronics. Superconducting spintronics has the potential and flexibility to become on of the major players in meeting the challenge of energy-efficient large-scale computing and data management. The building blocks of superconducting spintronics are equal-spin Cooper pairs, which are generated at the interface between superconducting and magnetic materials in the presence of non-collinear magnetism. Such spin-polarised Cooper pairs carry spin-supercurrents in ferromagnets and thus contribute to spin transport and spin control. Geometric Berry phases appear in structures with non-coplanar magnetisation profile, enhancing functionality. Spin-orbit locking in noncentrosymmetric materials may lead to topological superconductivity. I will present developments and discuss theoretical predictions in this young field.

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Critical behavior of correlated fermionic systems at classical and quantum phase transitions

In this talk I describe application of dynamic vertex approximation to studying critical behavior of correlated fermionic systems in three dimensions. Despite the absence of an infrared cutoff, which is consequently removed in renormalization-group approach, the described method allows to predict correct values of critical exponents. For the classical phase transition in the half-filled Hubbard model with nearest neighbor hopping we obtain O(3) Heisenberg critical exponents in agreement with the respective universality class; the width of the critical regime agrees with the Ginzburg criterion. For small deviations from half filling the critical exponents do not change, since the universality classes of antiferromagnetic and spin-density wave transitions are the same. However, when approaching quantum critical point, the new tipe of the quantum critical behavior, governed by Kohn anomalies of the electronic spectrum, emerge. This latter behaviour is not described by the dynamic version of the Landau-Ginzburg-Wilson theory.

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Negative charge transfer gaps, ligand holes and self doping, or how to make magnetic gold?

In this talk I will discuss some effects occurring in transition metal compounds with small or negative charge transfer gap and with large contribution of ligand (e.g. oxygen) holes. Special attention will be paid to the compounds of 4d and 5d elements. The apparent inversion of crystal field levels, as well as the tendency to spontaneous charge disproportionation will be discussed. Specifically, some systems containing gold, such as $Cs_2Au_2Cl_6$ and $AuTe_2$ will be discussed, and the question formulated in the title will be addressed.

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New phenomena in exciton-polariton condensate

Due to great successes in experiments with exciton polariton condensates in optical microcavity with embedded quantum well we consider new collective and transport effects in the system. We use two-component exciton-photon approach formulated particularly in terms of path integral formalism. The role of pumping and leakage are analyzed. In order to describe spatial distributions of the exciton and photon condensate densities, the two coupled equations of the Gross-Pitaevskii type are derived. The two-component approach gives an opportunity to describe different spatial profiles of coupled condensates photons and excitons. The photon subsystem in strong exciton traps appears to be much less localized. The inner structure of vortices in Bose-Einstein condensates of exciton polaritons was studied by two-component approach. The set of coupled equations of the Bogoliubov-de-Gennes type was derived to describe the spectra and spatial distributions of noncondensate photons and excitons. We predict exciton-photon oscillatory dynamics within polariton gas in the presence of energy detuning between the cavity photon and quantum well exciton modes. Whereas pure Rabi oscillations consist of the particle exchange between the photon and exciton states in the polariton system without any oscillations of the phases of the two subcondensates, we demonstrate that any nonzero detuning results in oscillations of the relative phase of the photon and exciton macroscopic wave functions. Different initial conditions reveal a variety of behaviors of the relative phase between the two condensates, and a crossover from Rabi-like to Josephson-like oscillations is predicted. Inner Josephson soliton-like excitations are described. Drag effect and control of polariton condensate by neighboring electron system are analyzed. We discuss the possible experimental observation of the drag effects in the system of electrons and microcavity polaritons, that also allow to observe the cavity polaritons superfluidity. Possible applications of this effect in photonics is discussed.

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(with I.M. Khaymovich, J.P. Pekola)

Nonequilibrium dynamics of Majorana states in superconductors

We report on the results of theoretical study of the nonequilibrium dynamics of Majorana states in superconducting systems. Starting from the time-dependent Bogolubov-de Gennes model we show that a pair of Majorana states is strongly sensitive to the low-frequency per-turbations which excite the beating of the wavefunction between the distant Majorana states. This beating phenomenon results from the mixing of the quasiparticle with the positive and negative energies in the dynamic processes. According to our consideration any driving of Majorana states with the typical operating frequency exceeding the energy of their coupling brings the system to the non-equilibrium regime imposing, thus, an important restriction on the operating frequencies of such a device and hampering the observation of non-Abelian physics due to the beating effect. We propose several experimental tests to measure the characteristic time scales of the dynamics of the Majorana pair.

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(with A .Subbotin)

The mechanism of solute-enriched clusters formation in neutron-irradiated pressure vessel steels

Irradiation-induced hardening of nuclear reactor pressure vessel (RPV) steels is related to dislocations pinning on ensembles of small size (2 – 4 nm) quasi-spherical clusters enriched with solute elements, such Cu, Mn, Ni, and Si. This phenomenon raises many questions about origination, the strength, and the lifetime of such objects as various type pinning centers. We propose a new mechanism of irradiation-induced formation of solute-enriched clusters in neutron-irradiated pressure vessel steels and solve the developed model in case of Fe-Cu model alloys. The proposed solute-drag mechanism is analogous to the well-known zone-refining process. It is based on local high-speed processes caused by the displacements cascade due to thermal spike, initiating the formation of a melt zone (during ps). In the second stage there is a gradual contraction (solidification) of the melt zone at temperatures slightly above the ambient temperature (K), i.e. in conditions of significant overcooling. This stage can last as long as ps, and it is on this stage the "solute drag" and the formation of the solute enriched clusters is happened. Upon completion of the local processes and temperature equilibration, the formed copper-enriched cluster becomes "quasi-frozen". We show that the obtained results are in good agreement with available experimental data on the parameters of clusters enriched with the alloying elements. Our model explains why the formation of solute-enriched clusters does not happen in austenitic stainless steels with fcc lattice structure. It also allows to quantify the method of evaluation of neutron irradiation dose for the process of RPV steels hardening.

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(with B. Karimi, A. Ronzani and J. Senior)

Superconducting quantum refrigerator

We describe a four-stroke quantum Otto refrigerator based on a superconducting qubit [A.O. Niskanen, Y. Nakamura and J.P. Pekola, Phys. Rev. B 76, 174523 (2007), B. Karimi and J.P. Pekola, Phys. Rev. B 94, 184503 (2016)]. Under stationary conditions, this element works also as a quantum heat switch, on which we present preliminary experimental results. In the final part we discuss the influence of noise correlation on the operation of a quantum refrigerator based on multiple qubits [B. Karimi and J.P. Pekola, submitted].

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Many-body localization: Metal-insulator transition at finite temperature

I will discuss recent advances in our understanding of the interplay of disorder and interactions in regard to many-body localization. The essence of this phenomenon is that certain interacting disordered systems in the absence of coupling to the external world cannot maintain ergodicity by themselves and become an insulator with respect to charge and energy transport below a critical temperature. In particular, the conductivity of the interacting system becomes exactly zero – despite the temperature being finite. The subject continues to develop at a rapid pace on the theory side and signatures of the many-body localization transition have recently been observed in indium-oxide films in the vicinity of the superconductor-insulator transition and in various systems of cold atoms in optical lattices. One of the important issues that will be primarily addressed in the talk is the scaling of the position of the localization threshold. One of the key concepts that will be discussed in this connection is that of dephasing by spectral diffusion. I will also discuss interaction-induced hybridization in Fock space of two systems that represent, in a certain sense, limiting cases: the interacting quantum dot and the interacting Anderson insulator in a continuum. In the latter case, the resistivity is predicted to increase in the limit of zero temperature faster than in the Arrhenius law.

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Dynamical quantum phase transition in Bose-Anderson impurity model

Phase transition can be defined as a point where a quantum system having perfectly regular Hamiltonian shows a singular dependence of its equilibrium properties on certain parameter. Recently, this concept has been extended to the out-of-equilibrium case: dynamical phase transitions were reported [M. Heyl, A. Polkovnikov and S. Kehrein, Phys. Rev. Lett. 110, 135704 (2013)], which are singularities arisen after a finite time of evolution of a quantum ensemble.

We will discuss the dynamical quantum phase transition occurring in the Bose-Anderson impurity model. This model describes a 2-4 nonlinear bosonic oscillator (impurity) coupled to the Gaussian lattice acting as a thermostat. For a power-law density of lattice states, a broken-symmetry phase emerges, in which the impurity is surrounded by the cloud of local Bose-Einstein condensate [H.-J. Lee, K. Byczuk, and R. Bulla, Phys. Rev. B 82,054516 (2010)]. After a sudden increase of the local chemical potential of the impurity (quench), the cloud start emitting particles. For small values of the quench, it evolves towards the new ground state. For larger quenches, the evolution ends with a stable excited state [D.V. Chichinadze, P. Ribeiro, Y.E. Shchadilova, A.N. Rubtsov Phys. Rev. B 94, 054301 (2016)]. The two regimes are separated by the dynamical transition. We observe [D.V. Chichinadze, A.N. Rubtsov arXiv:1701.03332] a critical time t^*, and detect a dynamical critical behavior at $t > t^*$.

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(with A.D. Zaikin)

QPS induced shot noise in superconducting nanowires

At low temperatures non-equilibrium voltage fluctuations can be generated in current-biased superconducting nanowires due to proliferation of quantum phase slips (QPS) or, equivalently, due to quantum tunneling of magnetic flux quanta across the wire. This phenomena is similar to the macroscopic quantum tunneling of phase in Josephson junctions and weak links.

In our talk we will review theoretical results related to these phenomenona and present our recent calculations of the voltage noise generated by quantum phase slips in short superconducting bridges and superconducting nanowires. We will discuss similarities and differences between cases of long and short length of the wires and demonstrate that quantum phase slips generate quantum shot noise which vanishes at frequencies beyond some threshold value in the zero temperature limit.

The results of our theoretical analysis can be directly tested in future experiments with superconducting nanowires and Josephson junctions.

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(with D.I. Khomskii)

"Molecules"in solids

We show that there are inorganic transition metal compounds, which demonstrate distinct features of molecular systems. Their physical properties look unusual and sometimes puzzling, if these materials are considered in a conventional paradigm of the solid state physics. E.g. one might hardly expect that layered SrRu2O6 would have a high magnetic ordering temperature, but in fact the Neel temperature is 540 K in this system, in spite of its quasi-2D structure. This is partially due to formation of the Ru6 molecular orbitals on a perfect honeycomb lattice [S. Streltsov, I.I. Mazin, K. Foyevtsova, Phys. Rev. B 92, 134408 (2015)], which are also expected to strongly affect optical properties of this material [Z.V. Pchelkina, S.V. Streltsov, I.I. Mazin, Phys. Rev. B 94, 205148 (2016)]. In addition to such a straightforward manifestation of the "molecular physics" it often peeks though conventional conceptions of the condensed matter physics and leads to such effects as orbital-driven Peierls transition, formation of nonmagnetic clusters, orbital-selective Mott transition and suppression of the double exchange [S.V. Streltsov and D.I. Khomskii, Phys. Rev. B 89, 161112(R) (2014), S.V. Streltsov and D.I. Khomskii, PNAS 113, 10491 (2016)].

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(with E.G. Idrisov and I.P. Levkivskyi)

Thermal decay of charge fluctuations in mesoscopic circuits

We study transport properties and the charge quantization phenomenon in a small metallic island connected to the leads through two quantum point contacts (QPCs). The linear conductance is calculated perturbatively in tunneling at QPCs as a function of the temperature T and gate voltage for the cases of weak tunneling and weak backscattering. The conductance shows Coulomb blockade oscillations as a function of the gate voltage that decay with the temperature as a result of charge fluctuations. The regimes of quantum, $T << E_C$ and thermal, $T >> E_C$, fluctuations are considered, where E_C is the charging energy of the isolated island. Our predictions for these oscillations in the quantum regime coincide with previous findings in [A. Furusaki and K. A. Matveev, Phys. Rev. B 52, 16676 (1995)]. In the thermal regime the visibility of Coulomb blockade oscillations decays with the temperature as $T^{1/2}\exp(-\pi^2 T/E_C)$, where the exponential dependence originates from the thermal averaging over the instant charge fluctuations, while the prefactor has a quantum origin. This dependence is robust and does not depend on the strength of couplings to the leads. The differential capacitance, calculated in the case of a single tunnel junction, shows the same exponential decay, however the prefactor is linear in the temperature. This difference can be attributed to the non-locality of the quantum effects. Our results agree with the recent experiment [S. Jezouin et al., Nature 536, 58 (2016)] in the whole range of the parameter T/E_C.

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(with V.N. Menshov, E.V. Chulkov)

Spin Hall conductivity in 3D topological insulator/normal insulator heterostructures

Our work shed light on the possibility for achieving a control of electron properties in the 3D topological insulator/normal insulator heterostructures. We demonstrate that the Spin Hall effect in the 3D topological insulator thin film sandwiched between normal insulator slabs is more complicated than it was thought before. The phase diagram of this system contains altered regions of normal and quantum spin Hall regime. So, experimental and theoretical explorations of the finite size and interface effects in studied heterostructures remain to be a challenging task.

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(with S.V. Lepeshkin, V.S. Baturin, N.A. Fokina)

Trends in the structure and properties of silicon nanoclusters

Semiconductor nanoparticles show many remarkable properties, which are promising for electronics, photovoltaics, biomedicine and other applications. Among their features is atomic structure, which is unique for each particle size and composition and differs significantly from the structure of a bulk semiconductor. As experimental data about nanoparticle structure are very scarce, most structural information is obtained from first-principles calculations. The present research applies first-principle approach to analyze structure, thermodynamics, a P-T phase diagram, an electron spectrum, etc in two large groups of silicon nanoclusters: SinH2m ($n \leq 12$, $2m \leq n + 10$) and SinOm ($n \leq 10$, $m \leq 2n + 8$). Because of differing H and O valences, structural trends in these groups are dissimilar.

Hydrogen atoms are disposed at the cluster surface, where they passivate the dangling bonds of Si atoms. As H-passivation is increased, the structure becomes less compact to house a growing number of H atoms. The most interesting issue is the demarcation between amorphous and crystalline cluster structures. We found that the most stable clusters are invariably crystalline and lie immediately after the demarcation line. This finding was also supported by our graph theory estimations.

This result is of interest for many applications, as the quantum yield of crystalline nanoparticles is much higher in comparison with amorphous ones.

Oxygen atoms prefer bridging positions between Si atoms, so strong Si-O-Si bonds are formed inside a cluster. When all bridging positions are filled, oxygen atoms occupy the cluster surface, where they form 10 characteristic groups of atoms, which can be classified rigorously. The most stable clusters are those of silicon dioxide composition (SiO2)n. An unexpected result is that super-oxidized clusters (of SinO2n+k composition with $k \geq 1$) are solely in equilibrium with oxygen gas at ambient conditions. Extra oxygen atoms are magnetic, responsible for light emission and relevant to reactive oxygen species (ROS). We discuss the importance of these results for nanotechnology and miscellaneous applications, including biomedical ones.

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(with A.V. Galaktionov, D.S. Golubev)

Andreev levels as a quantum dissipative environment

Employing the effective action theory [A.V. Galaktionov and A.D. Zaikin, Phys. Rev. B 82, 184520 (2010), A.V. Galaktionov and A.D. Zaikin, Phys. Rev. B 92, 214511 (2015)] we demonstrate that at subgap energies quantum behavior of superconducting weak links can be exactly described by an effective Hamiltonian for a Josephson particle in a quantum dissipative environment formed by subgap Andreev levels inside the junction. We investigate the problem of macroscopic quantum tunneling of the superconducting phase in such hybrid structures, evaluate both quantum and thermally activated supercurrent decay rates and identify the crossover conditions between these regimes. We also predict the possibility for non-monotonous dependence of the switching current distributions on temperature and elucidate the physics behind this non-trivial effect. In addition, we demonstrate that superconducting qubits fabricated with such highly transparent hybrid nanojunctions may be subjected to intrinsic dephasing caused by an effective dissipative environment formed by Andreev levels.

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High-Energy Physics

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Specific properties of elastic scattering and inelastic profiles of high energy protons

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Elastic and inelastic diffraction at the LHC

Diffractive phenomena at the LHC are studied by several collaborations there. In this paper we present our recent results connected with the current and future studies at the LHC, namely the deviation of the exponential behavior in elastic proton-proton scattering at low values of $|t|$ and central exclusive resonance production. Although the above phenomena occur in different kinematical regions, they are related e.g. by Regge-factorization.

Deviation from the exponential behavior of the diffraction cone observed near both at the ISR and the LHC (so-called break) follows from a two-pion loop in the -channel imposed by unitarity. By using a simple Regge-pole model we extrapolate the "break"from the ISR energy region to that of the LHC. A model for Pomeron-Pomeron total cross section in the resonance region is also presented.

Central production is treated in a Regge pole including the Pomeron and two different trajectories, as well as an isolated $f_0(500)$ resonance in the region. A slowly varying background is included. The presented Pomeron-Pomeron cross section is not directly measurable, but is an essential ingredient for calculating exclusive resonance production at the LHC.

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Sound in anisotropic hydrodynamics

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(with I.M. Dremin)

Model description of proton interactions

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(with A. Dolgov)

A cosmological bound on e^+e^- mass difference

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We demonstrate that CPT-violation due to the e^+e^- mass difference breaks an electric current conservation and generates a photon mass. Cosmological bounds on the photon mass lead to the bound for e^+e^- mass difference that is 10-15 orders of magnitude stronger than any direct experimental bounds.

A. Radovskaya

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Quantum correction to the Classical Statistical Approximation

Classical Statistical Approximation (CSA) is the well known semiclassical method of the quantum fields description. This approximation can be found (under different names) in a wide range of the physical topics like the ultrarelativistic heavy ion collisions, the early Universe, the ultracold gases, chemical physics and others. The CSA is often used for numerical simulations because it is a summation over a large amount of similar configurations. In our work we propose the method of calculation of the quantum corrections to the CSA. We explore the range of applicability of this approximation and some special properties of the method for the expanding coordinate system on the simple homogeneous $\phi 4$ model.

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(with J.-R. Cudell)

The local and integrate dispersion relations and the analytic structure of the hadron elastic scattering amplitude at LHC energies

The determination of the phase of the elastic scattering amplitude from the point of view of the local and integrate dispersion relations is presented. It is shown by the different methods that the local and integrate dispersion relations lead to the same results. Thw analysis of the new experimental data obtained by the TOTEM and ATLAS Collaborations at LHC is carried out with taking into account the statistic and systematic errors. The dependence of the slopes of the different parts of the scattering amplitude on the momentum transfer is examined under some model assumptions.

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Finite time measurements by Unruh-DeWitt detector and Landauer's principle

The model of Unruh-DeWitt detector coupled to the scalar field for finite time is studied. A systematic way of computing finite time corrections in various cases is suggested and nonperturbative effects like thermalization are discussed. It is shown in particular that adiabatic switching off the coupling between the detector and the

thermal bath leaves non-vanishing corrections to the detector's levels distribution. Considering the two level detector as an information bearing degree of freedom encoding one bit of information, limits on external work for the detector's (de)couling in finite time following from the Landauer's bound are formulated.

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Confinement and deconfinement in QCD

Theory of confinement in QCD,based on the vacuum averages of field correlators,called the Field Correlator Method(FCM),is studied in several directions.It explains the internal structure of confining fluxes and quark-antiquark interaction,including spin-dependent forces and hadron structure.It is shown how FCM generates chiral symmetry breaking with the resulting chiral Lagrangian and all known chiral relations. The FCM also yields the theory of deconfinemnt, where colorelectric confinement disappears and the colormagnetic instead becomes the dominant factor, resolving the Linde problem. The resulting thermodynamic potentials $p(T)$, $I(T)$, $s(T)$ demostrate a first order SU(3) transition and a crossover in full QCD.

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Triple parton scattering in perturbative QCD

The theoretical formulas for triple parton scattering cross sections are considered in the terms of the modified collinear three-parton distributions. The possible phenomenological issues are discussed.

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(with M. Baznat, K. Gudima, A. Sorin)

Vorticity and polarization in heavy-ion collisions: from micro- to macrophysics and back again

The particles produced in heavy-ion collisions may be described in the macroscopic manner, resulting in the appearance of velocity, vorticity and chemical potentials. The vorticity forms the toroidal structures ("femto-cuclones"or "small galaxies"). The analogy of velocity to gauge field and chemical potential to coupling leads to generation of induced axial currents by the triangle anomalies. These currents should lead, in turn, to polarization of hyperons rapidly decreasing with energy together with chemical potential. Such a behaviour, predicted several years ago, was recently discovered by STAR collaboration and can be studied in detail at NICA collider, whiich is currently under construction at JINR.

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(with S.I. Godunov and B. Machet)

On the resonances in positron scattering on a supercritical nucleus and e^+e^- pairs production

Solving the Dirac equation for a positron in the Coulomb field of the nucleus with $Z > Z_{cr}$ we observe (confirm) the resonance behavior of the scattering phase $\delta_\kappa(\epsilon_{\mathrm{positron}})$. Physical interpretation of these resonances is suggested.

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Quantum Field Theory

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Odd scalar curvature in Batalin-Vilkovisky formalism

We review our findings.

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(with A.I. Onishchenko)

Reggeon amplitudes in N=4 SYM and ambitwistor strings

We consider the description of form factors of Wilson line operators (reggeon amplitudes) within the framework of four dimensional ambitwistor string theory. We present the explicit expressions for string composite operators corresponding to Wilson line operators insertions. It is shown, that corresponding tree-level string correlation functions correctly reproduce previously obtained Grassmannian integral representations of Wilson line form factors. Some simple loop integrands are discussed as well. As by product we derive four dimensional tree-level scattering equations representations for the Wilson line form factors.

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One-loop divergences in $6D$, $N = (1, 0)$ and $N = (1, 1)$ SYM theories

We consider the general six-dimensional $N = (1, 0)$ SYM theory formulated in $6D$, $N = (1, 0)$ harmonic superspace. The theory is quantized in the framework of background field method. One-loop divergences are calculated off-shell in mnifestly gauge invariant and $N = (1, 0)$ supersymmetric form both in vector multiplet and in hypermultiplet sectors. The results are applied to $N = (1, 1)$ SYM theory which is treated as the $N = (1, 0)$ vector multiplet model coupled to hypermultiplet in adjoint representation of gauge group. It is proved that the $6D$, $N = (1, 1)$ SYM theory is one-loop finite off-shell.

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(with J.E. Andersen, G. Borot and N. Orantin)

The ABCD of topological recursion

Kontsevich and Soibelman approach to the topological recursion interpret it as a quantization of certain quadratic Lagrangians in tangent space for some vector space V. KS topological recursion is a procedure which takes as initial data a quantum Airy structure – a family of at most quadratic differential operators on V satisfying some axioms – and gives as outcome a formal series of functions in V (the partition function) jointly annihilated by these operators. We study problem of finding and classifying quantum Airy structures modulo gauge group action. I will exhibit a general construction supported by some infinite and finite-dimensional examples.

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(with T. Settlemyre, J. Merritt, K. Milton, P. Parashar, P. Kalauni)

Modeling boundary energy with a power-law potential

This is a progress report on an investigation of the vacuum expectation values of the stress-energy-momentum tensor of a scalar field near a flat boundary. To regularize the divergence caused by perfect reflection without causing an anomalous relation between energy and pressure, we model the boundary as a Klein-Gordon potential proportional to a power of the distance into the wall. The energy density and pressure at a point are expressed as integrals with respect to wave number over partial derivatives of the reduced Green function of the field equation. Calculations outside the wall have been done successfully, and the theory of renormalization of the interaction inside is in good shape. Detailed calculations inside are being done both numerically and by analytical approximations (perturbative, WKB, and spline) appropriate to various regimes of position and wave number.

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(with D.M. Gitman)

Vacuum instability in slowly varying electric fields

Nonperturbative methods are well-developed for QED with the so-called t-electric potential steps. In this case a calculation techniques is based on the existence of specific exact solutions (in- and out-solutions) of the Dirac equation. However, there are only few cases when such solutions are known. Here, we demonstrate that for t-electric potential steps slowly varying with time there exist physically reasonable approximations that maintain the nonperturbative character of QED calculations even in the absence of the exact solutions. Defining the slowly varying regime in general terms, we can observe an universal character of vacuum effects caused by a strong electric field. In the present work, we find universal approximate representations for the total density of created pairs and vacuum mean values of the current density and energy-momentum tensor that hold true for arbitrary t-electric potential step slowly varying with time. These representations do not require knowledge of corresponding solutions of the Dirac equation, they have a form of simple functionals of a given slowly varying electric field. We establish relations of these representations with leading terms of derivative expansion approximation. These results allow one to formulate some semiclassical approximations that are not restricted by smallness of differential mean numbers of created pairs.

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(with S.I. Godunov)

Spatial structure of the modified Coulomb potential in a superstrong magnetic field

The modification of the Coulomb potential due to the enchancement of loop corrections in a superstrong magnetic field $B > 10^{15}$ G is studied numerically. We calculated the modified potential with high precision and obtained the pattern of equipotential lines around a probe charge. The potential structure is significantly perturbed, so it become ellipsoidal and stretched along the magnetic field. The results confirm the general features known from previous studies [Shadab and Usov PRD 2008, Vysotsky PRD 2012], however we emphasize some differences in the potential structure that can be important for problems with spatially distributed charges.

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Superfield counterterms in 6D, $\mathcal{N} = (1,1)$ SYM theory from hidden $\mathcal{N} = (0,1)$ supersymmetry

Using the harmonic superspace approach and the $\mathcal{N} = (1,0)$ superfield description of $\mathcal{N} = (1,1)$ SYM theory as $\mathcal{N} = (1,0)$ SYM minimally coupled to the hypermultiplet in adjoint representation, we construct for this theory possible candidate superfield counterterms with the canonical dimensions d=6, 8 and 10. The d=6, 8 counterterms are at least on-shell vanishing that amounts to one- and two-loop UV finiteness of $\mathcal{N} = (1,1)$ SYM theory. In fact, the explicit quantum calculations demonstrate a stronger property of *off-shell* one-loop finiteness of this theory.

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UV divergences and RG equations in non-renormalizable theories

It is well known that in renormalizable theories the UV divergences (high-energy asymptotics) are governed by the renormalization group equations. However, the R-operation is valid in any local field theory irrespectively of renormalizable it is or not. As it follows from the Bogoliubov-Parasiuk theorem the counter terms are always local. This very statement applied to non-renormalizable theories allows one to construct the counter terms and to write down the RG equations. We consider this procedure on example of $D = 8$ SUSY gauge field theory. This choice though looking rather complicated in fact is essentially simplified using the modern spinor-helicity fornalism. To be more specific we consider the four-point amplitude on shell in the planar limit. We construct the RG equations in the leading approximation and solve them analytically in the ladder approximation. We consider then the subleading approximation for the same diagrams. This allows us to get explicitly the all loop leading and subleading divergences. Then we trace the scheme dependence of the obtained counter terms. The conclusion is surprisingly straightforward: the construction of the counter terms in renormalizable and non-renormalizable theories is just the same. The only difference is that while in renormalizable theories all UV divergences are absorbed into a single dimensionless coupling and the scheme dependence is reduced to the definition of this coupling, in non-renormalizable case this dimensionless coupling is constructed of the original gauge coupling multiplied by a kinematical factor like the Mandelstam variables s, t or u in our case. The interpretation of this observation remains still unclear.

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(with I.V. Tyutin)

Special values of coupling constants in Calogero models

It is known (due to P. Etingof, I. Losev) that the algebra of observables (deformed Fock space) of the Calogero models based on the root system is simple for almost all values of the coupling constants. We concider the Calogero model based on rank-2 root systems and the bilinear forms generated by traces or by supertraces. We found all the values of the coupling constants for which some nonzero such forms become degenerate, and the algebra of observables acquires ideals, i.e., is not simple anymore.

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Some more about helices and the spin-light effect

The major QED spin additions to the radiation rate and radiation power include the magnetic moment and inertial spin effects. Those could be described in full classically through the system of Lorentz - Frenkel equations. The latter lead to some generalization of the constant background world lines which, in the case of Lorentz - BMT theory, would be a helices. We analyze one 'soft' generalization of the backgrounds in the Lorentz - Frenkel case. The possible application of the Lorentz - Frenkel theory to the spin-light experiment is also discussed.

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Neutrino oscillations in the Standard Model

We constructed the Hilbert spaces of particle states in such a way that the fermions with the same electroweak quantum numbers (i.e. the neutrinos, the charged leptons, and the down- and up-type quarks) are placed in multiplets and are treated as different quantum states of a single particle. That is, in describing the electroweak interactions it is possible to use four fundamental fermions only.

In the theory based on the Lagrangian of the fermion sector of the Standard Model modified in accordance with this construction, the mixing and oscillations of the particles arise as a direct consequence of the general principles of quantum field theory.

This approach enables one to calculate the probabilities of the processes taking place in detectors at long distances from the source. Calculations of higher order processes including the computation of the contributions due to radiative corrections can be performed in the framework of perturbation theory using the regular diagram technique.

The developed approach is used to study neutrino oscillations. It is shown by the example of the pion decay that the states of the neutrino produced in the decay process can be described by a superposition of states with different masses and identical canonical momenta with very high accuracy.

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(with E. Buchbinder)

Superpotentials in Heterotic String Theory and Discrete Torsion

The non-perturbative superpotential in E8 × E8 heterotic string theory on a non-simply connected Calabi-Yau threefold Xwill be derived and discussed. The superpotential is induced by the string wrapping holomorphic, isolated, genus 0 curves. We point out that, in certain cases, curves can have different area with respect to the physical Kahler form and, hence, lie in different homology classes on the covering space. In these cases, the Beasley-Witten residue theorem is not applicable and the superpotential can be non-vanishing. We present a specific example where the superpotential is non-vanishing on the covering space and, due to discrete torsion, remains non-zero on the quotient space X.

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(with S.A. Smolyansky, D.V. Churochkin, A.M. Fedotov, D.B. Blaschke and N.T. Gevorgyan)

Nonperturbative kinetic description of e-h excitations in graphene due to a strong, time-dependent electric field

On the basis of a unitary transformation to the quasiparticle representation we obtain a non-perturbative kinetic equation (KE) which describes the e-h excitations in graphene in a spatially homogeneous, time-dependent electric eld. An analogous KE is well known in the standard $D = 3{+}1$ QED [S.M. Schmidt et al., Int. J. Mod. Phys. E

7, 709 (1998), D.B. Blaschke et al., Eur. Phys. J. D55 (2009) 341]. The corresponding unitary transformation is adopted from [B. Dora et al., Phys. Rev. B 81, 165431 (2010)]. We consider low energy model and tight binding model of nearest neighbour interaction. On this basis we obtain the following results:
- comparing the cases of linear and circular polarizations of the external eld we show that the latter is more eective way of creating e-h excitations and corresponding currents;
- we show that the polarization current dominates over the conductivity one;
- investigating features of the residual currents which remain after switching o the external eld pulse we show that the residual polarization current continues to oscillate on the background of some constant conductivity current;
- the character of these oscillations is examined;
- investigating features of the e-h excitations we draw analogies to the eld induced phase transition discussed for electron-positron pair creation in standard QED [S.A. Smolyansky et al., arXiv:1607.08775[hep-ph]].

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Interaction between two point-like charges in nonlinear quantum electrostatics

(with A.I. Breev)

We consider two point-charges in electrostatic interaction between them within the framework of a nonlinear model, associated with QED, that provides finiteness of their field energy [C.V. Costa, D.M. Gitman and A.E. Shabad, "Finite field-energy of a point charge in QED arXiv:1312.0447 [hep-th] (2013), Phys. Scr. 90 (2015) 074012]. We find the common field of the two charges in a dipole-like approximation, where the separation between them R is much smaller than the observation distance r, and in the opposite approximation, where $R \gg r$. We show that for the separation, small in the nonlinearity scale, the energy of the system of two point-charges can be presented as $a + bR^{1/3}$, where a and b are finite constants depending only on the charges and include the electron mass and charge. Hence the force between two point-like charges turns to infinity following the law $(b/3)R^{-2/3}$. This formula replaces the Coulomb law $\sim R^{-2}$.

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Strong field QED with heavy ions

The present status of QED theory of heavy ions is reviewed. The high-precision calculations of the Lamb shift, hyperfine splitting, and bound-electron g factor are compared with the corresponding experimental data. Special attention is focused on tests of QED at strong coupling regime and determination of fundamental constants. Possibilities for tests of QED at supercritical fields are also considered. The recent progress on calculations of pair-creation processes in low-energy heavy ion collisions is reported. The current status of studying the parity nonconservation effects with heavy atoms and ions is discussed.

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New method of quantization of nonabelian gauge fields

New method of quantization of nonabelian gauge fields is proposed.

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(with A.M. Fedotov, A.D. Panferov)

Kinetic description of pair creation from vacuum under the action of strong fields

We review the methods and results of kinetic description of particle-antiparticle plasma creation from vacuum under the action of strong classical fields of various nature. The approach is based on a transform to the quasiparticle representation (QPR) for a class of quantum field theories with quadratic Hamiltonian. After transition to QPR the dynamics is described by distribution functions in the momentum space obeying the nonperturbative kinetic equations (KE's). The mathematical structure of these KE's (e.g., in the form of integro-differential equations of non-Markovian type with rapidly oscillating kernels, the latter corresponding to the vacuum Zitterbewegung) is similar for different classes of the theories ($D = 3 + 1$ and $D = 2+1$ QED, graphen, QCD, etc.). Mathematical unification allows to relate the processes of particle and quasiparticle creation from vacuum in these theories, thus identifying a class of field induced phase transitions with common characteristic features but specific order parameters. These phase transitions are strongly non-equilibrium and are accompanied by nonmonotoni c entropy growth. More details on the obtained results and prospects can be found in the reviews of applications to the strong field laser physics [D.B. Blaschke, A.V. Prozorkevich, G. Roepke, C.D. Roberts, S.M. Schmidt, D.S. Shkirmanov and S.A. Smolyansky, Eur. Phys. J.D 55, 341(2009), A. Otto, T. Nousch, D. Seipt, B. Kaempfer, D. Blaschke, A.D. Panferov, S.A. Smolyansky, and A.I. Titov, J. Plasma Phys. 82, 655829301 (2016)] and the theory of quark-gluon plasma production in the heavy ion collisions [S.A. Smolyansky, Lection, XIIIth Winter School "Physics of Heavy Ions: from LHC to NICA JINR, Dubna, Russia, Jan.30-Feb.4(2017), D.V. Vinnik, V.A. Mizerny, A.V. Prozorkevich, S.A. Smolyansky, V.D. Toneev, Phys. Atomic Nuc., 64, 775(2001)]. Up to now QPR was limited to the simplest strong field models with spatially homogeneous time dependent linearly polarized elecrtomagnetic or gluon vector fields, but we are currently searching for the ways to overcome these limitations. In particular, we demonstrate that circularly polarized fields create electron-positron pairs more efficiently than the linearly polarized ones. Another foreseen extension in progress would be description of selfsustained QED cascades in laser fields [A.M. Fedotov, N.B. Narozhny, G. Mourou, G. Korn, Phys. Rev. Lett. 105, 080402 (2010)]. Here QPR can serve as a valuable alternative to the presently used Monte Carlo simulations [N.V. Elkina, A.M. Fedotov, I.Yu. Kostyukov, M.V. Legkov, N.B. Narozhny, E.N. Nerush, H. Ruhl, Phys. Rev. ST Accel. Beams 14, 054401 (2011), N.B. Narozhny, A.M. Fedotov, Physics-Uspekhi 58, 95 (2015)].

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Weyl quantization map and star product for the charge-monopole system

We compare two different ways of constructing a Weyl-type quantization map for an electrically charged particle in the field of a magnetic monopole and examine the relation between them. In the first setting, the quantum operators are defined on the Hilbert space of sections of a non-trivial complex line bundle associated with the Hopf bundle, whereas the second approach uses a Hilbert module of sections of a trivial quaternionic line bundle. Special attention is paid to the functional analytic aspects of both approaches. Using an operator analog of the twisted convolution, we derive integral and differential representations for the phase-space star product induced by the Weyl correspondence and show that the result agrees completely with the Kontsevich formula for deformation quantization of Poisson structures.

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Black Holes, Holography and Quantum Photosynthesis

There are successful applications of the holographic anti-de Sitter/conformal field theory (AdS/CFT) correspondence to high energy and condensed matter physics. We apply the holographic approach to photosynthesis that is an important example of nontrivial quantum phenomena relevant for life which is being studied in the emerging field of quantum biology. We use the holographic approach to evaluate the time dependence of entanglement entropy and quantum mutual information in the Fenna-Matthews-Olson (FMO) light-harvesting complex in bacteria during the transfer of an excitation from a chlorosome antenna to a reaction center. We show that the time evolution of the mutual information simulating the Lindblad master equation in some cases can be obtained by means of a dual gravity describing black hole formation in the AdS-Vaidya spacetime.

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Superstrings, Higher-Spin Theory and AdS/CFT

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Scale hierarchies and string cosmology

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Holograpic approach to Heavy Ions Collisions

I briefly review how in the holographic setup one can describe the QGP formation in heavy ion collisions and how to get quantitatively the main characteristics of the QGP formation – the total multiplicity and the thermalization time. To fit the experimental form of dependence of total multiplicity on energy, obtained at LHC, we have to deal with a special anisotropic holographic model, related with the Lifshitz-type background.

Our conjecture is that this Lifshitz-type background with non-zero chemical potential can be used to describe future data expected from NICA. In particular, we present the results of calculations of the holographic confinement/deconfinement phase transition in the (μ, T) (chemical potential, temperature) plane in this anisotropic background and show the dependence of the transition line on the orientation of the quark pair. This dependence leads to a non-sharp character of physical confinement/deconfinement phase in the (μ, T)-plane. We use the bottom-up soft wall approach incorporating quark confinement deforming factor and vector field providing the non-zero chemical potential. In this model we also estimate the holographic photon production.

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Spinor helicity formalsim and (super)amplitudes of $D = 11$ supergravity and $D = 10$ SYM theory

We show that $10D$ spinor helicity formalism can be understood as spinor moving frame approach to supersymmetric particles extended to the description of amplitudes. This allows us to develop the spinor helicity formalism for $11D$ supergravity and also to find a new superfield representation for $D = 10$ supersymmetric Yang-Mills (SYM) and $D = 11$ supergravity (SG) amplitudes. We obtain the generalizations of the BCFW recurrent relations for these $10D$ and $11D$ superamplitudes. We have found a convenient gauge fixed on the spinor frame variables corresponding to scattered particle, which might provide a convenient Lorentz-covariant counterpart of the light cone gauge, and show that in it the expressions for 3- and 4- fermion amplitudes simplify essentially. We also discuss $10D$ and $11D$ counterparts of the $D = 4$ chiral on-shell superfield formalism in which the higher dimensional, $10D$ and $11D$ superamplitudes resemble the ones of four dimensional $N = 4$ SYM and $N = 8$ SG.

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BMS current algebra and field dependent central extension

The BMS current algebra in four-dimensional asymptotically flat spacetimes at null infinity that generalizes the Bondi mass loss formula is discussed. Different formulations of the associated field-dependent central extension are presented.

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Beyond Newton-Cartan gravity

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(with A. Addazi and G. Venziano)

On black-hole formation/evaporation in ultra-planckian string scattering

We revisit black-hole formation in ultra-planckian string-string collisions at very high final-state multiplicity. We compare results obtained by means of the optical theorem, the resummation of ladder diagrams at arbitrary loop order and the AGK cutting rules, with the more recent study of graviton-graviton scattering in the same regime. We argue that some apparent tension between the two approaches disappears once a reinterpretation of the latter's results in terms of suitably defined infrared-safe cross sections is adopted. Under that assumption, the typical final state produced in an ultra-planckian collision does indeed appear to share some properties with those expected from the evaporation of a black hole of mass of order the center-of-mass energy, although no compelling sign of thermalization is seen to emerge at this level of approximation.

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M. Cederwall

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Algebraic structures in exceptional field theory

Exceptional field theory (EFT) gives a geometric underpinning of the U-duality symmetries of M-theory. In this talk I give an overview of the surprisingly rich algebraic structures which naturally appear in the context of EFT. This includes Borcherds superalgebras, Cartan type superalgebras (tensor hierarchy algebras) and L_∞ algebras.

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(with E. Ivanov)

Gauged spinning multiparticle models with the $N = 4$ deformed supersymmetry

New models of the $SU(2|1)$ supersymmetric mechanics based on gauging the systems with dynamical and semi-dynamical supermultiplets will be presented. $N = 4$ extension of Calogero-Moser multiparticle system will be obtained by gauging the $U(n)$ isometry of matrix $SU(2|1)$ harmonic superfield model.

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Local current interactions from nonlinear higher-spin equations in AdS4

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Interactions of massless fields of all spins with conserved currents are shown to result from a linear problem that describes a gluing between rank-one massless system and rank-two current system in AdS4 and flat Minkowski space.

A. Gorsky

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New critical and collective phenomena in the constrained random networks

We discuss new phenomena in the Erdos-Renyi networks supplemented by the degree conservation constraint and in regular random graphs. The key tool is the analysis of spectral properties of adjacency and Laplacinan matrices in particular the phenomena of eigenvalue tunneling. When the chemical potential for the triangles is introduced the networks undergo the complete defragmetration into the maximally possible number of cliques generalizing the Strauss phase. If the chemical potentials for the unicolor trimers are introduced in the multicolor constrained networks it turns out that they are absolutely unstable with respect to fragmetration into the weakly coupled multilayer networks. The phenomena of the finite plateau formation for the network spectral gap occurs at some interval of chemical potentials for trimers. The localization-delocalization transition in the constrained networks will be explained.

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Gravity, Duality and Conformal Symmetry

The supersconformal 6-D theory with $(4, 0)$ Supersymmetry and its relation with gravity is discussed.

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A. Isaev

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R-matrix, star-triangle relations and Yangians for conformal algebras

My talk will be based on papers
1) D. Chicherin, S. Derkachov, A.P. Isaev, Conformal algebra: R-matrix and star-triangle relation, Journal of High Energy Physics (JHEP) 1304 (2013) 020 arXiv:1206.4150 [math-ph].

2) D. Chicherin, S. Derkachov, A. P. Isaev, Spinorial R-matrix , J. Phys. A: Math. Theor. 46 (2013) 485201 (21pp), arXiv:1303.4929 [math-ph].

3) A.P.Isaev, D.Karakhanyan, R.Kirschner, Orthogonal and symplectic Yangians and Yang-Baxter R-operators Nuclear Physics, B904 (2016) 124–147; arXiv:1511.06152 [math-ph]

4) J. Fuksa, A. P. Isaev, D. Karakhanyan, R. Kirschner, Yangians and Yang-Baxter R-operators for ortho-symplectic superalgebras, Nucl.Phys. B917 (2017) 44-85; arXiv:1612.04713 [math-ph]

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Traversable wormholes

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S. Krivonos

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(with O. Lechtenfeld and A. Sorin)

Hidden symmetries of the (deformed)oscillators

We associate with each simple Lie algebra the system of the second order differential equations possessing this symmetry. In the special limits, these equations reduced to the system of ordinary harmonic oscillators. We provide the clarifying example: systems of (deformed)oscillators invariant with respect to G_2 symmetry. The important question of existence of the corresponding action is analysed and for the considered case the proper algorithm for construction of the invariant actions is proposed.

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S. Kuzenko

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Superconformal higher spin multiplets

Conformal field theories can be studied by embedding them into superconformal ones. This talk will review the off-shell construction of $N = 1$ superconformal higher spin multiplets in four space-time dimensions, both in Minkowski superspace and on curved supergravity backgrounds. The structure of three-dimensional $N = 1$ and $N = 2$ superconformal higher spin multiplets and their applications will also be discussed.

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W. Li

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(with Euihun Joung, K. Mkrtchyan)

Colored gravity in the non-relativistic limits

Colored gravity is an interacting theory of multiple spin-2 and spin-1 fields in three dimensions. In the Chern-Simons formulation, the gauge algebra is the tensor product of an isometry algebra $gl(2)+gl(2)$ and a color algebra $u(N)$. The isometry algebra is extended to an associative one by adding two abelian generators, which is interestingly analogous to the double central extensions in non-relativistic gravities. In this talk, I will discuss how to construct the colored versions of extended Bargmann gravity and extended Newton-Hooke gravity by Inonu-Wigner contractions. A classification of non-relativistic colored gravities is achieved based on some consistency conditions of the contraction procedure.

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(with V.E. Didenko, M.A. Vasiliev)

Charges in nonlinear higher-spin theory

Nonlinear higher-spin equations in four dimensions admit a closed two-form that defines a gauge-invariant global charge as an integral over a two-dimensional cycle. Is is argued that this charge gives rise to partitions depending on various lower- and higher-spin chemical potentials identified with modules of topological fields in the theory. The resulting partition is non-zero being in parametric agreement with the ADM-like behavior of a rotating source.

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More on Lagrangian theory for higher spin fields

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U(N) $D = 3$ Matter Coupled to Chern-Simons field. Spontaneous Breaking of Scale Invariance, AdS/CFT correspondence and Fermion-Boson Dual Mapping

Will discuss three dimensional, large N O(N) and U(N) symmetric, field theory with fermion and boson matter coupled to a topological Chern-Simons term. Will determine the conditions for the existence of a massless conformal invariant ground state as well as the conditions for a massive phase. Will analyze the phase structure and consider also a massive ground state where the scale symmetry is spontaneously broken. Will show that such a phase appears only in the presence of a marginal deformation that is introduced by adding a certain scalar auxiliary field and discuss the fermion-boson dual mapping. The ground state contains in this case a massless U(N) singlet bound state goldstone boson- the Dilaton whose properties are determined. Will show that the massive phase and the massless Dilaton appears in the spectrum provided certain relations between coupling constants are satisfied. Moreover, will show that the conditions for spontaneous breaking of scale invariance in the boson and fermion theories are dual copies of each other.

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N. Nekrasov

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Tying together instantons and anti-instantons

In quantizing classical mechanical systems to get (non-perturbative in hbar corrections to) the eigenvalues of the Hamiltonian one often sums over the classical trajectories as in localisation formulas, but also take into account the contributions of the so-called "instanton-antiinstanton gas". The latter is an ill-defined set of approximate solutions of equations of motion. The talk will attempt to alleviate some of the frustrations of this 40+ yrs old approach by making use of honest solutions of equations of motion of complexified classical mechanical system. The examples will include algebraic integrable systems, from the abstract Hitchin systems to the well-studied anharmonic oscillator. If time permits, I will explain the origin of these ideas in the Bethe/gauge correspondence of Nekrasov-Shatashvili which lead to the supersymmetric Landau-Ginzburg description of the set of solutions.

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D. Ponomarev

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On higher-spin theories in flat space

For a long time it is known that interactions of massless higher-spin fields in flat space are problematic. It turns out that at least some of these problems can be avoided if one abandons manifest Lorentz covariance inherent to approaches where higher-spin fields are represented by Lorentz tensors. On the contrary, in the light-cone deformation procedure Lorentz covariance is not manifest, being controlled manually order by order. Remarkably, this allows to construct additional consistent interactions already at cubic order. Among these additional interactions one finds the minimal coupling of higher-spin fields to gravity, which is, moreover, universal. Also, based on earlier results of Metsaev, we propose a complete chiral higher spin theory, which features only cubic interactions. I will also discuss some other developments in this direction.

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A. Sharapov

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Pre-symplectic currents and weak Lagrangians for massless higher-spin fields

I will present a family of pre-symplectic currents for the unfolded representation of free HS field dynamics in 4d AdS space. Besides the problem of covariant quantization, one can use these pre-symplectic currents for the construction of conserved currents by the global symmetries of free HS fields. Also, each pre-symplectic current is shown to give rise to a 'weak' action functional, whose stationary surface includes all the solutions to the original (non-Lagrangian) field equations. There are reasons to believe that the functionals of this type can find applications in the context of AdS/CFT correspondence.

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Chern-Simons matter theories and higher-spin symmetry

Chern-Simons matter theories exhibit a phenomenon of bosonization in three dimensions. Also, in these theories there is a trace of infinite-dimensional higher-spin symmetry that turns out to be slightly broken: an infinite number of tensor operators - higher-spin current - have small anomalous dimensions. Using the slightly broken higher-spin symmetry we find the anomalous dimensions of higher-spin currents and observe that they are in the agreement with the bosonization conjecture.

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C. Sleight

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Spinning Witten diagrams

We develop a systematic framework to compute the conformal partial wave expansions (CPWEs) of tree-level four-point Witten diagrams with totally symmetric external fields of arbitrary mass and integer spin in AdS_{d+1}. Employing this framework, we determine the CPWE of a generic exchange Witten diagram with spinning exchanged field. As an intermediate step, we diagonalise the linear map between spinning three-point conformal structures and spinning cubic couplings in AdS.

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D. Sorokin

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Spontaneously broken supergravity, constrained superfields and branes

We will review a recent revival of interest to the study of spontaneous breaking of local supersymmetry and the super-Higgs effect in four-dimensional supergravity, related to the possibility of building relevant cosmological models with de Sitter vacua in the framework of supergravity and string theory. We will compare two realizations of this effect, one which uses constrained (nilpotent) superfields and another one involving a space-filling 3-brane. The latter can be regarded as a

dimensionally reduced relic of anti-D-branes causing supersymmetry breaking and generating de Sitter vacua in corresponding stringy scenarios.

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K. Stelle

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New black hole families in gravity with quadratic curvatures

The talk will discuss the existence of a branch of non-Schwarzschild black holes that exist when the d=4 Einstein action is extended by incorporating quadratic curvature terms. These produce a renormalizable system, but also give rise to new solutions. A second branch of black holes appears, crossing the Schwarzschild branch at a point governed by the Gross-Perry-Yaffe eigenfunction of the Lichnerowicz operator. This appears to have an impact on the relative stability of the old and new black hole branches for small mass black holes.

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(with N. Kozyrev, S. Krivonos, O. Lechtenfeld and A. Nersessian)

N=4 supersymmetric multiparticles system on the conformally flat manifold

We obtain, starting with the basic relations of the N=4 supersymmetric algebra in d=1,the Hamiltonian which corresponds to the multiparticles system on the conformally flat manifold. The supersymmetry generators depend, at the beginning, on a set of arbitrary functions. Two of these functions satisfies the following symmetry relations under the permutation of the indices: $F_{ijk}(x_n) = F_{jik}(x_n)$, $G_{ijk}(x_n) = -G_{jik}(x_n)$. We demonstrate that the requirement of closure of a superalgebra leads to a set of nonlinear equations on the functions entering the supercharges and that all equations have a natural description in terms of geometric objects such as the covariant derivatives, the Riemannian tensor etc. It is shown that the totally symmetric part of tensor $F_{(ijk)}(x_n)$ has to satisfy to the generalized WDVV equation. We also give some explicit solutions for the system of equations in the case of a two-particles model.

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Holographic reconstruction

In this talk I will review some recent progress on constructing standard actions for Higher-Spin gauge theories dual to free theories on the boundary of AdS. I will discuss novel tests in general dimension of the higher-spin holographic dualities, as well as some aspects of the flat limit of the AdS theory.

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On conformal higher spin theory

We will discuss the structure of the action for a tower of conformal higher spin fields in non-trivial 4d background metric. The action is defined as an induced one from path integral of a conformal scalar field in curved background coupled to higher spin fields. In particular, we will analyse the dependence of the quadratic part of the induced action on the spin 1 and spin 3 fields.

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Effective field theory methods for classical and quantum gravity

The direct detection of gravitational waves provides an extraordinary confirmation of the general relativity. This opens a new window on our observable Universe. Shortly after having formulated the theory of general relativity, Albert Einstein said that quantum mechanism requires modifying his new theory of gravity. Today, we are still looking for experimental and observational indication of quantum gravity effects.

I will present the point of view of effective field theory approach to gravity. This approach allows computing classical general relativity effects as well as quantum gravity effects. I will explain that at large distance some quantum gravity effects are universal being independent of the high-energy description. This approach may be a route for finding signature of quantum gravity.

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Yang-Baxter deformations and generalized supergravity

It is well-known that type IIB superstring theory on the AdS_5xS^5 background is classically integrable. Recently, integrable deformations of this system have been studied very actively by adopting a systematic way called the Yang-Baxter deformation.

In this talk, I will give a review on recent progress on this issue. The deformations under the unimodularity condition lead to solutions of type IIB supergravity including the Lunin-Maldacena backgrounds (dual for beta deformations of the $N = 4$ super Yang-Mills theory), the Maldacena-Russo backgrounds (dual for non-commutative gauge theories) and Schroedinger spacetimes (dual for non-relativistic conformal field theories). In general, however, the resulting deformed backgrounds are not solutions of the standard type IIB supergravity, but of the generalized supergravity. Finally I will describe the relation between noncommutative gauge theories and the generalized supergravity.

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Infinite spin fields in the frame-like formalism

We provide infinitely many explicit examples for the infinite (continuous) spin representations in the frame-like formalism. For this we use previously constructed frame-like gauge invariant description for massive mixed symmetry bosonic and fermionic fields corresponding to the Young tableau with two rows and take the limit where spin goes to infinity while mass goes to zero.

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Quantum Gravity and Cosmology

B.L. Altshuler

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Scalar field on AdS: quantum one loop "in one line"

It is shown that quantum one-loop potentials of the bulk fields in the Randall and Sundrum (RS) model may be immediately expressed in integrals with use of Barvinsky-Nesterov or equivalently Gelfand-Yaglom methods of calculation of quantum determinants. The relationship of spectra of excitations of scalar field corresponding to the mixed (Robin) or to the double-trace asymptotic boundary conditions is traced. Simple expression is received for the UV-finite difference of one-loop quantum energies for two arbitrary values of parameter of the double-trace asymptotic boundary condition in one-brane and two-brane RS-models. This result generalizes the Gubser and Mitra calculation for the particular case of the UV-finite difference of "regular" and "irregular" one-loop energies in the one-brane model.

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Black holes and solitons in an extended Proca theory

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Cusps vs. cores in the center of dark matter halos: a real conflict with observations or a numerical artefact of cosmological simulations?

Galaxy observations and N-body cosmological simulations produce conflicting dark matter halo density profiles for galaxy central regions. While simulations suggest a cuspy and universal profile of this region, the majority of observations favor variable profiles with a core in the center. We investigate the convergency of standard N-body simulations, especially in the cusp region. We find that, although the cuspy profile is stable, all integrals of motion characterizing individual particles suffer strong unphysical variations along the whole halo, revealing an effective interaction between the test bodies. This result casts doubts on the reliability of the velocity distribution function obtained in the simulations. Moreover, we find unphysical Fokker-Planck streams of particles in the cusp region. The same streams should appear in cosmological N-body simulations, being strong enough to change the shape of the cusp or even to create it. Our analysis, based on the Hernquist model and the standard N-body code, strongly suggests that the universal density profile generally found by the cosmological N-body simulations may be a consequence of numerical effects. A much better understanding of the N-body simulation convergency is necessary before a 'core-cusp problem' can properly be used to question the validity of the CDM model.

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(with V. Dokuchaev and Y. Eroshenko)

Cosmological particle creation, conformal invariance and A.D. Sakharov's induced gravity

We constructed a phenomenological model for cosmological particle creation. It allows to take into account the back reaction on the space-time metric not only of the energy-momentum tensor of the already created particles, but also the very process of the creation. Adopting the well-known fact that the particle production rate is proportional to the square of the Weyl tensor, we found that there is no more need to include, ad hoc, the conformal gravity term into the action integral, it is already there. Such a feature is in accordance with the idea of the induced gravity, first proposed by A.D. Sakharov. Assuming, then, the simplest possible (without self-interaction) action for the scalar field responsible for the particle creation, we found that the requirement for the local conformal transformation to be the fundamental physical law, leads not only to the induced scalar term in the action (Einstein-dilaton gravity), but also to the appearance of the self-interaction for the scalar field absent before. Moreover, the exponent of this self-interaction term ($= 4$) is due to the dimensionality of our space-time.

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(with A. Giugno and A. Giusti)

Quantum post-Newtonian corpuscular models of black holes and cosmology

We study an effective quantum description of the static gravitational potential for spherically symmetric systems up to the first post-Newtonian order. The classical Newtonian results are reproduced by a coherent quantum state and post-Newtonian corrections are briefly addressed. Our findings establish a connection between the corpuscular model of black holes and post-Newtonian gravity, and we further speculate on the application of these quantum models in cosmology.

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(with V. Berezin,Y. Eroshenko)

Global geometry of the Vaidya space-time

The classical Vaidya metric is transformed to the special diagonal coordinates in the case of the linear mass function allowing rather easy treatment of the corresponding global geometry. We find the exact analytical expressions for metric functions in this diagonal coordinates. Using these coordinates, we elaborate the maximum analytic extension of the Vaidya metric with a linear growth of the black hole mass and construct the corresponding Carter-Penrose diagrams for different specific cases. We reveal the specific coordinate singularity outside of the Vaidya black hole apparent horizon. his singularity is located very close the apparent horizon in the weak accretion case. The derived global geometry seemingly is valid also for a more general behavior of the black hole mass in the Vaidya metric.

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Asymptotic fragility, $T\bar{T}$ deformation and flat space holography

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A new approach to cosmological models of very early Universe: on general solution of the dynamical equations in theories with scalar or vector fields coupled only to gravity.

The dynamics of a fairly general early cosmology with a scalar or vector "matter"field coupling to gravity can be described by the nonlinear second-order differential equations for two metric functions and the scalaron (vecton) field depending on a "time"parameter. The equations also depend on a matter potential and on the arbitrary gauge function that defines time parameterizations. In the standard approach, this dynamical system can be explicitly integrated only for flat isotropic models with very special potentials. But, replacing the time variable by one of the metric functions allows us to completely integrate the general isotropic model in any gauge and with apparently arbitrary potentials. The main restrictions on the potential arise from positivity of the derived analytic expressions for the solutions, which are essentially the squared canonical momenta. An interesting consequence is emerging of classically forbidden regions for these analytic solutions. It is also shown that in this approach the exact inflationary solutions can be identified and perturbatively compared to the standard approximate expressions [arXiv:1506.01664, 1605.03948]. Note that the perturbative expansions converge for a wide class of the scalar potentials and thus represent the exact analytic solution at least in the inflationary domain. This approach is alsoapplied to deriving exact anisotropic scalaron solutions in the limit of weak anisotropy. It is shown that the new isotropic solution is an attractor for the general ones. The present report also presents preliminary results obtained by applying a similar approach to the massive vecton model of dark matter an dark energy [arXiv:0812.2616], with the gravity - vecton square - root coupling term invented by Einstein in 1923 (a simpler version of it is known as the Born - Infeld term). The Lagrangian looks like one describing a massive relativistic particle in a gravitational field [arXiv:1011.2445, 1112.30323]. In this theory, anisotropy might only emerge at the end of inflation scenarios.

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Remarks on non-singular black hole models

We discuss spherically symmetric metrics which represent non-singular black holes in four-and higher-dimensional spacetimes. We first consider static metrics, which obey the following conditions: (i) Regularity at the center and (ii) Validity of the limiting curvature condition. We describe the Hayward model and its generalizations, which obey these properties. After this we discuss quantum radiation of a massless scalar field from an evaporating spherically symmetric non-singular black hole with finite lifetime. We demonstrate that in a general case there exists a huge outburst of the quantum radiation, emitted from the black hole interior from the domains close to the inner horizon. We discuss a relation of this phenomenon with the mass inflation effect. Finally, we shall make remarks on attempts to solve this problem and to provide self-consistency of the non-singular model in the quantum domain.

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(with S.N. Solodukhin, A.F. Astaneh and C. Berthiere)

Holographic entanglement entropy in BCFT

A holographic description of entanglement entropy in CFT's with boundaries (BCFT) under spatial partition of a system by an entangling surface crossing the boundary is discussed. The Ryu-Takayanagi formula and its modifications in the presence of a holographic boundary in the bulk are compared with field theoretical computations of the boundary terms in the logarithmic part of the entropy. A relation between boundary charges in the entropy and in the integrated conformal anomaly is emphasized. Computations are mostly concern 4D N=4 super-gauge multiplet where boundary conditions preserve half of supersymmetries.

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Relaxing cosmic censorship and chronology protection

Motivated by the Event Horizon Telescope and the BlackHoleCam projects, we explore some alternatives for metrics of compact objects containing naked singularities and/or closed time-like curves, focussing on possibility of "mild"violation of these principles.

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Problems with changing Hilbert space in Quantum Mechanics. Questions for Cosmology

Let we have initially the infinite potential well disposed between points 0 and a_1 and than width of this well is changed during final time T $a_1 \to a_2$. Standard methods of description of transition between the states of an initial and final well don't applicable since the states of these wells belong to the different Hilbert spaces. We discuss two problems.
1. How to calculate probabilities of mentioned transitions.
2. How to compare complete measures of these spaces. In the terminology of regularization by well with finite depth V it corresponds transitions to the continuous spectrum which does not disappear at regularization removal $V \to \infty$. How to calculate the probability of this transition.

The possible relation to the phenomena accompanied Electroweak transition in the earlier Universe is also discussed briefly.

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Bugaboo black holes

It has recently been argued that microscopic black holes can induce fast tunneling of the Higgs field from the Electroweak vacuum to the true (subplanckian) minimum. If so (that is not obvious at all), it implies either the new physics in the Higgs sector or suppression of the primordial black hole production in the early Universe. We examine the second option and show dynamical mechanisms which may lead to the black hole formation. The examples are matter contrasts growth at preheating and scalar field instability due to negative self-coupling. The evident absence of the black holes imply severe constraints on the inflationary models and axion-like particles, which we discuss.

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Hawking radiation of black hole with supertranslation field

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Cosmological structure formation in mildly–nonlinear regime: from IR to UV

I will present a new analytic approach to describe cosmological structure formation in the mildly non-linear regime relevant for the scales ranging from 10 to 100 Mpc. The key object of this approach is the time-dependent probability distribution function that generates correlation functions of cosmological fields at fixed redshifts. I will show that the proposed method overcomes the notorious drawbacks of standard

approaches, namely the appearance of non - physical enhancements from the very long (IR) and very short (UV) modes. I will demonstrate that our scheme is manifestly free of spurious IR contributions, which allows to systematically resumm physical IR effects relevant for the accurate description of the baryon acoustic oscillations. Finally, I will show that our approach provides a natural framework to account for the influence of UV modes along the lines of Wilsonian effective field theory. Taking into account effective Wilsonian operators allows us to accurately reproduce the power spectrum and bispectrum of dark matter from N-body simulations on mildly non-linear scales.

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(with E. Pozdeeva, A. Tronconi, G. Venturi and S. Vernov)

Bianchi-I cosmological model and crossing singularities

We consider a rather simple method for the description of the Big Bang - Big Crunch cosmological singularity crossing. For the flat Friedmann universe this method gives the same results as more complicated methods, using Weyl symmetry or the transitions between the Jordan and Einstein frames. It is then easily generalized for the case of a Bianchi-I anisotropic universe. We also present early-time and late-time asymptotic solutions for a Bianchi-I universe, filled with a conformally coupled massless scalar field.

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Chern-Simons term in the geometric theory of defects

The Chern-Simons term is used in the geometric theory of defects. The equilibrium equations with δ-function source are explicitly solved with respect to the $SO(3)$ connection. This solution describes one straight linear disclination and corresponds

to the new kind of geometrical defect: it is the defect in the connection but not the metric which is the flat Euclidean metric. This is the first example of a disclination described within the geometric theory of defects. The corresponding angular rotation field is computed.

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(with A. Panin and I. Tkachev)

Relativistic axions from collapsing Bose stars

The substructures of light bosonic (axion-like) dark matter may condense into compact Bose stars. We study collapses of the critical-mass stars caused by attractive self-interaction of the axion-like particles and find that these processes proceed in an unexpected universal way. First, nonlinear self-similar evolution (called "wave collapse"in condensed matter physics) forces the particles to fall into the star center. Second, interactions in the dense center create an outgoing stream of mildly relativistic particles which carries away an essential part of the star mass. The collapse stops when the star remnant is no longer able to support the self-similar infall feeding the collisions. We shortly discuss possible astrophysical and cosmological implications of these phenomena.

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Cosmological bounce beyond Horndeski

We study a "classical"bouncing scenario in the beyond Horndeski theory. We obtain an example of spatially flat bouncing solution that is non-singular and stable throughout the whole evolution. The model is arranged in such a way that the scalar field driving the cosmological evolution initially behaves like the generalized Galileon, then it is full-fledged beyond Horndeski and after that it becomes a massless scalar field minimally coupled to gravity.

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V. Mukhanov

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On the problem of Singularities in General Relativity

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Field-theoretical approach to gravity

1. Treating the Schwarzschild problem in G^2 approximation by the theory of sources I get the exterior solution which depends on the radius of the metter ball in contradiction to Birckhoff theorem.
2. I consider the consequences of replacing the 3-graviton vertex of general relativity by a vertex suggested by field theory.

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Restriction on the charge of Q-ball due to radiative corrections

We discuss stability of Q-balls interacting with fermions in theory with small coupling constant g. We argue that for configurations with large global U(1)-charge Q the problem of classical stability becomes more subtle. For example, in model with flat direction there is maximal value of charge for stable solutions with $Q \sim 1/g^4$. We study origin of additional instability and discuss possible ways to avoid it.

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(with A. Silenko and O. Teryaev)

Dirac fermions in arbitrary external classical fields: quantum spin dynamics

Understanding the dynamics of fermion particles with dipole moments (electrons, protons, neutrons, neutrinos) in arbitrary electromagnetic, gravitational and inertial fields is important for many astrophysical problems. We study the classical and quantum dynamics of spinning particles with dipole moments in the framework of the general-relativistically covariant Dirac theory. The exact Foldy-Wouthuysen transformation for the most general case of a fermion in arbitrary configurations of superimposed strong gravitational (inertial) and electromagnetic fields is derived. These results are used to obtain the quantum and quasiclassical equations of motion of fermion particles. We demonstrate the complete consistency of the quantum and classical dynamics. Physical applications are discussed, including the case of the external wave configurations.

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(with E. Babichev)

Caustic free completion of pressureless perfect fluid and k-essence

Both k-essence and the pressureless perfect fluid develop caustic singularities at finite time. We discuss the connection between the two and show that they belong to the same class of models, which admits the caustic free completion by means of the canonical complex scalar field. Specifically, the free massive/self-interacting complex scalar reproduces dynamics of pressureless perfect fluid/shift-symmetric k-essence under certain initial conditions in the limit of large mass/sharp self-interacting potential. We elucidate a mechanism of resolving caustic singularities in the complete picture. The collapse time is promoted to complex number. Hence, the singularity is not developed in real time. The same conclusion holds for a collection of collisionless particles modelled by means of the Schroedinger equation, or ultra-light

axions (generically, coherent oscillations of bosons in the Bose–Einstein condensate state).

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Renormalization of gauge theories in the background-field approach

Using the background-field method I'll demonstrate the Becchi-Rouet-Stora- Tyutin (BRST) structure of counterterms in a broad class of gauge theories. This proves that the renormalization procedure for these gauge theories is compatible with their gauge invariance. This class encompasses Yang-Mills theories (with possibly Abelian subgroups) and relativistic gravity, including both renormalizable and non-renormalizable (effective) theories. It also contains non-relativistic models such as Yang-Mills theories with anisotropic scaling or Horava gravity. The proof strengthens and generalizes the existing results in the literature concerning the renormalization of gauge systems. I will illustrate the general approach with several explicit examples.

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P. Stamp

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Correlated worldline theories of quantum gravity

In a correlated wordline (CWL) theory of gravity, the worldlines of matter fields are correlated by gravity in the form of a metric field – this leads to a breakdown of the superposition principle, and departures from quantum mechanics on macroscopic scales. I give a review of the prehistory of this idea, notably in papers of Kibble et al. and Penrose. I then describe a specific example of a CWL theory by myself, and a recent elaboration of this theory by Barvinsky, Carney, and Stamp. I also discuss how the theory can be tested, in optomechanics experiments.

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(with A.O. Barvinsky, D. Blas, M. Herrero-Valea and S. Sibiryakov)

Quantum properties of Lifshitz theories

Lifshitz theories are characterized by an anisotropic scaling of space and time. Such theories break fundamental Lorentz invariance but show promising quantum UV properties. New methods and techniques have to be formulated to analyze general renormalization properties and to perform explicit calculations. I discuss some of these techniques and present new results with a special emphasis on Horava gravity.

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(with D. Gorbunov)

On the dark radiation problem in the axiverse

String scenarios generically predict that we live in a so-called axiverse: the Universe with about a hundred of light axion species which are decoupled from the Standard Model particles. However, the axions can couple to the inflaton which leads to their production after inflation. Then, these axions remain in the expanding Universe contributing to the dark radiation component, which is severely bounded from present cosmological data. We place a general constraint on the axion production rate and apply it to several variants of reasonable inflaton-to-axion couplings. The limit merely constrains the number of ultralight axions and the relative strength of inflaton-to-axion coupling. It is valid in both large and small field inflationary models irrespectively of the axion energy scales and masses. Thus, the limit is complementary to those associated with the Universe overclosure and axion isocurvature fluctuations. In particular, a hundred of axions is forbidden if inflaton universally couples to all the fields at reheating. In the case of a gravitational sector being responsible for the reheating of the Universe (which is a natural option in all inflationary models with modified gravity), the axion production can be efficient. We find that in the Starobinsky R^2-inflation even a single axion (e.g. the standard QCD-axion) is in tension with the Planck data, making the model inconsistent with the axiverse. The general conclusion is that an inflation with the inefficient reheating mechanism and low reheating temperature may be in tension with the presence of light scalars.

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(with D. Muller)

Generality of Starobinsky inflation

Starobinsky inflation currently is one of the models with very good agreement with observational data, so its detail analysis is important. Usually conformal transformation to Einstein frame can be applied to get corresponding results. However, we can not use such approach in studing the problem of initial conditions leading to Starobinsky inflation. The reason is that we can not expect that the analog of the Plank energy has the same role in Jordan frame as it has in Einstein frame. In the present work we use numerical integration in Jordan frame to get initial conditions good for Starobinsky inflation. We also present some euristic argument supporting the numerical results.

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(with E. Pozdeeva)

Bouncing models with non-monotonic Hubble parameter

In the General Relativity cosmological models the initial period of the Universe evolution with energies above the Planck scale should be described by quantum gravity because the classical evolution includes the initial singularity. Important question of theoretical cosmology is whether the entire Universe evolution can remain classical and has no singularity. Modified gravity models of bouncing universes with a period of contraction followed by a bounce and a resent period of expansion attract a lot of attention. We consider cosmological models with non-minimally coupled scalar fields and seek bounce solutions with non-monotonic Hubble parameter.

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Canonical exorcism for cosmological ghosts

Abstract I will discuss time-dependent classical and quantum canonical transformation. In particular, I will demonstrate that for the quantum canonical transformations the Hamiltonian is transformed as a connection in non-abelian gauge theories. I will discuss how to construct such classical and quantum transformations which change the sign of the Hamiltonian. Hence one can canonically transform a ghost into a field with the correct standard sign in front of the quadratic action for cosmological perturbations. Therefore the usual naive criteria for the presence or absence of ghost-like instabilities of time-dependent backgrounds are not well physically motivated and the actual information on the presence of instabilities and their strength is hidden in the interaction terms.

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Weyl metrics and wormholes

We study solutions obtained via applying dualities and complexifi- cations to the vacuum Weyl metrics generated by massive rods and by point masses. Rescaling them and extending to complex parameter values yields axially symmetric vacuum solutions containing singularities along circles that can be viewed as singular matter sources. These solutions have wormhole topology with several asymptotic regions interconnected by throats and their sources can be viewed as thin rings of negative ten- sion encircling the throats. For a particular value of the ring tension the geometry becomes exactly flat although the topology remains non-trivial, so that the rings literally produce holes in flat space. To create a single ring wormhole of one metre radius one needs a negative energy equivalent to the mass of Jupiter. Further duality transformations dress the rings with the scalar field, either conventional or phantom. This gives rise to large classes of static, axially symmetric solutions, presumably including all previously known solutions for a gravity-coupled massless scalar field, as for example the spherically symmetric Bronnikov-Ellis wormholes with phantom scalar. The multi-wormholes contain infinite struts everywhere at the symmetry axes, apart from solutions with locally flat geometry.

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Ultra-high energy particle collisions near black holes and singularities and super-Penrose process

A brief review of the effect of acceleration of particles to unbounded energies in their centre of mass frame due to collision is suggested. The main emphasis is made on the properties of debris after collision that can be observed at infinity. When collission occurs near a black hole, the efficiency of the process is limited. However, near singularities an unbounded efficiency (the so-called super-Penrose process) becomes possible. Consideration applies to a wide class of axially symmetric stationary rotating spacetimes.

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Quantum radiation from a sandwich black hole

We discuss quantum radiation of a massless scalar field from a spherically symmetric nonsingular black hole with finite lifetime. Namely, we discuss a sandwich black-hole model, where a black hole is originally created by a collapse of a null shell of mass M, and later, after some time it is disrupted by the collapse of the other shell with negative mass -M. We assume that between the shells the metric is static and either coincides with the Hayward metric or with a special generalization of it. For a sufficiently large lifetime of a black hole the radiation after the formation of the

black hole practically coincides with the Hawking result. We also calculated the quantum radiation, emitted from the black hole interior. This radiation contains an exponentially large outburst of the energy at a moment when the second shell intersects the inner horizon. We also study quantum radiation in the modified metric, which includes additional non-trivial redshift parameter, and show that this exponent is suppressed.

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Nonlinear Dynamics of Complex Systems

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(with N.I. Semenova, G.I. Strelkova)

Characteristics and properties of Chimera states in ensembles of nonlocally coupled chaotic oscillators

We analyze numerically the transition from coherence to incoherence in ensembles of nonlocally coupled chaotic maps when varying the coupling strength. Amplitude and phase chimera states are studied and their formation, properties and lifetimes are explored. In particular, the bifurcation mechanisms of chimera state appearance are described. The regularities of evolution of the cross-correlations are established and analyzed for phase and amplitude chimeras. The effect of intermittency between these types of chimeras is discussed and the duration of this phenomenon in time is studied. It is shown that the amplitude chimera and the non-stationary regime of intermittency are characterized by a finite lifetime. The phase chimera regime is appeared to be temporally stable.

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Anomalous scaling in turbulence with direct and/or inverse energy cascades

We present a series of recent results concerning direct numerical simulations of three dimensional turbulent flows at changing the Fourier support. We investigate the role of Fourier mode reduction concerning both small-scale anomalous scaling and transition from direct to inverse energy cascade. In particular, we show that depending on the helical contents of the Fourier waves it is possible to reverse the energy transfer even in fully three dimensional isotropic flows. Comments concerning implications for rotating turbulent flows and flows in thick laters will also be presented.

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Mechanisms of chemical kinetics: detailed modelling and model reduction

Steadily growing computational power and increase of efficiency of numerical algorithms and integration packages require development of more and more complex mathematical models describing chemically reacting systems. However, this trend is very challenging with respect to both modeling and computations. Recently developed reliable detailed models of typical chemical reaction mechanisms of combustion are high dimensional (many species and elementary reactions involved), non-linear and stiff. This complicates enormously numerical treatment and post-processing analysis of results of integrations. Therefore, definition of reduced model, finding key parameters controlling the system dynamics and delineating critical regimes automatically have become very important issues. The questions of development of reliable detail mechanisms and of mechanism reduction is in the focus of this work. The progress in development of methods to cope with the system complexity and its high dimensionality will be discussed. A combination of geometric and timescale analyses will be proposed to treat this problem. Hydrogen oxygen combustion system will be considered to verify and illustrate the suggested approach. The results will be compared to those of the standard Quasi-Steady States Approximation.

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(with H. Stage)

Anomalous metapopulation dynamics on scale-free networks

We model transport of individuals across a heterogeneous scale-free network where a few weakly connected nodes exhibit heavy-tailed residence times. Using the empirical law of the axiom of cumulative inertia and fractional analysis, we show that “anomalous cumulative inertia” overpowers highly connected nodes in attracting network individuals. This fundamentally challenges the classical result that individuals tend to accumulate in high-order nodes. The derived residence time distribution has a nontrivial U shape which we encounter empirically across human residence and employment times.

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(with V.N. Kurdyumov)

Chaotic dynamics of combustion wave propagation in shell-core composite solid fuel structure

In this work the dynamics of combustion wave propagation in solid fuel is studied by using the one-step Arrhenius kinetic mechanism and one-dimensional geometry. The structure of the combustible material consists of the thin inert thermally conducting core, which is covered by a layer of solid energetic material. It is demonstrated that different dynamical regimes such as traveling, pulsating, and chaotic waves can be realized as the parameters of the model are changed.

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(with P.V. Kuznetsov, D.A. Ivlev, Sh.N. Shirinly)

Blowup phenomena in human blood coagulation and fibrinolysis

Far from equilibrium phase transitions are responsible for coagulation phenomena in human blood. The analysis of biochemical regulatory pathways and hydrodynamic intravascular conditions demonstrated that under physiologic conditions blood is sustained in metastable state. It was found that significantly broad class of overcritical biochemical and hydrodynamic perturbations can destabilize liquid state of blood. An ultrasonic technic for macroscopic phenomena of intravascular clotting detection were developed. An appropriate strategy for fibrinolytic injection is suggested.

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Quantum bifurcation diagrams

Asymptotic state of an open quantum system can undergo qualitative changes upon small variation of system parameters. We demonstrate it that such 'quantum bifurcations' can be appropriately defined and made visible as changes in the structure of the asymptotic density matrix. By using an N-boson open quantum dimer, we present quantum diagrams for the pitchfork and saddle-node bifurcations in the stationary case and visualize a period-doubling transition to chaos for the periodically modulated dimer. In the latter case, we also identify a specific bifurcation of purely quantum nature.

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(with G. Sivashinsky)

Numerical simulations of deflagration-to-detonation transition in gases

A self-sustained wave of an exothermic chemical reaction spreading through a homogeneous combustible mixture is known to occur either as a subsonic deflagration (premixed gas flame) or supersonic detonation. In unconfined obstacle-free systems the realization of the specific propagation mode is, as a rule, controlled by the ignition conditions. Normally, deflagrations are initiated by a mild energy discharge, i.e., by a spark, while detonations are provoked by shock waves via localized explosions. It is know however, that in the presence of obstacles or confinement the initially formed deflagration undergoes gradual acceleration abruptly converting into detonation.

Deflagration-to-detonation transition (DDT) is an extremely intricate, highly nonlinear, multiple-scale process. Despite more than a century of research, identification of the crucial flame-flow interaction involved is still far from complete, and DDT remains one of the major areas of activity in combustion research. Understanding DDT has recently undergone a significant improvement thanks to fascinating experimental studies in DDT in capillaries, as well as recent theoretical/numerical exploration of simplified models.

Whereas DDT in confined systems is a matter of common knowledge, feasibility of the transition in unconfined systems is more problematic. There are opinions that in truly unconfined systems transition is actually unfeasible.

The present review is intended as a wide brush discourse on the fifteen years of theoretical and numerical efforts in this area undertaken at Tel Aviv University.

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Chaos and pattern formation in weakly nonlinear detonations

Weakly nonlinear multi-dimensional shock waves are characterized by small amplitude and weak curvature of the shock front. Propagation of such shock waves in a chemically reacting gas can be sustained by energy released in the reactions in which case they are called detonations. Here we derive an asymptotic model for the dynamics of detonations from the compressible reactive Navier-Stokes equations. The resultant model in two dimensions consists of a 2D forced Burgers equation, a zero-vorticity equation, and a rate equation of chemistry. In various limits, the model reduces to small-disturbance unsteady transonic flow equations of aerodynamics, weakly nonlinear models of acoustics (Zabolotskaya-Khokhlov (ZK) equation), and equations of water waves (dispersionless Kadomtsev-Petviashvili (KP) equation). The model predicts regular and irregular multi-dimensional patterns in 2D and in 1D, it exhibits transition from steady and stable traveling waves to oscillatory traveling waves through a Hopf bifurcation as a parameter characterizing sensitivity to chemical reactions is increased above a critical value. A cascade of period-doubling bifurcations leading to chaos is also observed.

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(with I.S. Yakovenko)

Peculiarities of ignition phenomenon in shock-tube experiments

Shock-tube experiment represents basic experimental method of studying exothermic reactions in gaseous mixtures at certain conditions. The paper discusses the gasdynamical processes evolving in shock-tubes on the basis of multidimensional numerical model. It is shown that the origins of ignition kernels formation are related with the birth and evolution of entropic perturbations in the shear flow formed behind the incident

shock wave. Numerical model predicts the non-uniform temperature field which allows to estimate the position of ignition kernel as well as the value of ignition temperature. Obtained estimations can be useful to understand the experimental error of ignition delay determination. The evolution of exothermic reaction wave at non-uniform temperature field can proceed in different regimes that determines the data registered by the gauges.

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(with M.B. Kuznetsov)

Dynamics of interstitial fluid with tumor growth

Interstitial fluid plays an important role in functioning of the tissue as tt provides transport of nutrients and chemical mediators to the cells of the body. Interstitial fluid enters the tissue from the arteriolar end of the microcirculatory system, and the absorption of its greater part occurs at its venous end A smaller part, about 10-15 percent, returns to the bloodstream through the lymphatic system. Angiogenesis, the process of new capillary formation, accompanying tumor growth, disrupts the regulation of interstitial fluid transport and often leads to edema formation in the peritumoral region. Experimental studies have shown that anti-angiogenic anticancer therapy leads to the edema reduction, and in some cases not just to tumor growth rate decrease, but also to its shrinkage. We believe that it is the dynamics of the interstitial fluid that is responsible for this effect. However, from the mathematical point of view, the description of such a biological system represents a challenge, since it is necessary to take into account a large number of interrelated processes. In the present talk, approaches to such a description will be considered and mathematical model will be presented to explain the experimentally observed facts.

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(with M. Matalon)

Effects of gas compressibility on the dynamics of premixed flames in long narrow adiabatic channels

Dynamics of premixed flames in long, narrow, adiabatic channels are examined focusing, in particular, on the effects of gas compressibility on the propagation. Recognizing the importance of the boundary conditions, we examine and compare three cases: flame propagation in channels open at both ends, where the pressure must adjust to the ambient pressure at both ends and the expanding gas is allowed to leave the channel freely, and flame propagation in channels that remain closed at one of the two ends, where the burned/unburned gas remains trapped between the flame and one of the two walls. Earlier studies have shown that a flame accelerates when traveling down a narrow channel as a result of the combined effects of wall friction and thermal expansion. In the present work we show that compressibility effects enhance the transition to fast accelerating flames in channels open at both ends and in channels closed at the ignition end.

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Fermi-Pasta-Ulam recurrence and modulation instability

We give a qualitative conceptual explanation of the Fermi-Pasta-Ulam (FPU) like recurrence in the one-dimensional focusing nonlinear Schrodinger equation (NLSE). The recurrence can be considered as a result of the nonlinear development of the modulation instability. All known exact localized solitary wave solutions describing propagation on the background of the modulationally unstable condensate show the recurrence to the condensate state after its interaction with solitons. The condensate state locally recovers its original form with the same amplitude but a different phase after soliton leave its initial region. Based on the integrability of the NLSE, we demonstrate that the FPU recurrence takes place not only for condensate, but for a more general solution in the form of the cnoidal wave. This solution is periodic in space and can be represented as a solitonic lattice. That lattice reduces to isolated soliton solution in the limit of large distance between solitons. The lattice transforms into the condensate in the opposite limit of dense soliton packing. The cnoidal wave is also modulationally unstable due to soliton overlapping. The recurrence happens at the nonlinear stage of the modulation instability. Due to generic nature of the underlying mathematical model, the proposed concept can be applied across disciplines and nonlinear systems, ranging from optical communications to hydrodynamics.

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(with A.V. Nikolaev)

The platelets role in fibrin polymerization

Functional modeling of blood clotting and fibrin-polymer mesh formation is of a significant value for medical and biophysics applications. Despite the fact of some discrepancies present in simplified functional models their results are of the great interest for the experimental science as a handy tool of the analysis for research planning, data processing and verification. Under conditions of the good correspondence to the experiment functional models can be used as an element of the medical treatment methods and biophysical technologies. The aim of this work is a modeling of a pointwise system of the fibrin-polymer formation as a multistage polymerization process with a sol-gel transition at the final stage. A mechanistic model including the role of platelets is proposed for clot formation and growth in plasma in vitro. Initiation of clot formation is by the addition of tissue factor, and initiation via the intrinsic pathway is neglected. Activation of zymogens follows the extrinsic pathway cascade and reactions on platelet membranes are included. Platelet activation occurs due to thrombin and due to other activated platelets. Inhibition of the active clotting factors is by ATIII and TFPI. Inhibition due to APC is not relevant in the conditions modeled. Complex-value Rosenbroke method of second order (CROS) used for computational experiments. The results of computational experiments are presented and discussed. The sensitivity analysis methods for large ODE systems employed and give insights on physiologically meaningful ranges of model kinetic constants values and initial conditions. It was shown that in the physiological range of the model coefficients there is a lag period of between initiation of the reaction and fibrin gel appearance which fits well experimental observations of fibrin polymerization dynamics observed in various whole blood clotting tests like Lee-Whiite, Sukharev, Mas-Magro. The value of the lag period depends on the kinetic constants of system and the number of sites on platelet membranes. At the final stage the solution of fibrin oligomers of length 10 can reach a semidilute state, leading to an extremely fast gel formation controlled by oligomers' rotational diffusion. Otherwise, if the semidilute state is not reached the gel formation is controlled by significantly slower process of translational diffusion. Such a duality in the sol-gel transition led authors to necessity of introduction of a switch-function in an equation for fibrin-polymer formation kinetics. The relative contribution of platelet reactions and fibrin polymerization itself in magnitude of lag is discussed.

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(with S. Minaev, R. Fursenko, H. Nakamura)

Study on non-linear dynamics and kinetics of flames in a micro channel with a temperature gradient

Study on flame characteristics using a small-scale quartz channel with a controlled temperature profile by an external heat source will be introduced. In general, three kinds of flame responses were observed in the channel, i.e., stable normal flames at high mixture flow velocity, dynamic pulsating flames at intermediate mixture flow velocity and stable weak flames at low mixture flow velocity. By employing those three kinds of flames, several new concept combustion researches have been conducted. Dynamic pulsating flames at intermediate flow velocity, termed as FREI (Flames with Repetitive extinction and Ignition), provide non-linear flame responses of given fuels. Stable weak flames at low flow velocity were found to represent the ordinary ignition property of given fuels, thus ignition characteristics of various fuels have been examined. Research Octane numbers of various fuels were found to be indicated by the appearances of weak flames. Chemical kinetics at low temperatures up to 1200 K for hydrogen flames, C1 to C16 hydrocarbon flames and syngas flames have been successfully elucidated and some possible modifications to the existing chemical kinetics were suggested.

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(with R. Fursenko, E. Sereshchenko)

Oscillating and rotating flame patterns in radial micro channel

The thermal-diffusive model was applied to demonstrate possibility of formation of oscillating or rotating spatial flame structures, which were described previously in experimental works on premixed gas combustion in the clearance between two disks with radial feeding of combustible premixture and external heating of the disks. The gas flow was assigned and described by the Poiseuille-flow velocity profile. The across size of the channel was smaller than the critical diameter depending of the ambient medium temperature. Gas combustion took place in the area where the wall

temperature was higher than the ambient temperature. Formation of oscillating flames in a straight channel and rotating structures in a radial channel occurred within a certain range of the gas flow rate. Beyond this range, at higher flow rates stationary flame mode took place. At smaller flow rates the instability leads to formation of rotating flame patterns reminding blades of turbine. The rotating structures resembling spiral flame in radial were found in some narrow range of gas flow rates too. These nonstationary flame patterns are formed due to gas preheating by hot walls and to non-uniform velocity distribution inside the microchannel.

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(with O. Maslennikov)

Hypernetwork as an upper level of describing dynamics and evolution of a neuron network

We propose a paradigmatic model of an adaptive network of spiking neurons that gives rise to a hypernetwork of its dynamic states at the upper level of description. We study basic properties of the model and illustrate it by a simple network of map-based spiking neurons.

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(with O.S. Sarıyer and M. Rubinstein)

Nonlinear deformation of swollen gels

Polymer gels can change their volume many folds by absorbing or expelling a large amount of a solvent. A large deformation of swollen gels can be achieved by applying relatively small forces. This feature, in addition to their biocompatibility and permeability, makes gels ideal materials for tissue engineering, drug delivery, and sensing. We develop a non-linear elasticity theory of gels swollen in various solvents (athermal, good, marginal, and Θ-solvents) and calculate the response of swollen gel to a general biaxial deformation. We argue that microscopic network strand statistics are different in compression and stretching regimes. They are controlled by polymer concentration in compression regime, and by externally applied stress or strain in the stretching regime. This difference is reflected in different values of Poisson's ratios in these regimes. We show that in athermal solvent, the Poisson's ratios μ, μ_e and μ_p for uniaxial, equibiaxial and planar biaxial deformations vary with the applied deformation in the intervals $0.21 < \mu < 0.26$, $0.31 < \mu_e < 0.35$, and $0.29 < \mu_p < 0.35$. We calculate stress-strain relations and propose a universal master equation, describing general biaxial deformations of a gel. We also develop a renormalization group description of the crossovers between different solvent and deformation regimes and construct diagrams of states for swollen and deformed gels. Our analytical results for the stress-deformation curves agree well with experimental data, unlike the simplest mean-field-like approaches.

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(with M. Kuznetsov)

Investigation of self-organization mechanisms In non-equilibrium systems using block model approach

Spatial-temporal patterns formed in systems far from thermodynamic equilibrium are widely spread in nature. They are observed in systems of different nature: physical, chemical, biological. We will give some examples of complex self-organization both presented by natural living systems and by experimental chemical reactions. Then we will demonstrate that the so-called block models, which are composed of two or more submodels, interacting with each other, can often effectively explain mechanisms of such phenomena.

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(with S. Nechaev)

Number-theoretic aspects of 1D localization: "popcorn function"with Lifshitz tails and its continuous approximation by the Dedekind η

We discuss the number-theoretic properties of distributions appearing in physical systems when an observable is a quotient of two independent exponentially weighted integers. The spectral density of ensemble of linear polymer chains distributed with the law $\sim f^L$ $(0 < f < 1)$, where L is the chain length, serves as a particular example. At $f \to 1$, the spectral density can be expressed through the discontinuous at all rational points, Thomae ("popcorn") function. We suggest a continuous approximation of the popcorn function, based on the Dedekind η-function near the real axis. Moreover, we provide simple arguments, based on the "Euclid orchard"construction, that demonstrate the presence of Lifshitz tails, typical for the 1D Anderson localization, at the spectral edges. We emphasize that the ultrametric structure of the spectral density is ultimately connected with number-theoretic relations on asymptotic modular functions. We also pay attention to connection of the Dedekind η-function near the real axis to invariant measures of some continued fractions studied by Borwein and Borwein in 1993.

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Nonlinear Schrödinger equation and classical-field description of quantum phenomena

It is shown that all of the basic properties of the hydrogen atom can be consistently described in terms of classical electrodynamics if the Schrödinger equation is considered to be the field equations similar to Maxwell equations for the electromagnetic field. In the framework of classical electrodynamics, the nonlinear Schrödinger equation is derived, which completely describes the spontaneous emissions of an atom, the thermal radiation and the light-atom interaction. The Planck's law for the spectral energy density of thermal radiation and the Einstein A-coefficient for spontaneous emission are derived in the framework of classical field theory without quantization of radiation. It is shown that three well-known laws of the photoelectric effect can also be derived within classical field theory.

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(with A.S. Il'yn and K.P. Zybin)

Passive scalar transport by a non-Gaussian turbulent flow (Batchelor regime)

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Three-dimensional numerical simulation of combustion, detonation and deflagration to detonation transition processes

Self-sustaining waves can propagate in meta-stable media; energy needed to support such waves is released by the wave itself. As a rule, two regimes of propagation exist, subsonic and supersonic; the difference is based on the different mechanisms of medium activation. Processes of transition between those regimes are less studied up to now, in comparison with pure subsonic or supersonic modes. Knowing mechanisms of controlling detonation initiation is important in order to work out effective preventive measures, such as suppressing deflagration to detonation transition (DDT) in case of combustible mixture ignition, and mitigation of a detonation wave in case it is already developed. On the other hand, the advantages of burning fuel in a detonation regime in comparison with slow burning at constant pressure attract increasing attention to pulse detonation burning chambers and to their possible application to new generation engines. Codes for simulation of deflagration, detonation and transition processes in homogeneous turbulized mixtures accounting for hybrid structure of supercomputer were developed. Technical description of numerical code and simulation method is assembled describing two algorithmic solutions (Scheme 1 and Scheme 2) adapted for two types of hardware: universal and hybrid. A unique validation and verification basis, incorporating the data of laboratory experiments and exact solutions was developed. Comparison of numerical results with experimental data present in the validation basis was performed. The validation basis could be used for validating different codes including commercial ones for description of unsteady-state processes in chemically reacting mixtures in the domains of complex geometry. Investigation confirming the validity of the developed simulator are performed based on comparison of numerical results with exact solutions and experimental data present in verification basis. Results of multiparametric comparison of numerical simulations with experimental data on unsteady-state reflection of shock wave in chemically reacting gas from wedge or cone demonstrate that difference in values of pressure and velocity for experiments and numerical simulations does not exceed 7%, difference in characteristic time of transition process – 10%. In time, reflected wave velocity reaches equilibrium value. The difference between theoretical and experimental data for shock waves does not exceed 20 m/s, for detonation waves – 70 m/s. The deviation of equilibrium characteristics does not exceed 2.6% for reflected shock wave, and 3.5% for reflected detonation wave.

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A critical network is what you hear

For hundreds of years, mankind has wondered about how the mammalian hearing system maps the world around us. By this mapping, we are confronted with a number of strange, puzzling, phenomena that are relevant to hearing. We will show, that the understanding of these phenomena requires, before all, a proper understanding of the nature of the hearing sensor, the mammalian cochlea, in particular, of its nonlinear properties. We will see that a stunning network of active nonlinear nodes is at the origin of mammalian hearing [F. Gomez, T. Lorimer, and R. Stoop, PRL 116 (10), 108101 (2016)], and we will show, moreover, that these nodes co-operate in a complex network, that in its relaxed state, has properties of a critical system, whereas in the tuned state [F. Gomez, V. Saase, N. Buchheim, and R. Stoop, Phys. Rev. Appl. 1 (1), 014003 (2014)], this property is abandoned [R. Stoop and F. Gomez, PRL 117 (3), 038102 (2016)]. This, first of all, changes our view of hearing perception happening mostly at the level of the cortex, to one where the salient phenomena of hearing are established at the level of the sensor itself. Second, the hearing system can be taken as a blueprint of sensory systems, which indicates a novel approach for a modern understanding of sensors based on networks of nonlinear dynamical elements. Finally, the hearing system can be seen as a very ancient type of nervous system, which provides us with a fundamental coherent view on the nature of biological information processing.

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(with M. Olshanskii, A. Lozovskiy and A. Danilov)

A finite element method for incompressible Navier-Stokes equations in a time-dependent domain

We present a finite element method for the Navier-Stokes equations governing the incompressible viscous fluid flow in a time-dependent domain. The method builds on a quasi-Lagrangian formulation of the problem and handles geometry in a time-explicit way. The numerical solution is shown to satisfy a discrete analogue of the fundamental energy estimate. This stability estimate does not require a CFL time-step restriction. Also, a brief sketch of the convergence estimates is given. The method is further applied to hemodynamics in the human heart left ventricle. The ventricle wall motion is reconstructed from a sequence of contrast enhanced Computed Tomography images.

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(with E.H. Hellen)

How to couple identical ring oscillators to get Multistability, Quasiperiodicity and asymmetric Chaos?

Synthetic genetic oscillators have become popular since 2000 when a simple ring circuit with unidirectional repression, called the Repressilator, was engineered and realized inside bacterial cells. The oscillators are considered to be an effective test bed for assessing ideas about gene expression regulation, as well as possible instruments for gene therapy. However, the effectiveness of oscillators depends on how they can function collectively, thereby requiring some coupling method. An almost obvious suggestion was to use natural bacterial quorum sensing (QS) as the method for synchronization. The core of QS is the production of small molecules (autoinducer) which can, first, easily diffuse across the cell membrane and, second, work to activate target gene transcription. Manipulating the gene positions and QS-sensitive promoters in the genetic circuits, one can obtain different coupling types and, as a result, different sets of collective modes in bacterial populations. The effective synchronization of relaxation QS-dependent oscillators was recently demonstrated in an impressive experiment. We use the reduced Repressilator model with the QS mechanism added in a way that autoinducer diffusion provides for repulsive coupling. This type of coupling of two identical Repressilators leads to the domination of the antiphase limit cycle, the formation of stable inhomogeneous stationary states and inhomogeneous limit cycles, as well as to the emergence of chaos in a wide range of parameters. The phase diagram structure and the degree of stable attractor overlapping in the parameter space depends strongly on the degree of cooperativity (steepness of nonlinear terms in the ODE system) in the regulation of gene expression: the higher the cooperativity the larger the parameter area occupied by the chaotic regime. Apart from usual chaos emerging via torus bifurcation, we found the asymmetric chaotic regime in which the amplitudes of oscillations differ significantly. This chaos is located far from torus bifurcation and includes the set of "periodic windows" with asymmetric regular oscillations).

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(with V. Yakhno)

Dynamics of spatial inhomogenities in colloidal systems. Possible mechanisms

Slow long-lived fluctuations of mechanical properties of drying drops of instant coffee water solutions have been found by means of the Drying Drop Technology (DDT), developed earlier. Parameters of fluctuations depended on extent of dilution and didn't depend on additional hashing of solution, closing by a cover and shielding from external electromagnetic fields. We compared dynamics of physicochemical and morphological processes in bulk. This comparison has led us to unexpected idea which will be proved here.

We observed microscopically periodic emergence, growth, aggregation and the disappearance of spherical cavities in bulk of dispersion (10-50 μm in diameter), which was followed by agreed fluctuations of physicochemical parameters of colloidal system. As far as we showed, these spheres were huge hydrate covers of liquid crystal water around colloidal particles.

Phase transitions between free and bound (liquid crystal) water in a bulk of colloidal system is a pacemaker of fluctuations its physicochemical properties. These changes are regulated and coordinated by the value of osmotic pressure. At low osmotic pressure hydrate covers grow, forcing out particles and ions in a bulk; at high - they collapse to small size, reducing osmotic pressure. Existence of self-oscillatory processes was confirmed by mathematical model.

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The basic models to describe the characteristic modes of processing information signals

Models representing "basic elements of a Toolkit for the designer"are discussed, using which it is possible to formulate "technical counterparts"of living systems. A classes of models are considered, which can be described by:

1) fast, automatic processes of selection or suppression of those signals for which the system was trained earlier (unconscious perception);

2) various modes as unconscious perception, the skip signal (cognitive filters) and conscious processing, which is optimizing the system settings; perhaps the implementation of procedures for planning future states of the system, own goal-setting; perhaps the release of such architectural relationships in the system which is similar to the process of intuitive perception of information;

3) multi-level modes of processing input signals with the aim of "professional and appropriate"reactions to external stimuli; control by higher levels, so-called modules "EGO"; modes, specialized by type of processed information, for example: a) "single-step"decision-making by associations, usually make an analogy with the work of the right brain; and b) step - by-step logical decision-making with multiple outputs, usually make an analogy with the work of the left brain;

4) procedures for addressing conflicts in "data "knowledge "decisions- making etc., which are triggered by conditions different kind of "dissonance the errors between the actual and expected signals; description of the procedures of transformation, the development of a hierarchy of "EGO"with various levels of reflection and understanding of processes in nature.

It is shown that the model of processes of active recognition with elements of "thinking"allows us to consider a set of processes, which without their use would be enigmatic.

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(with S.A. Dyachenko)

Simple analytical model of wave breaking

Wave breaking, albeit the formation of white caps on the fluid surface, is one of the most common physical events. Nevertheless, in spite of enormous amount of efforts, there is no any convincing analytical model of this event so far. It is explained by very nontrivial circumstances. The Euler equation describing the potential motion of the deep fluid with free surface is a completely integrable Hamiltonian system; as a result, there is no universal scenario describing this phenomenon. Moreover, there is no particular scenario that is a "local attractor". We have developed a set of approximate analytical scenarios replacing the exact Euler equation by much more simple "Laplace growth equation" that admits complete analytical treatment. We claim that the wave-breaking takes place due to development of the "finger-like" configuration of the surface. This configuration soon becomes unstable and generates turbulent "white-capping". The analytical results are supported by the massive numerical simulations.

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Precise Measurements, Constants and Tests of Fundamental Theories

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(with D.B. Tretyakov, V.M. Entin, E.A. Yakshina, G.N. Hamzina, M .Saffman, S. Bergamini and I.I. Ryabtsev)

Resonant dipole-dipole interaction of Rydberg atoms for quantum information

Ultracold neutral atoms in optical lattices are promising candidates for implementation of a quantum computer. Two-qubit quantum gates can be performed via long-range dipole-dipole interaction of atoms, temporarily excited into Rydberg states. We study Förster resonances between Rydberg atoms which are observed as transitions to neighboring Rydberg states, induced by dipole-dipole interaction. The interaction strength is controlled by Stark tuning of the atomic energy levels. In our experiments we have studied the line shapes of the Förster resonances between Rb Rydberg atoms, confined in a small volume inside the magneto-optical trap, with atom-number resolution. We have also shown that additional Förster resonances can be induced by applying a radiofrequency electric field due to the Floquet sidebands of Rydberg states. We proposed the schemes of two-qubit gates using double adiabatic rapid passage across the Förster resonance with nonlinear detuning in order to reduce the sensitivity of the quantum gate fidelity to the fluctuations of the interatomic distance. We have shown that double adiabatic rapid passage results in deterministic phase shift of the atomic state in a two-level system. From numerical simulations we expect that the gate fidelity can be higher than 99% for realistic experimental conditions.

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Precision laser spectroscopy of leptonic atoms

Positronium (the positron and electron bound state, Ps) and Muonium (the positive muon-electron bound system, Mu) are made of two leptons which are believed to be point like particles. These purely leptonic atoms are thus free from the finite-size effects which are increasingly important in H spectroscopy. A renewed interest in these atomic systems has been triggered by the recent results of the muonic hydrogen experiment at PSI that gave rise to the so called proton charge radius puzzle. Furthermore, weak interaction effects are negligible at the current level of experimental accuracy, and thus these systems provide an excellent testing ground for bound-state QED and a way for the determination of fundamental constants such as the positron electron mass ratio, the muon mass and the charge ratio between the first two generation of leptons. The 1S-2S transition frequencies have been measured in the past for both systems reaching a precision of the order of few ppb. In this talk, we will present the status of our experiments aiming to improve the uncertainty of the current measurements.

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M. Eides

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(with V.A. Shelyuto)

Hard three-loop corrections to positronium energy levels

We review recent calculations of hard nonlogarithmic corrections of order $m\alpha^7$ to positronium energy levels. Our new results will be presented.

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(with C. Ohae, J. Zheng, M. Suzuki and K. Minoshima)

Taylor nonlinear optical frequency conversions and its application to high resolution laser spectroscopy in the vacuum ultraviolet region

Nonlinear optical processes are governed by the relative-phase relationships among the relevant electromagnetic fields in these processes. If we can arbitrarily manipulate such relative phases, we can have a large freedom to tailor the nonlinear optical processes.

In this paper, on the basis of this idea, we will show an attractive optical frequency conversion which can potentially cover an ultrabroad wavelength region of 100 nm to 30 um with a near-unity quantum efficiency, including a recent experimental evidence for this conceptual idea. We will also discuss how we can utilize such coherent light sources for high resolution laser spectroscopies in the vacuum ultraviolet region.

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with L. Maisenbacher, A. Beyer, A. Matveev, D.C. Yost, R. Pohl, Th. Udem, T.W. Hänsch and N. Kolachevsky

Qunatum interference in precision spectroscopy experiment

Quantum interference from distant neighboring resonances has been shown to cause considerable line shape distortions in precision spectroscopy experiments based on excited state fluorescence detection. The corresponding line shifts are geometry dependent and significant even in the case of far detuned neighboring resonances. We present the first dedicated measurement of these effects for resonances separated by more than 100 natural line widths in the 2S-4P transition spectroscopy in atomic hydrogen. Apparent line center shifts of up to ± 51 kHz were observed. A simplified model of the effect and ways for correction of the corresponding shifts will be discussed.

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Precision spectroscopy of the 2S-4P transition in atomic hydrogen: new values for the Rydberg constant and the proton charge radius

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Precision spectroscopy of light atoms and molecules and fundamental physical constants

We plan to present state of the art in theoretical calculations of the hydrogen molecular ion and antiprotonic helium. We show that for fundamental transition frequency a fractional uncertainty of $7 \cdot 10^{-12}$ is achieved. These results have direct impact on the potential determination of the fundamental constants such as the Rydberg constant, proton-to-electron mass ratio, and may help to resolve the problem of the proton rms electric charge radius.

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M. Musha

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Frequency-stabilized lasers and their applications, from X-FEL to gravitational wave detection

We have developed frequency stabilized lasers, and applied them to many fields. In my talk I first focus on the developments of the light source for the space gravitational wave detector. Japanese space gravitational wave detection mission, DECIGO, is triangle shaped Fabry-Perot Michelon Interferometer with the arm length of 1000 km, and we have developed iodine-stabilized Yb:fiber DFB lasers. And in addition to this topic, the precision distributions of the frequency-stabilized lasers through long optical fibers are also presented, which are applied to the timing and phase synchronizations in large science missions such as X-ray free electron laser or large-scale mm-telescope array.

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New results on gravitational and whispering-gallery quantum states of neutrons and constraints for extra short-range forces

Quantum gravitational spectroscopy with ultracold systems is an emerging field based on recent major experimental and theoretical advances. Gravitational spectroscopy profits from exceptional sensitivity due to the extreme weakness of gravitation compared to other fundamental interactions; thus, it provides an access to the precision frontier in particle physics and other domains. Quantum gravitational spectroscopy is its ultimate limit, which addresses fragile and sensitive quantum states of ultracold particles and systems. Sufficiently high phase-space density of ultracold particles – neutrons, atoms, and antiatoms – is the condition for providing observable phenomena with gravitational quantum states. Some such studies, like those with ultracold neutrons, have become reality [V.V. Nesvizhevsky, H.G. Boerner, A.K. Petukhov et al., Quantum states of neutrons in the Earth's gravitational field, Nature 415, 297 (2002)]; others with ultracold atoms and antiatoms are in preparation. GRANIT is one of projects pushing forward the precision and sensitivity of quantum gravitational spectroscopy with ultracold neutrons [D. Roulier, F. Vezzu, S. Baessler et al., Status of the GRANIT facility, Adv. High En. Phys. 730437 (2015)]. Quantum states of antihydrogen atoms in GBAR are the key for pushing the precision of measurements of gravitational properties of antimatter [P. Perez, D. Banerijee, F. Biraben et al., The GBAR antimatter gravity experiment, Hyper. Inter. 233, 21 (2015)]. These domains were discussed at GRANIT workshop and presented in ref. [I. Antoniadis, S. Baessler, V.V. Nesvizhevsky, and G. Pignol, Quantum gravitational spectroscopy, Adv. High En. Phys. 467409 (2015)]; they are analyzed in textbook [V.V. Nesvizhevsky, and A.Yu. Voronin, Surprising Quantum Bounces (Imperial College Press, London, UK, 2015]. We present status, advances in the field and prospects.

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Current trend in relativistic gravitational experiments

After a first registering of GW radiation from binary BH coalescence practically all non Newtonian effects predicted by GR have got its experimental confirmation. Further development of experimental gravitation is now associated with a more precise measurement of the same effects to check a border of GR validity and to search for a new physics. It is believed that such experiments must be carried in a deep underground or in the board of cosmic apparatus to depress influence of environmental noises. Common feature of the experiments consists in registration of space-time curvature variations produced by small changes of weak gravity fields.

Hope of increasing accuracy of measurement at present is associated with the new instrumentation based on optical frequency standards and matter wave interferometers admitting the gain in three order of value of space -time intervals. In this talk we put attention on gravitational experiments are carried out at present in RAS: i) an original underground gravitational detector OGRAN and ii) the gravitational red shift test with the Earth satellite. In the final part we discuss briefly a new possibility of gravity gradient measurement using the new instrument - the atomic fountain gradiometer.
i) The opto-acoustical gravitational setup OGRAN structurally combines the principles of interferometer and solid-state gravitational antennas. A large acoustical resonator matched to the commensurate Fabry–Perot (FP) optical cavity serve both as the sensitive elements for registering gravity gradient variations induced by GW. At room temperature the sensitivity of the setup is $\sim 10^{-19}$ Hz$\breve{}^{1/2}$ at a frequency of 1.3 kHz and it can be enhanced up to 10^{-21} Hz$\breve{}^{1/2}$ with the cooling to nitrogen temperature. The new antenna is designed for detecting relativistic catastrophes (collapses) in the Galaxy and the nearest vicinity during joint (multi-channel) monitoring with neutrino telescopes of the Baksan Neutrino Observatory INR RAS
ii) The unique test of general relativity is carried out by Astro Space Center of LPI RAS with the space cosmic apparatus RadioAstron. The ultra-stable on-board hydrogen maser and the highly eccentric orbit make RadioAstron an ideal instrument for probing the gravitational redshift effect. Gravitational potential variations, occurring on the orbiting time scale, causes large variations of the on-board H-maser clock rate, which can be detected via comparison with frequency standards installed at ground radio astronomical observatories. The experiment requires specific on-board hardware operating modes and support from ground radio telescopes capable of tracking the spacecraft with 8.4 or 15 GHz receivers. Estimates show that accumulation of data at 30 orbits allows to reach $\sim 210^{-5}$ accuracy in the test, which would constitute a factor of 10 improvement over the well known result achieved with GP-A mission.

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A. Voronin

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(with V. Nesvizhevsky)

Interferometry and spectroscopy of antihydrogen gravitational quantum states

We discuss a novel approach to precision meausrement of antihydrogen gravitational mass via spectroscopy and interferometry of quantum states of antiatoms near material surface in the Earth gravitational field. Existense of long-living metastable quantum states of antihydrogen near material surface is explained in terms of quantum reflection phenomenon. The level spacing of such states is determined by gravitational properties of antihydrogen. We demonstrate principal possibility to achieve relative accuaracy of one part in a million for the ratio of gravitational to inertial mass of antihydrogen in feasible spectroscopic and interferomic measurements with ultracold antihydrogen.

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Precision spectroscopy of (anti)hydrogen for tests of CPT and Lorentz Invariance

The ground-state hyperfine structure (GS-HFS) of hydrogen is known from the hydrogen maser to relative precision of 10^{-12}. It is of great interest to measure the same quantity for its antimatter counterpart, antihydrogen, to test the fundamental CPT symmetry, which states that all particles and antiparticles have exactly equal or exactly opposite properties. Since CPT is strictly conserved in the Standard Model of particle physics, a violation, if found, would point directly to theories behind this framework. The application of the maser technique requires the confinement of the atoms in a matter box for 1000 seconds and is currently not applicable to antihydrogen. Therefore, the ASACUSA collaboration at the Antiproton Decelerator of CERN has built a Rabi-type beam spectroscopy setup for a measurement of GS-HFS.

With the initial aim of characterizing the setup devised to measure the GS-HFS and to evaluate its potential, a beam of cold, polarized, monoatomic hydrogen was built and used together with the microwave cavity and sextupole magnet designed for the antihydrogen experiment. The $(F, M) = (1, 0)$ to $(0, 0)$ transition was measured to a precision of several ppb [M. Diermaier et al., arxiv : 1610.06392], more than a factor 10 better than in the previous measurement using a hydrogen beam. This result shows that the apparatus developed is capable of making a precise measurement of the GS-HFS of antihydrogen provided a beam of similar characteristics (velocity, polarization, quantum state) becomes available.

In a recent publication on the non-minimal Standard Model Extension (SME), describing possible violations of Lorentz and CPT invariance, Kostelecky and Vargas [V.A. Kostelecky and A.J. Vargas, Physical Review D 92, 056002 (2015)] conclude that the in-beam hyperfine measurements of hydrogen alone can be used to constrain certain coefficients of their model, which have never been measured before. The status and prospects of in-beam measurements of hydrogen and antihydrogen will be presented.

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