The Modern Physics of Compact Stars and Relativistic Gravity 2021

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Book of Abstracts

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Hot Quark Matter at Neutrino Confinement in the Framework of the local SU(3) Nambu - Jona-Lasinio Model

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The thermodynamic characteristics of hot β -equilibrium electrically neutral three-flavor quark matter at neutrino confinement are investigated. For the thermodynamic description of such a quark-lepton system, the local SU(3) Nambu-Jona-Lasinio (NJL) model is used, in which also takes into account the 't Hooft interaction, leading to the quark flavor mixing effect. The energy density ε and pressure P of quark matter are numerically determined for different values of the baryon number density in the range n_B $[0.02\div1.8]$ fm-3 and temperatures in the range T $[0\div100]$ MeV. The results obtained are compared with the results of cold quark matter calculated within the framework of the same model, but under the assumption that all neutrinos have already left the system. The dependence of the contribution of individual quark flavors to the baryon charge of the system at different temperatures is discussed. Both isothermal and adiabatic speeds of sound in hot quark matter are determined depending on the baryon number density.

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The neutron star equation of state under new constraints

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Recent constraints from neutron star measurements and nuclear experiments have narrowed the allowed physical regions for the compact stars equation of state (EoS) resulting in some of the well established models being less probable than before. These new constraints include the NICER mass-radius measurement of the object PSR J0740+6620, whereas laboratory experiments like Spectral Pion Ratio by Radioactive Ion Beams (SπRIT Collaboration) and parity-violating asymmetry in the elastic scattering of longitudinally polarized electrons from ^{208}Pb (PREX collaboration) have reported values of the slope of the nuclear symmetry energy at saturation, a quantity strongly correlated to the neutron star radius. In this talk I will review mostly EoS models of hadronic and hybrid stars, and will present the results of a Bayesian Analysis that includes the state-of-the-art astrophysical constraints in order to select the most probable EoS parameters.

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Nuclear Physics and GW170817

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The GW170817 event answered one of the important questions regarding a potential site of heavy element synthesis in the cosmos. The observations of the gravitational waves (VIRGO and LIGO) along with signatures from 70 electromagnetic transients indicated that heavy element synthesis was indeed going on up to the rare-earth region of the chart of nuclides. These series of connected observations answered an important question but unveiled a number of new ones. Questions about the extent of the synthesis, did it reach the actinides? The role of fission was once again explored. Does fission of the very neutron rich nuclei follow expected distributions? There is ample evidence that very different fission distributions result from the very neutron rich nuclei. What is the role of cluster decays and the potential population of the island of stability or the synthesis of super-heavy elements. Perhaps even more importantly, what are sources of the neutrons? Stellar evolution from the very first generation of stars to the explosive astrophysical scenarios that contribute to the solar abundances of the elements require abundances of neutrons. This talk will explore questions and answers.

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Scalar-Connection Gravity and Spontaneous Scalarization

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Scalar-tensor theories of gravity are known to allow significant deviations from general relativity through various astrophysical phenomena. In this talk, we present scalar-connection gravity; a theory based on scalar fields and connection configurations instead of metric. Since the matter sector is not straightforward to conceive without a metric, we invoke cosmological fluids in terms of their one-form velocity in the volume element of the invariant action. This leads to gravitational equations with a perfect fluid source and a generated metric, which are expected to produce reasonable deviations from general relativity in the strong field regime. As a relevant application, we study a spontaneous scalarization mechanism and show that the Damour-Esposito-Farèse model arises in a certain class of scalar-connection gravity. Furthermore, we investigate a general study in which the present framework becomes distinguishable from the famed scalar-tensor theories.

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Equation of State table with exotic matter for supernova and neutron star merger

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We develop a new equation of state (EoS) table involving thermal (anti)kaons, Bose-Einstein condensate of K^- mesons and Λ-hyperons for core-collapse supernova and neutron star merger simulations. This EoS table is based on a finite temperature density-dependent relativistic hadron field theory where baryon-baryon interaction is mediated by scalar σ, vector ω and ρ mesons, using the parameter set DD2 for nucleons. The repulsive hyperon-hyperon interaction is mediated by an additional strange ϕ meson. The EoS for the K^- condensed matter is also calculated within the framework of relativistic mean field model, whereas the low-density, inhomogeneous matter is calculated in the extended Nuclear Statistical Equilibrium model (NSE). The EoS table is generated for a wide range of values of three parameters - baryon density (10^{-12} to ~ 1 fm^{-3}), positive charge fraction(0.01 to 0.60) and temperature(0.1 to 158.48 MeV).

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Constraining the properties of superdense matter with observations of low-mass X-ray binaries: the case of HETE J1900.1–2455

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New observations of a transient neutron star in a low mass X-ray binary HETE J1900.1–2455 were carried out in 2018. Despite detecting only six net photons, it was still possible to infer the effective surface temperature of the star. It turned out to be quite low, ≈30 − 39 eV (for an observer at infinity) depending on the assumed mass, radius and distance to the star. Taking into account the amount of energy deposited during the ≈10 years accretion outburst as well as previous temperature measurements in 2016, these values can either indicate that the core has a very high heat capacity or that it undergoes rapid neutrino cooling. Unfortunately, current observational data does not allow us to distinguish between these two possibilities. However, both of them suggest that a significant fraction of the core is not superfluid (superconductor). Also, our modeling shows that the star can cool even further, up to the temperature of ≈15 eV. In this case future observations (that are already scheduled) might allow us to obtain constraints on the fraction of unpaired baryons in the core.

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Special points for hybrid neutron stars in the mass-radius diagram

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We present a systematic investigation of the possible locations for the special point (SP), a unique feature of hybrid neutron stars in the mass-radius diagram. The study is performed within the two-phase approach where the high-density (quark matter) phase is described by the constant-sound-speed (CSS) equation of state (EoS) and the nuclear matter phase around saturation density is varied

from very soft (APR) to stiff (DD2 with excluded nucleon volume). Different construction schemes for the deconfinement transition are applied: Maxwell construction, mixed phase construction and parabolic interpolation. We demonstrate for the first time that the SP is invariant not only against changing the nuclear matter EoS, but also against variation of the construction schemes for the phase transition. Since the SP serves as a proxy for the maximum mass and accessible radii of massive hybrid stars, we draw conclusions for the limiting masses and radii of hybrid neutron stars.

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Stripping model for short Gamma-ray Bursts in neutron star mergers

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I overview the current status of the stripping model for short gamma-ray bursts. After the historical joint detection of the gravitational wave event GW170817 and the accompanying gamma-ray burst GRB170817A, the relation between short gamma-ray bursts and neutron star mergers has been reliably confirmed. Many properties of GRB170817A, which turned out to be peculiar in comparison with other short gamma-ray bursts, are naturally explained in the stripping model, suggested by us in 1984. I point out the role of late Dmitriy Konstantinovich Nadyozhin (1937-2020) in predicting the GRB and kilonova properties already in 1990. I review also the problems to be solved in the context of this model.

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The gravitational energy-momentum pseudo-tensor in higher-order theories of gravity

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We derive the gravitational energy momentum tensor for a general Lagrangian of any order and prove that this tensor, in general, is not covariant but only affine, then it is a pseudo-tensor. Furthermore, the pseudo-tensor is calculated in the weak field limit up to a first non-vanishing term of second order in the metric perturbations. The average value of the pseudo-tensor over a suitable spacetime domain is obtained. Finally we calculate the power per unit solid angle carried by a gravitational wave. These results are useful in view of searching for further modes of gravitational radiation beyond the standard two modes of General Relativity and to deal with non-local theories of gravity. The general aim of the approach is to deal with theories of any order under the same standard.

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Thermodynamics of one-component plasma for astrophysical applications

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We apply path-integral Monte Carlo simulations to calculate the energy of crystallized one-component plasma: the system of atomic nuclei and a uniform incompressible background (electrons). We consider full range of conditions, which are typical for core of white dwarfs and envelope of neutron stars. The results are approximated by analytic formulae, which allow us to obtain various thermodynamic functions. In particular, we demonstrate that the total crystal specific heat can exceed the well-known harmonic contribution by a factor of 1.5 due to anharmonic effects. Combining our results with the thermodynamics of the quantum Coulomb liquid, we determine the density dependence of the melting temperature and the latent heat. The results are necessary for realistic modelling of the thermal evolution of white dwarfs and neutron stars.

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Effects of anisotropy on strongly magnetized neutron and strange quark stars

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We investigate the properties of anisotropic, spherically symmetric compact stars, especially neutron stars and strange quark stars, made of strongly magnetized matter. The neutron stars are described by SLy equation of state, the strange quark stars by an equation of state based on the MIT Bag model. The stellar models are based on an a priori assumed density dependence of the magnetic field and thus anisotropy. Our study shows that not only the presence of a strong magnetic field and anisotropy, but also the orientation of the magnetic field itself, have an important influence on the physical properties of stars. Two possible magnetic field orientations are considered, a radial orientation, where the local magnetic fields point in the radial direction, and a transverse orientation, where the local magnetic fields are perpendicular to the radial direction. Interestingly, we find that for a transverse orientation of the magnetic field, the stars become more massive with increasing anisotropy and magnetic field strength and increase in size, since the repulsive, effective anisotropic force increases in this case. In the case of a radially orientated magnetic field, however, the masses and radii of the stars decrease with increasing magnetic field strength, because of the decreasing effective anisotropic force. Importantly, we also show that in order to achieve hydrostatic equilibrium configurations of magnetized matter, it is essential to account for both the local anisotropy effects as well as the anisotropy effects caused by a strong magnetic field. Otherwise, hydrostatic equilibrium is not achieved for magnetized stellar models.

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On registration of a massless Bose particle - Hion with spin 1, whose Bose- Einstein condensation forms dark energy

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Recently, author theoretically proved the possibility of the existence of a massless spin 1 particle within
the framework of the stochastic extension of Yang-Mills theory within the framework of the gauge symmetry group SU(2) x U(1) [1]. We have shown that these particles (vector bosons called hions), entangling in pairs, form Bose particles with spin-0, which in turn form a Bose-Einstein condensate. In

order to be convinced of the reasonableness and accuracy of the developed theoretical concept, we decided to carry out the following quite illustrative and simple experiment, which can confirm the real
existence of such massless particles.
As well-know, the quantum vacuum or dark energy fills all space without any special obstacles, including where the usual types of matter (mass particles and fields) are absent. The latter means that a
certain number of non-entangled and free hions under the action of external fields can change their orientation, thereby polarizing and creating phase objects in certain regions of space, relative to which
the scattering photons are very sensitive.

Not so long ago we set up an experiment, the purpose of which was to detect nonlocal interactions between two spatially divided light beams [2]. Note that this is practically impossible given the very small light-to-light scattering cross section, especially for the visible region of light (~10-68cm2
).
Nevertheless, as the experiment showed, there is such a nonlocal interaction between light rays, which
is quite measurable, and the reason for this phenomenon could be a material environment unusual in its
properties. Figure 1 illustrates a modification of the experiment [2], when the light diffracted from the
slit is affected by the laser beam of the second source, which circulates in cylindrical symmetry, and when all this equipment is in a vacuum. Measurements of the brightness of light in different zones showed that when the experiment is carried out in a high vacuum (~10-5 Pa), then again a certain

redistribution of the light intensity in the zones is observed, and some distortion of the sizes of the zones
themselves is also observed.
Thus, a simple experiment in the field of visible light (l~ 510-530nm) indirectly shows the presence of matter with unusual properties, consisting of massless vector bosons. Further research into the properties of this matter, which can lay claim to the place of dark energy will require new experiments.
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Making (neutron-star) mountains out of molehills

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Over the past few years, we have enjoyed a wide variety of gravitational-wave detections of compact binary coalescences. However, the wait continues for the first observation of a rotating neutron star via gravitational waves and, so far, only upper limits on the size of the involved deformations have been obtained. For these reasons, the maximum quadrupole deformation (or mountain) that a neutron star can sustain is of great interest. In this talk, I will outline how neutron-star mountains are calculated, while identifying issues with previous studies relating to boundary conditions. In light of these issues, I shall present a novel scheme for modelling neutron-star mountains, which requires a description of the fiducial force that takes the star away from sphericity. I will show some results computed in full general relativity, exploring the roles of both the deforming force and the equation of state in supporting mountains.

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Calculation of the kinetic coefficients of arbitrary degenerate electrons in magnetized dense matter

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Analytical expressions for the components of the tensors of thermal conductivity, diffusion, thermal diffusion and the diffusional thermal effect are obtained from the solution of the Boltzmann equation by the Chapman-Enskog method, taking into account electron-electron collisions for the case of non-degenerate electrons in a magnetic field. For strongly degenerate electrons, asymptotically accurate analytical expressions are obtained for the tensors of kinetic coefficients in the Lorentz approximation, taking into account the magnetic field. For the case of partial degeneracy at □ □ / □ □ =1.011, the analytical expressions for the kinetic coefficients in the absence of a magnetic field are obtained from the solution of the Boltzmann equation in the 3-polynomial approximation. It is shown that the convergence of the polynomial approximation to the exact value is slower than for non-degenerate electrons.The calculations of the transfer coefficients allow us to estimate the influence of the magnetic field on the transfer of heat and charge in the dense regions of neutron stars and white dwarfs. The obtained expressions can also be used to describe the transfer coefficients in other magnetized objects containing free arbitrarily degenerate electrons.

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Bulk viscosity from Urca processes: $npe\mu$-matter with neutrinos

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In this work, we extend our previous study of the bulk viscosity of hot and dense □□□ matter induced by the Urca process in the neutrino trapped regime to □□□□ matter by adding the muonic Urca processes as well as the purely leptonic electroweak processes involving electron-muon transition.
The nuclear matter is modeled in a relativistic density functional approach with two different parametrizations which predict neutrino dominated matter (DDME2 model) and anti-neutrino dominated matter (NL3 model) at temperatures for which neutrinos/anti-neutrinos are trapped.
In the case of neutrino-dominated matter, the main equilibration mechanism is lepton capture, whereas in the case of antineutrino-dominated matter this is due to neutron decay. We find that the equilibration rates of Urca processes are higher than that of the pure leptonic processes, which implies that the Urca bulk viscosity can be computed with the leptonic reactions assumed to be frozen. We find that the bulk viscosity decreases with temperature as □~□−2 at moderate temperatures. At high temperatures this scaling breaks down by sharp drops of the bulk viscosity close to the temperature where the proton fraction is density-independent and the matter becomes scale-invariant. This occurs also when the matter undergoes a transition from the antineutrino-dominated regime to the neutrino-dominated regime where the bulk viscosity attains a local maximum. We also estimate the bulk viscous dissipation timescales and find that these are in the range ≥ 1 s for temperatures above the neutrino trapping temperature. These timescales would be relevant only for long-lived objects formed in binary neutron star mergers and hot proto-neutron stars formed in core-collapse supernovas.

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Realtivistic density functional approach to quark matter in compact stars

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A principal element of strongly interacting matter phenomenology is the quark confinement at low baryonic densities. We develop an approach based on the relativistic density functional motivated by the string-flip model, which provides the low density suppresion of quarks due to rise of their self-energy already at the mean-field level. Dynamical restoration of chiral symmetry is ensured by construction of the density functional. The connection of the present approach to the Nambu-Jona-Lasinio model with density dependent coupling constant is demonstrated. Supplemented with the vector repulsion and diquark pairing channels it is applied to model a cold quark matter. We also use the corresponding equation of state for modelling compact stars with quark cores.

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Diffusion as the main source of dissipation in superconducting neutron stars

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We show that the diffusion of various particle species in superconducting neutron star cores can be extremely powerful dissipative mechanism. In particular, it can be much more efficient than the shear and bulk viscosities. This result has important implications for the damping times of NS oscillations, development and saturation of dynamical instabilities in NSs, and for the excitation and coupling of oscillation modes during the late inspiral of binary NSs.

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How can a neutron star avoid the Ejector stage?

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Recently discovered high-mass X-ray binary (HMXB) in the supernova remnant MCSNR J0513-6724 (Maitra et al., 2019) is a puzzle for the standard magneto-rotational evolution of neutron stars. If the observed period of 4.4 s corresponds to the critical period of Proppeller-Accretor transition, the magnetic field should be about 3×1011 G. With such a magnetic field, the duration of the Ejector and Propeller stages will significantly exceed the age of the supernova remnant, which is less than 6 thousand years. In this work, we propose a scenario, when a neutron star does not go through the Ejector stage due to fallback accretion and the Hysteresis effect. The Hysteresis effect is that the equality of pressures during the reverse transition, which determines the condition for the onset of a new stage, is set not at the the gravitational capture radius, but at the radius of the light cylinder. As a result, the transition is possible with a significantly shorter period. This leads to a reduction in the time before the Accretor phase.

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Stiffening of matter in quark-hadron continuity

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I argue how the concept of the quark-hadron continuity leads to stiffening of matter just above the nuclear saturation density. The relation to the McLerran-Reddy model of quarkyonic matter is also discussed.

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Three-dimensional simulation of stationary heat transfer in magnetized neutron stars

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The Magnificent Seven is a unique group of seven nearby thermally emitting isolated neutron stars. They are visible mostly in a soft X-ray band, their spectrum is close to a blackbody one, and their lightcurves show pulsations (up to 25%) in detected radiaton. These pulsations tell us, that temperature distributions in such neutron stars may be highly non-uniform due to the effect of their magnetic fields of order ~10^13 G on a thermal conductivity coefficient in the crust and the envelope of these objects.

We solve a three-dimensional stationary heat transfer equation with anisotropic thermal conduction in the crust and the envelope of the neutron star for a given superposition of non-coaxial dipolar and quadrupolar fields. Synthetic lighcurves and spectra are computed for calculated temperature distributions, and possible observational manifestations are discussed. The obtained results may help to determine better the structure of magnetic fields in objects like ones in the Magnificent Seven.

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Vacuum currents near horizon of a cylindrical black hole

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Vacuum currents near horizon of a cylindrical black hole V. Kh. Kotanjyan, A. A. Saharian, M. R. Setare We investigate the vacuum expectation value (VEV) of the current density for a charged massive scalar field with general curvature coupling parameter near a cylindrical black hole in background of (D+1)-dimensional spacetime. It is shown that, to the leading order, the near-horizon geometry is reduced to locally Rindler spacetime with toroidally compact subspace. For the latter geometry and assuming that the field is prepared in the Fulling-Rindler vacuum state, the Hadamard function is evaluated for the general case of compact and uncompactified spatial dimensions. Quasi-periodic conditions with general phases are imposed along compact dimensions. By using the expression for the Hadamard function, the VEV of the current density is studied. It shows that it has non-zero components only along compact dimensions. They are periodic functions of the magnetic flux enclosed by compact dimensions with the period equal to the flux quantum.

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Non-analytic relativistic r-modes of slowly rotating neutron stars

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Since 1997 the attempts to build the relativistic generalization of the Newtonian r-modes - predominantly toroidal oscillations, inherent to rotating neutron stars, - have lead to contradictory results concerning the properties of their frequency spectrum. While numerical calculations predict the discrete oscillation spectrum, theoretical studies in the slow-rotation approximation relying on traditional techniques predict the presence of continuous part in the spectrum. In this talk we present a new original approach to the study of relativistic perturbation equations. Within this approach under a number of assumptions we show, that relativistic r-modes form a class of non-analytic in stellar angular velocity solutions to the oscillation equations, characterized by discrete oscillation spectrum very similar to that of Newtonian r-modes. The elaborate analysis of the obtained equations in the limit of extremely slow stellar rotation allows to obtain the explicit expressions for the r-mode eigenfunctions and oscillation spectrum in this limit. We find no indications of the presence of the continuous part in the spectrum neither in theoretical analysis nor in numerical calculations.

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Nuclear Symmetry Energy from Experiment and Astrophysics

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Nuclear mass measurements and neutron matter theory tightly constrain the parameters SV and L of the nuclear symmetry energy. Corroboration can be found from measurements of the neutron skin thicknesses and dipole polarizabilities of neutron-rich nuclei, as well as astrophysical measurements of the neutron star radius.

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High-density nuclear symmetry energy from neutron star observations

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The density dependence of nuclear symmetry energy is among the most uncertain parts of the Equation of State (EOS) of dense neutron-rich nuclear matter. It is currently poorly known especially at suprasaturation densities partially because of our poor knowledge about isovector nuclear interactions at short distances. Because of its broad impacts on many interesting issues, to pin down the density dependence of nuclear symmetry energy has been a longstanding and shared goal of both astrophysics and nuclear physics. New observational data of neutron stars including their masses, radii, and tidal deformations since GW170817 have helped improve our knowledge about nuclear symmetry energy especially at high densities. In this talk, after reviewing existing constraints on characteristics of nuclear symmetry energy around the saturation density of nuclear matter from terrestrial nuclear experiments and observations of canonical neutron stars, we discuss how the lower radius boundary $R_{2.01} = 12.2$ km from NICER's very recent observation of PSR J0740+6620 of mass $2.08 \pm 0.07\ M_{\odot}$ and radius $R = 12.2 - 16.3$ km at 68\% confidence level sets a tight lower limit for nuclear symmetry energy at densities above **twice** the saturation density of nuclear matter.

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Neutron stars in f (R, T) gravity using realistic equations of state

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In this work we investigate neutron stars (NS) in f (R, T) gravity for the case R + 2λT , R is the Ricci scalar and T the trace of the energy-momentum tensor. The hydrostatic equilibrium equations are solved considering realistic equations of state. The neutron stars masses and radii obtained are subject to a joint constrain from massive pulsars and the event GW170817. The parameter λ needs to be negative as in previous NS studies, however we found a minimum value for it. The pressure in this modified theory of gravity depends on the inverse of the sound velocity v . Since, v is low in the crust, |λ| need to be very small. We found that the increment in the star mass is less than 1%, much smaller than previous ones obtained not considering the realistic stellar structure, and the star radius cannot become larger, and its changes compared to GR is less than 3.6% in all cases. The NS crust effect implying very small values of |λ| does not depend on the theory's function chosen, since for any other one the hydrostatic equilibrium equation would always have the dependence on the inverse of the sound velocity. Finally, we highlight that our results indicate that conclusions obtained from NS studies done in modified theories of gravity without using realistic EsoS that describe correctly the NS interior can be unreliable.

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Cosmology ensuing from Machine Learning

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Machine Learning opens a new era in Physics, Cosmology, and Astrophysics. In the last couple of years, indeed, the effort of applying Machine Learning to tackle various problems seems to be very promising. The growing number of research papers and the nature of solved problems is a bright example of this.

One of the widely used Machine Learning techniques is Gaussian Processes. This approach provides a way to study problems in a model-independent way. Because, instead of using a parameterized function, we learn the function from the data. There are many studies based on this particular approach. Among them is the study of the swampland criteria for dark energy-dominated Universe [1]. Here for the first time, the analysis has been done without involving any explicit form of the potential for the scalar field dark energy. Moreover, for the first time, it has been applied and the model-independent form of f(T) gravity has been reconstructed [2].

On the other hand, recently, in a series of papers [3,4,5], it has been demonstrated that Bayesian Machine Learning can be used in Cosmology, too. It is an approach based on a generative process allowing to use of the model to analyze the model. It should be mentioned that real observational data can be used to validate learned results and at the end only. The last one obviously makes this approach different from more traditional approaches and allows to learn different features of the model that due to bias in data can be either hidden or wrongly interpreted.

During this talk, we will discuss one of our results where the Bayesian Machine Learning has been used and for the first time viscous fluid cosmological models where the well-known H_0 tension can be solved have been crafted. The talk is mainly based on [6]. However, we will discuss particular results of [5] demonstrating how deviation from cold dark matter can solve the H_0 tension problem, too.

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NICER and Neutron Star Radii

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Precise and reliable measurements of neutron star radii are essential to our understanding of cold, catalyzed matter beyond nuclear saturation density. Recently, NASA's Neutron Star Interior Composition Explorer (NICER) satellite has provided high-quality data sets that have yielded measurements of the mass (M=1.44+-0.15 Msun) and radius (R=13+1.2-1.0 km) of the 206 Hz pulsar PSR J0030+0451, and of the radius (R=13.7+2.6-1.5 km) of the M=2.08+-0.07 Msun, 346 Hz pulsar PSR J0740+6620. I will discuss our group's work on these pulsars and will in particular discuss the assumptions that have gone into our analyses, to help the assessment of our results. I will also discuss the implications of our results for the properties of the dense matter in the cores of neutron stars.

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Late time cosmic acceleration in f(Q,T) gravity

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The dynamical aspects of some accelerating models are investigated in the framework of an extension of symmetric teleparallel gravity dubbed as f (Q, T) gravity. In this gravity theory, the usual Ricci tensor in the geometrical action is replaced by a functional f (Q, T) where Q is the non-metricity and T is the trace of the energy-momentum tensor. Two different functional forms are considered in the present work. In order to model the Universe, we have considered a signature flipping deceleration parameter simulated by a hybrid scale factor (HSF). The dynamical parameters of the model are derived and analyzed. We discuss the role of the parameter space in getting viable cosmological models. It is found that, the models may be useful as suitable geometrical alternatives to the usual dark energy approach.

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Formation, possible detection and consequences of highly magnetized compact stars

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Over the last few decades, there are enormous interest in massive neutron stars and white dwarfs with their indirect/direct evidences. Here I will touch upon their possible formation channels and possible direct detection. They have many consequences including possible second standard candle.

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The CompOSE data base for equations of state

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In simulations of compact stars, binary mergers and core-collapse supernovae an equation of state (EoS) is needed to close the system of combined Einstein and hydrodynamics equations. I will discuss requirements for such an equation of state. Then I will present the data base Compose, part of the PHAROS project, which contains EoS and related data ready for use in simulations. I will show some examples of results obtained with publicly available data and the computational tools from CompOSE.

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Boundary-induced quantum effects in the hyperbolic vacuum of dS spacetime

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The vacuum expectation values (VEVs) of the field squared and energy-momentum tensor for a massive scalar field with general curvature coupling parameter are investigated inside and outside a spherical shell in background of de Sitter (dS) spacetime. It is assumed that the field is prepared in the hyperbolic vacuum state. The latter differs from the maximally symmetric Bunch-Davies vacuum state and is realized by the mode functions corresponding to the foliation of dS spacetime by spatial sections having a constant negative curvature. In the flat spacetime limit the hyperbolic vacuum is reduced to the conformal vacuum in the Milne universe. The sphere-induced contributions in the VEVs are extracted explicitly and their behavior in various asymptotic regions of the parameters are investigated. The vacuum energy-momentum tensor has a nonzero off-diagonal component that describes the energy flux in the radial direction. The latter is a purely boundary-induced effect and is absent in the boundary-free geometry.

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The Hubble tension and the magnetic universe

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Magnetic fields, if present in the plasma prior to last scattering, would induce baryon inhomogeneities and speed up the recombination process. As a consequence, the sound horizon at last scattering would be smaller, which would help relieve the Hubble tension. Intriguingly, the strength of the magnetic field required to alleviate the Hubble tension happens to be of the right order to also explain the observed magnetic fields in galaxies, clusters of galaxies and the intergalactic space. I will review this proposal and provide an update on its status in the context of the latest data.

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Finite temperature equations of state

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We review the equation of state (EoS) models covering a large range of temperatures, baryon number densities and electron fractions presently available on the \textsc{CompOSE} database. These models are intended to be directly usable within numerical simulations of core-collapse supernovae, binary neutron star mergers and proto-neutron star evolution. We discuss their compliance with existing constraints from astrophysical observations and nuclear data. For a selection of purely nucleonic models in reasonable agreement with the above constraints, after discussing the properties of cold matter, we review thermal properties for thermodynamic conditions relevant for core-collapse supernovae and binary neutron star mergers. We find that the latter are strongly influenced by the density dependence of the nucleon effective mass. The selected bunch of models is used to investigate the EoS dependence of hot star properties, where entropy per baryon and electron fraction profiles are inspired from proto-neutron star evolution. The Γ-law analytical thermal EoS used in many simulations is found not to describe well these thermal properties of the EoS. However, it may offer a fair description of the structure of hot stars whenever thermal effects on the baryonic part

are small, as shown here for proto-neutron stars starting from several seconds after bounce.

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Cosmological models with Big rip and Pseudo rip Scenarios in extended theory of gravity

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In this talk, we will propose the big rip and pseudo rip cosmological models in an extended theory of gravity. The matter field is considered to be that of perfect fluid. The geometrical parameters are adjusted in such a manner that it matches the prescriptions given by cosmological observations, to be specific to the H0 range. The models favour phantom behaviour. The violation of strong energy conditions are shown in both the models, as it has become essential in an extended gravity. The representative values of the coupling parameter are significant on the evolution of the universe.

3

Neutron stars as dark matter probes

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We study an impact of asymmetric fermionic and bosonic dark matter on general properties and tidal deformabilities of neutron stars and their ability to reach the two solar masses limit. It allows us to present a new range of masses of dark matter particles and their fractions inside the star. Our analysis is based on the observational fact of the existence of two pulsars reaching this limit and on the theoretically predicted reduction of the neutron star maximal mass caused by the accumulation of dark matter in its interior. We also explore conditions of formation a dense dark matter core or an extended dark halo around a neutron star. By using recent results on the spatial distribution of dark matter in the Milky Way, we present an estimate of its fraction inside the neutron stars located in the Galaxy center.

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Quantum vacuum effects induced by branes in AdS spacetime

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We discuss the vacuum expectation values (VEV) of the field squared and energy-momentum tensor for quantum fields in background of anti-de Sitter (AdS) spacetime in the presence of branes. The boundary conditions imposed on the fields modify the spectrum of vacuum fluctuations and give rise to contributions in the VEVs depending on the geometry of the branes and on the specific boundary conditions. The vacuum forces acting on the branes are investigated and the possibility for the stabilization of the interbrane distance is discussed. In models with locally AdS spacetime and with a part of spatial dimensions compactified on a torus, the vacuum current densities may appear for charged fields. These currents flow along compact dimensions and are periodic functions of the magnetic flux enclosed by compact dimensions, with the period equal to the flux quantum. They can serve as sources of large scale magnetic fields in braneworlds.

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Hyperonization in dense matter

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I will describe the recent progress in the studies of hyperonization and onset of delta-resonances in compact stars, their effect on the integral parameters of compact stars. I will then focus on the recent extension of zero-temperature equations of state to finite temperatures in a manner suitable for implementation in the numerical studies of proto-neutron stars and binary neutron star merger remnants

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New vortices in two flavor dense quark core of compact star

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A new "2SC"+"dd" phase containing 1S0 "ud" and 3P2 "dd" condensates is proposed [1]. Semi superfluid vortices carrying color magnetic fluxes together with fractionally quantized superfluid circulations appear in this phase [2].

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LOCV calculation of the equation of state and r-mode instability of neutron stars

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R-modes are well known quasi-toroidal oscillations in rotating fluids that happen because of the Coriolis effect [1]. These modes are driven instable by gravitational radiation reactance via the Chandrasekhar-Friedman-Schutz (CFS) mechanism and can increase toroidal magnetic field by inducing differential rotation in neutron stars [2]. The bulk viscosity is the basic dissipation mechanism at high temperature and the shear viscosity is the dominant mechanism at low temperature [3].

In this paper, we study r-mode instability windows and present the calculation of critical angular velocity Ωc [4]. We have used the microscopic lowest order variational (LOCV) method to extract the EOS by employing the realistic nucleon-nucleon interaction [5][6].

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Twin star solutions considering exotic matter in compact stars

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The discovery of gravitational waves from a binary neutron star merger event GW170817 has allowed for the study of the neutron stars' interior, particularly the matter at nuclear densities [1]. This detection has also resulted in the improvement of our insight into the maximum mass of neutron stars and their tidal deformability. Moreover, the new knowledge of matter at extreme densities and temperatures has been provided by the product of the merger, which necessitates applying a microscopic model of strongly interacting matter [2]. Indeed, the equation of state (EOS) of dense matter, which is dependent on the gravitational wave signal relevant to the mergers of binary neutron stars, has a key role in modeling the formation of compact stars. On the other hand, the possible existence of the third family of compact stars due to the strong phase transitions in dense matter has long been debated by many authors. There may be two phase transitions for hadronic matter at large densities: the phase in which hadrons are deconfined to quarks and gluons and the one with restoration of chiral symmetry [3]. One can perceive that the existence of two stars with the same mass but of different sizes is a signature of a phase transition in dense matter.

In this research, we aim to study the categories of twin star solutions and also the tidal effects of binary neutron star mergers involved in GW170817. Considering the first-order phase transition from hadronic matter to exotic matter, we apply the EOS with the lowest order constrained variational (LOCV) approach and potentials like Argonne family potentials with and without three nucleon interaction (TNI) contribution for the hadronic phase [4]. It is also noted that we consider the excluded nucleon volume, which makes the EOSs stiff enough and thus this can be regarded as a signal of phase transition to the high-density matter [5].

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Deep crustal heating for realistic compositions of thermonuclear ashes

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The deep crustal heating, associated with exothermal nuclear reactions, is believed to be a key parameter for describing the thermal evolution of accreting neutron stars. In this talk, we present the first thermodynamically consistent calculations of the crustal heating for realistic compositions of thermonuclear ashes. In contrast to previous studies based on the traditional approach, we account for neutron hydrostatic/diffusion (nHD) equilibrium condition imposed by superfluidity of neutrons in a major part of the inner crust and rapid diffusion in the remaining part of the inner crust. We apply a simplified reaction network to model nuclear evolution of various multi-component thermonuclear burning ashes (superburst, KEPLER, and extreme rp-process ashes) in the outer crust and calculate the deep crustal heating energy release Q, parametrized by the pressure at the outer-inner crust interface, P_{oi}. The work of N. N. Shchechilin was supported by the Foundation for the Advancement of Theoretical Physics and Mathematics "BASIS" (grant #20-1-5-79-1). The work of M. E. Gusakov was supported by RFBR [Grant No. 19-52-12013].

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Constraining quark matter inside hybrid stars

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The existence of quark matter inside the cores of massive neutron stars is supported by many recent studies. We model hybrid stars using the extended linear sigma model — which reproduces vacuum quantities and finite tempreture behaviour accurately — to describe quark matter, together with various hadronic models. We show that crossover phase transitions between the hadronic and quark phases can naturally create equations of state that are stiffer than both the hadronic and quark ones, enabling more massive neutron stars. We also show that the properties of the maximum mass hybrid star can be used to constrain the parameters of the quark model, while radius limits from GW170817 also give restraints on them. Preliminary results from a Bayesian analysis are also shown.

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Rip Cosmology in Brans-Dicke Theory

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We construct some Rip cosmological models in the framework of Brans-Dicke theory where the Brans-Dicke parameter is considered to be a function of the scalar field. We obtained the time evolution of the scalar field, the Brans-Dicke paramete and the Newtonian Gravitational constant for the rip cosmological models. The cosmic dynamics of the model have been discussed.

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Uncovering the origin and propagation of gravitational waves

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In this talk I will present recent results about cross-correlation techniques between gravitational waves and galaxy catalogues. I will report on the possibility of combined near-future gravitational wave detectors and galaxy surveys constraining the origin of binary black holes, as well as the cosmic propagation law of gravitational waves. The former might shed light on whether the observed black hole binaries are of stellar or primordial origin. The latter is important for constraining deviations from general relativity on cosmological scales, because such deviations predict modified propagation of gravitational waves compared to general relativity.

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About anomalous superfluidity, superconductivity and ferromagnetism in nuclear systems

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First 1S0 nn and pp pairings in baryon matter will be discussed. Then focus will be made on the study of phases of the complex neutral and charged vector boson coupled with magnetic field by the Zeeman coupling. I will discuss presence of nonmagnetic and ferromagnetic superfluid phases. It will be shown that in a strong magnetic field spin-triplet pairing and ferromagnetic superfluidity continue to exist above the "old" phase-transition critical temperature. Spin-triplet pairing of neutral and charged fermions at negligible spin-orbital interaction will be similarly considered. Then various sub-phases of 3P2 nn, pp and 3S1 np pairings in baryon matter will be described. Some estimates will be done in the BCS limit and beyond.

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Ferromagnetic neutron stars in scalar-tensor theories of gravity

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Ferromagnetic spin ordering can take place in neutron stars. This phase transition
alters the neutron star equation of state. Here, applying the scalar-tensor theories of gravity, we investigate the structure of neutron stars which are in the ferromagnetic phase. Considering the equation of state of ferromagnetic neutron matter with Skyrme-type interactions at zero temperature and using the scalar-tensor theories of gravity with sufficiently negative coupling constant, we explore the spontaneous scalarization in ferromagnetic neutron stars.

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Magnetically Deformed Neutron Stars: An Analytic Approach

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In this work, we develop an analytic treatment that would allow us to model the magnetic deformation of neutron stars in the quasi-Newtonian framework. We analyze the problem with taking density profiles from various analytic approaches. The first density profile is the n=1 solution of the Lane-Emden equation, the second one is a parabolic ansatz for density and the last density distribution is a fourth-order polynomial fit to a relativistic solution we obtained with a microphysical EoS. The last density profile is an accurate modeling obtained by fitting to the true density profile acquired numerically for various EoSs [1] and it allows us to have an analytical solution for the magnetic field profile for almost a universal EoS. Contour plots of purely poloidal field indicate that the poloidal field components contribute most of the interiors of the star and have the maximum and minimum values of field strength at the origin and the edge of the star, respectively. While the projection of the toroidal magnetic field lines on the meridional plane shows that the toroidal field distribute in wide regions in the vicinity of the equatorial plane and the maximum toroidal fields occur in the center of torus. We almost incorporate all the magnetic field configurations assessed from different density profiles. The excess mass calculated in this quasi-Newtonian framework is analogous to the excess mass obtained in the general relativity framework and the polynomial magnetic field profile [2,3].

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