The Modern Physics of Compact Stars and Relativistic Gravity 2023

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Book of Abstracts

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Hot β-equilibrium hadronic matter in the neutrino-trapped regime within the framework of relativistic mean-field theory

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We investigate the thermodynamic properties of the hot β-equilibrated hadronic matter, which consists of neutrons(n), protons(p), electrons(e), electron neutrinos(ν_e), muons(μ), and muon neutrinos(ν_e). To describe such matter, we use an improved version of the relativistic mean field theory (RMF) at a finite temperature, where, in addition to the effective fields of σ-, ω-, and ρ-mesons, the scalar-isovector δ-meson effective field is also taken into account.
For different values of temperature T in the range of 0-100 MeV, the dependences of pressure P, energy density ε, entropy density S, and baryon chemical potential μ_B on the baryon number density n_B are determined. We studied the effect of temperature on the splitting of the effective masses of the proton and neutron due to the presence of the δ-meson field.
The temperature dependencies of the parameters of the first-order phase transition from hadronic matter to strange quark matter are studied. In this case, the Nambu - Jona-Lasinio (NJL) local SU (3) model was used to describe the quark phase.
A phase diagram is obtained corresponding to the equilibrium coexistence of hadron and quark phases in the T-μ_B plane. The thermodynamic parameters of the critical endpoint in the phase coexistence curve are found. Four different areas were identified in the T-n_B plane. The area of existence of matter with a purely hadronic structure. The area of existence of matter with a purely quark structure. The region corresponds to the crossover transition between the hadron and quark phases. And, finally, the range of values (T,n_B), does not correspond to any structure.

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Studying the effects of the symmetry energy in hybrid stars

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In this contribution we consider hybrid compact stars located in the third branch of the corresponding mass-radius diagram. We introduce a set of equations of state whose symmetry energy parameters vary. These are described by multi-polytropes and by a RMF model with several isovector mesons, fulfilling laboratory constraints. We find correlations between tidal deformabilities, stellar radii and symmetry energy parameters. Properties for the crust of hybrid stars in relation to the pure hadronic configurations are derived. Astrophysical applications include derivations of the properties of rotating compact stars and their moment of inertia as well as estimates of the energy released in evolutionary transitions from hadron to hybrid configurations. Moreover, state-of-the-art neutron star observations are used to constrain the space of parameters of the models used in this work.

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Vacuum densities for branes orthogonal to AdS boundary

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Vacuum expectation value for the energy-momentum tensor of a massive scalar field is investigated in the geometry of two parallel branes perpendicular to the AdS boundary. On the branes the field operator obeys Robin boundary conditions. Depending on the coefficients in those conditions and on the separation between the branes, the vacuum energy density can be either positive or negative. In addition to the diagonal components, the vacuum energy-momentum tensor has a nonzero off-diagonal stress. The Casimir forces acting on the branes are decomposed into components perpendicular and parallel to the branes. Unlike to the problem of parallel plates in the Minkowski bulk, the normal Casimir forces acting on separate branes differ if the boundary conditions on the branes are different. Those forces can be either repulsive or attractive. Depending on the coefficients in the boundary conditions, the parallel component of the force (shear force) is directed toward or from the AdS boundary. Both the forces may change the sign as functions of the distance between the branes. At large distances they show a power-law decay as functions of the proper distance.

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Pro and Con the Phase Transition to Quark Matter in Neutron Stars

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Recently, on the basis of a Bayesian analysis with new observational data for masses, radii, and tidal deformability of neutron stars, the authors of Ref. [1] came to the conclusion that there is evidence against a strong first-order phase transition to quark matter in neutron star cores.
On the other hand, numerous models for hybrid neutron star equations of state with a strong first-order phase transition have been published that correspond to mass-radius curves and tidal deformabilities perfectly fulfilling the observational constraints, see [2-8] for recent examples.
I will discuss the question of physics-informed versus agnostic Bayesian analyses and observable signals for quark deconfinement in supernovae, neutron star
mergers [9,10] and neutron stars in binaries [11,12].

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Three-quark dynamical system immersed in a color gluon thermostat

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Shortly after the postulation of quarks by Zweig and Gell-Mann in 1964 and the experimental confirmation of these subnucleon formations [1,2] in 1969, Feynman, Ravndal and Kislinger (FRK) in 1971 proposed a relativistic three-quark model of nucleons [3] to study the internal structure and state of these dynamical systems and explain a number of thier important properties. The idea of this model is that all three quarks effectively interact with each other through the potential of a four-dimensional harmonic oscillator, which does not allow the system to decay into individual free quarks. Despite the obvious progress in describing the internal motion of nucleons within the framework of this model, we have to state that it is not realistic enough, since continuous processes of gluon exchange between quarks are ignored. To overcome this difficulty, we considered the problem of self-organization of a dynamical quark system immersed in a color gluon thermostat in the framework of the mathematical representation of a complex probabilistic process [4] that satisfies an equation of the Kline-Gordon-Langevin type. Obviously, this is a natural and essential generalization of the FRK nucleon model.

In this work, using the hidden symmetry of the internal motion of a dynamical system, we have developed a mathematical approach that allows us to construct the wave function of the nucleon in the form of a two-fold integral representation, taking into account the relaxation of the quark system in a color gluon thermostat. It should be noted that the generalized model can be especially useful for studying the state of nucleons under critical conditions, which takes place, for example, in massive and dense stellar formations, such as neutron stars, etc.

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Neutrino oscillations effects on the thermodynamic properties of hot electrically neutral quark matter in beta-equilibrium

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In our study, we analyzed how neutrino oscillations impact the thermodynamic properties of three-flavor hot electrically neutral beta-stable quark matter that cannot be penetrated by neutrinos. Through the use of the local SU(3) Nambu-Jona-Lasinio (NJL) model, we were able to determine the thermodynamic characteristics of quark matter for two different temperatures, specifically at T = 60 and 100 MeV, while taking into consideration neutrino oscillations. We then compared these results to those obtained without considering neutrino oscillations. Our calculations revealed that

the energy released per unit of baryon charge during the cooling of quark matter that is opaque to neutrinos ranged from 150 to 350 MeV.

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Electrical conductivity of warm neutron star crust in magnetic fields: Neutron-drip regime

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We compute the anisotropic electrical conductivity tensor of the inner crust of a compact star at non-zero temperature by extending a previous work on the conductivity of the outer crust. The physical scenarios, where such crust is formed, involve proto-neutron stars born in supernova explosions, binary neutron star mergers and accreting neutron stars. The temperature-density range studied covers the transition from a non-degenerate to a highly degenerate electron gas and assumes that the nuclei form a liquid, i.e., the temperature is above the melting temperature of the lattice of nuclei. The electronic transition probabilities include (a) the dynamical screening of electron-ion interaction in the hard-thermal-loop approximation for the QED plasma, (b) the correlations of the ionic component in a one-component plasma, and (c) finite nuclear size effects. The conductivity tensor is obtained from the Boltzmann kinetic equation in relaxation time approximation accounting for the anisotropies introduced by a magnetic field. The sensitivity of the results towards the matter composition of the inner crust is explored by using several compositions of the inner crust which were obtained using different nuclear interactions and methods of solving the many-body problem. The standard deviation of relaxation time and components of the conductivity tensor from the average are below $\leq 10\%$ except close to crust-core transition, where non-spherical nuclear structures are expected. Our results can be used in dissipative magneto-hydrodynamics (MHD) simulations of warm compact stars.

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Probing hybrid stars and tihe properties of the special points with radial oscillations

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We study the properties of hybrid stars containing a color superconducting quark matter phase in their cores, which is described by the chirally symmetric formulation of the confining relativistic density functional approach. It is shown that depending on the dimensionless vector and diquark couplings of quark matter, the characteristics of the deconfinement phase transition are varied, allowing us to study the relation between those characteristics and mass-radius relations of hybrid stars. Moreover, we show that the quark matter equation of state can be nicely fitted by the Alford-Braby-Paris-Reddy model that gives a simple functional dependence between the most important parameters of the equation of state and microscopic parameters of the initial Lagrangian. Based on it, we analyze the special points of the mass-radius diagram in which several mass-radius curves intersect. Analyzing a found empirical relation between the mass of the special point, maximum mass of the mass-radius curve and onset mass of quark deconfinement, we constrain the range of values of the vector and diquark couplings of quark matter. To find a distinguishable observational characteristic of the stars with the same mass and radius in the special points and probe their interior composition we calculate the frequencies of the fundamental mode of radial oscillations

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Baryons' coupling constants in the Sigma-Omega-Rho model and the mass-radius relation of neutron stars in the presence of hyperons

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It is expected that the density at the center of neutron stars will be high enough that hyperons or quark matter may be present. In this paper, we investigate the presence of hyperons (Λ, Σ^-) along with Leptons (Muons, Electrons) and nucleons in the neutron star. For this purpose, we used a relativistic model called the Sigma-omega-rho model. In this method, the coupling constants of the mesons' interaction with the nucleons were proposed as a function of the mass of the nucleons and baryons. Using this proposed model for the coupling constants, the particles fraction in beta equilibrium is investigated and the neutron star mass-radius profile is obtained in the presence of hyperons. The phenomenon of \textit{Hyperon puzzle} is also briefly studied.

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On learning new about the Universe with the H0 tension problem

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It is thought that the H0 tension problem can be an indicator of new physics. It seems to be an easy task to solve. However, this is not the case and strongly depends on the assumptions used to craft a theoretical model. In this talk, we will discuss some of our results on searching for a solution to the problem using some Machine Learning tools.

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FRW cosmology with chiral tensor particles

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We discuss an extended model of FRW cosmology with additional chiral tensor particles. We discuss the influence of these particles on the expansion rate of the Universe, their cosmological place and derive cosmological constraints on their interaction strength.

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A dual model for neutron star equations of state

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We discuss a model of quark-hadron duality to explain soft-to-stiff evolution of stiffness in neutron star equations of state. To explain rapid stiffening, the quark substructure of a baryon plays essential roles, already at density as low as a few times nuclear saturation density. We present an analytic model of the duality as a representative model of quarkyonic matter. We also argue the importance of non-perturbative power corrections which would substantially affect the high density constraints predicted by pQCD. Some results of QCD-like theories are briefly mentioned to address the recently proposed positivity conjecture of the trace anomaly.

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Pions in nuclear and neutron star matter

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In the most equation of state the electron chemical potential in the neutron star (NS) matter reaches the value of the free pion mass already at rather moderate baryon densities. That would lead to pionization of the NS matter when negative pions replace electrons. The repulsive s-wave pi- -neutron interaction could prevent it. We apply the effective chiral Lagrangian at the second chiral order to construct the pion polarization operator. The pion spectrum is calculated, and the possibility of the s-wave pion condensation is analyzed for various forms of the nuclear symmetry energy. Also, the possibility of the p-wave (pi+) and (p+-pi-) condensation is reinvestigated. Some old classical results are revised, and new spectral branches are discussed.

5

Universal Relations for the Increase in the Mass and Radius of a Rotating Neutron Star

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Rotation causes an increase in a neutron star's mass and equatorial radius. The mass and radius depend sensitively on the unknown equation of state (EOS) of cold, dense matter. However, the increases in mass and radius due to rotation are almost independent of the EOS. The EOS independence leads to the idea of neutron star universality. In our paper, we computed sequences of rotating

neutron stars with constant central density. We use a collection of randomly generated EOSs to construct simple correction factors to the mass and radius computed from the equations of hydrostatic equilibrium for nonrotating neutron stars. The correction factors depend only on the nonrotating star's mass and radius and are almost independent of the EOS. This makes it computationally inexpensive to include observations of rotating neutron stars in EOS inference codes. We also construct a mapping from the measured mass and radius of a rotating neutron star to a corresponding nonrotating star. The mapping makes it possible to construct a zero-spin mass–radius curve if the masses and radii of many neutron stars with different spins are measured. We showed that the changes in polar and equatorial radii are symmetric, in that the polar radius shrinks at the same rate in which the equatorial radius grows. This symmetry is related to the observation that the equatorial compactness (the ratio of mass to radius) is almost constant on one of the constant-density sequences.

3

Properties of the fermionic vacuum in Rindler spacetime with a compactified subspace

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The local properties of the fermionic vacuum are investigated for Rindler spacetime with a spatial subspace compactified to a torus. It is assumed that the field is prepared in the Fulling-Rindler vacuum state. The expression for corresponding Hadamard function is given and the renormalized current density, fermionic condensate and the vacuum expectation value of the energy-momentum tensor are investigated. The near-horizon and large-distance asymptotics are discussed for the expectation values around cylindrical black holes. In the near-horizon approximation the lengths of compact dimensions are determined by the horizon radius. At large distances from the horizon the geometry is approximated by a locally anti-de Sitter spacetime with toroidally compact dimensions and the lengths of compact dimensions are determined by negative cosmological constant.

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Symmetry Energy From Experiment, Theory and Observation

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Nuclear mass measurements and neutron matter theory tightly constrain
the parameters J, L and K_sym 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. The recent PREX and CREX neutron skin measurements, while apparently independently predicting disparate results for these parameters, nuclear interaction models that best fit both measurements suggest values commensurate with those from neutron matter calculations, recent NICER neutron star radius measurements, and GW170817 tidal deformability measurements. A detailed correlation analysis of saturation and symmetry energy properties, nuclear structure observables and typical-mass neutron star observables predicted by hundreds of published nuclear force models is presented.

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Probing the symmetry energy of dense neutron-rich matter with terrestrial experiments and astrophysical observations

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Neutron-rich matter exists naturally in neutron stars and some nuclei. It can also be created during mergers of neutron stars in space and collisions between two heavy nuclei in terrestrial nuclear laboratories. The nature and Equation of State (EOS) of such matter are still very poorly known while they have broad impacts on many interesting issues in both astrophysics and nuclear physics. In particular, nuclear symmetry energy encoding the energy cost to make nuclear matter more neutron rich has been the most uncertain part of the EOS of dense neutron-rich nucleonic matter. It affects the masses, radii, tidal deformations, cooling rates and frequencies of various oscillation modes of isolated neutron stars as well as the strain amplitude and frequencies of gravitational waves from neutron star mergers. In this talk, we will discuss several outstanding issues and recent progresses in probing the symmetry energy of dense neutron-rich matter as well as its impacts on properties of nuclear reactions and neutron stars.

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Neutron star observations and dense matter

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In the last 10-15 years, observations of neutron stars have revolutionized our understanding of cold, catalyzed matter beyond nuclear saturation density. These observations include the discovery of high-mass neutron stars, limits on tidal deformability from gravitational wave observations, and measurements using NICER data of the radii of two neutron stars. These observations, combined with laboratory measurements and the application of chiral effective field theory, promise to improve even further within the next several years. I will discuss the observations, implications, and prospects for improvement.

1

Constraining the teleparallel gravity with trace from dynamical system analysis

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The dynamical system analysis of the cosmological models in f(T,T) gravity, where T and T respectively represents the torsion scalar and trace of the energy-momentum tensor has been investigated. It demonstrates how first-order autonomous systems can be treated as cosmological equations and analyzed using standard dynamical system theory techniques. Two forms of the function f(T,T) are considered (i) one with the product of trace and higher order torsion scalar and the other (ii) linear combination of linear trace and squared torsion. For each case, the critical points are derived and their stability as well the cosmological behaviours are shown. In both the models the stable critical points are obtained in the de-Sitter phase whereas in the matter and radiation dominated phase unstable critical points are obtained. At the stable critical points, the deceleration parameter shows the accelerating behaviour of the Universe whereas the equation of state parameter shows the ΛCDM

behaviour. Finally the obtained Hubble parameter of the models are checked for the cosmological data sets

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Intense Magnetic field effect on mass-radius relation of Neutron stars

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Neutron stars possess very strong magnetic fields of order 10^11~10^12 G. Such strong magnetic fields
modify properties of Neutron star matter. We investigate the effect of this strong magnetic field on EOS
(Equation of State) of neutron stars. So far, various models and EOS for neutron stars have been
proposed and properties of neutron stars are calculated and compared with observations. In this study,
the equation of state of the neutron star core is extracted from the lowest order constrained variational
method by employing two body AV18 interaction supplemented by Urbana type three body force and two
various models are considered as basic EOS of crust of neutron
In this study we focused on Landau levels of electrons in the crust.

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Applications of the QCD Sum Rules (QCDSR) Method to Hybrid Stars

Authors: Fateme Moradi Jangal[1]; Hamidreza Moshfegh[1]; Kazem Azizi[1]

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The study of matter at extreme densities has been a major focus in theoretical physics in the last half-century. The wide spectrum of the information provides an insight into the world around us. The models and concepts put forward by the study of nuclear matter help to solve mystery of the interaction in the universe. Through the study of neutron stars we are able to investigate the process involves all four known fundamental forces of nature.

In this study we first use a relativistic model within the mean-field approximation to refine our knowledge of the workings of the strong interaction in neutron stars with the presence of hyperons and then we use Baryon-Meson coupling constants from QCD sum rules method to describe the stellar matter. Using both methods for the coupling constants, the particle fraction in beta equilibrium is investigated and the neutron star mass-radius profile is obtained in the presence of hyprons.

Keywords: neutron strar, hyperon, coupling constants

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Indirect Detection of Massles Particles (Hions) Through Light Difractions Experiments

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Recently, within the framework of the stochastic Yang-Mills equations for the gauge symmetry group SU(2)xU(1), the possibility of the evidenc of massless Bose particles with spin-1-Hions has been proved [1]. Theoretically, the formation of a vector field from Hions in the form of a spin glass and, accordingly, a scalar field as a result of Bose condensation of entangled pairs of Hions with a total spin-0 was justified. The goal of our experiment was the demonstration of the feasibility of manipulating the refractive indices of empty space (vacuum) by exerting of an external influence on the vector field.
As is well known, light passing through one slit forms a diffraction pattern. We modified this experiment by placing a cylinder behind the diffraction slit, on which a light guide is wound. When two independent low-power laser sources of the visible range of light are switched on, one of which falls on the slit and the other propagates along the light guide, a redistribution of light intensity is observed in individual diffraction zones. This effect is so significant that it cannot be explained within the framework of classical or quantum electrodynamics. Latter indicates the formation of a phase object of a complex structure on the path of propagation of a diffracting light beam and, accordingly, a new, still unknown type of polarization of the quantum vacuum. As multilateral analysis and numerical estimates show, such polarization can arise as a result of reorientation of Hions spins under the action of an external electromagnetic field.
In other words, this experiment indirectly proves the existence of massless and uncharged particles that fill space or, more precisely, shape space itself. The latter can fundamentally change our understanding of the physical world and its properties.

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Massive compact stars and their detection possibility in gravitational wave astronomy

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Since the last several years, there are enormous interest in the understanding of the possible formation of massive compact objects: white dwarfs and neutron stars (also intermediate-mass black holes). This stems from many direct and indirect observations related to pulsars, type Ia supernovae, gravitational waves, and even quasi-periodic oscillations. The question also arises, if a massive compact star, e.g., a neutron star fills in the so-called mass gap between the conventional lightest mass black hole and the heaviest neutron star. One of the promising ingredients of such a massive compact star is the magnetic field. Also, varied modern equations of state may also increase mass. I will explore these possibilities to check the major responsible factor(s) for a massive compact star. Subsequently, I will explore their time evolution to determine if they can be detected by gravitational waves and electromagnetic astronomy. Note that, however, no compact star has been yet detected by continuous gravitational wave search. I will enlighten the reason for it.

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Self-similarities of Equations of State and Mass–Radius Curves of Neutron Stars

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Determining the equation of state (EoS) of superdense matter from neutron star (NS) observations is an important problem of modern physics. In the literature one can find several hundreds of EoS models (nucleonic, hyperonic, hybrid), based on different approaches to the NS microphysics. In spite of the differences, for a wide set of such models, the relation between pressure P and density ρ of the NS core matter can be accurately described by a single family of curves defined by few parameters (Lindblom, 2010, PRD, 82, 103011). There is a bijection between $P-\rho$ and mass $M-$ radius R relations called the Oppenheimer-Volkoff mapping (Lindblom 1992, ApJ, 398, 569). Thus, the families of $M-R$ and $P-\rho$ curves have the same number of parameters.

In this work, using a sample of 160 EoS models, we show that it is instructive to choose two of these parameters as properties of maximum-mass NS (specific to a given EoS), namely either its mass M_{max} and radius R_{Mmax}, or pressure P_{max} and density ρ_{max} at its center. For different EoSs, the dimensionless relations $M/M_{\mathrm{max}} - R/R_{\mathrm{Mmax}}$ and $P/P_{\mathrm{max}} - \rho/\rho_{\mathrm{max}}$ show self-similar behavior. This allows us to build the analytical fits for the $M-R$ and $P-\rho$ curves, which are universal with respect to EoS model.

In addition, there is an approximate one-to-one mapping between the pairs of values M_{max}, R_{Mmax} and P_{max}, ρ_{max} (Ofengeim 2020, PRD, 101, 103029), also described by universal analytical fits. We use these fits together with those of $M-R$ and $P-\rho$ to propose a semi-analytical inverse Oppenheimer-Volkoff mapping from mass-radius relation to the pressure-density dependence. It appears to be a handful tool to constrain the high-density EoS from modern observational data on masses and radii of NSs.

2

Properties of hyperbolic and Bunch-Davies vacua in de Sitter spacetime

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The Hadamard function and the vacuum expectation values (VEVs) of the field squared and energy-momentum tensor are evaluated for a massless conformally coupled scalar field in de Sitter (dS) spacetime with general number of spatial dimensions, described by coordinates with negative constant spatial curvature. It is assumed that the field is prepared in the hyperbolic vacuum state. An integral representation for the difference of the Hadamard functions corresponding to the hyperbolic and Bunch-Davies vacua is provided which is well adapted for the evaluation of the VEVs in the coincidence limit. The relations obtained for the difference in the VEVs for the hyperbolic and Bunch-Davies vacua are compared with the corresponding relations for the Fulling-Rindler and Minkowski vacua in flat spacetime. The similarity between those relations is explained by the conformal connection of dS spacetime with hyperbolic foliation and Rindler spacetime. As a limiting case, the VEVs for the conformal vacuum in the Milne universe are discussed. It is shown that the Bunch-Davies state is interpreted as thermal with respect to the hyperbolic vacuum. An expression for the corresponding density of states is provided. The thermal distribution is of Bose-Einstein type

for odd number of spatial dimensions and of Fermi-Dirac type for even number of spatial dimensions. It is emphasized that this feature is also present in relations between the VEVs in Fulling-Rindler and Minkowski vacua in flat spacetime.

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Singular Bounce in Generalised Brans-Dicke Theory

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In this work, we present singular bounce scenario
in the framework of the generalised Brans-Dicke (GBD)theory where an evolving BD parameter along with a self-interacting potential is considered. The GBD field equations are derived for an anisotropic space time to provide a more general approach to the cosmic expansion. The evolutionary behaviour of the Brans-Dicke scalar field, dynamical Brans-Dicke parameter and the self interacting potential are studied.
Observational bounds on our model favours the Phantom dark energy phase.

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Shedding New Light on Bosonic Dark Matter with X-ray and Gravitational-Wave observations of Neutron Stars

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In this study, we consider different features induced by the presence of dark matter (DM) in a new type of compact object so-called DM admixed neutron star (NS), in light of the latest observational data of NICER X-ray telescope and LIGO/Virgo Gravitational-Wave (GW) detectors. We investigate self-repulsive sub-GeV bosonic DM which can be distributed as a core inside the NS or as an extended halo around it altering the NSs' observable quantities. Regarding astrophysical constraints of maximum mass, radius and tidal deformability, we probe the bosonic DM parameter space and its fraction within the mixed object. Taking a wide range of bosonic particle mass, self-coupling constant and its fraction, and considering the fact that DM core/halo formation might disapprove the limits of maximum mass, radius and tidal deformability, stringent constraints have been obtained for the DM parameters. Finally, as a novel probe to explore the DM halo formation around NSs by X-ray telescopes, the pulse profile modeling of X-ray pulsars is applied in our investigation. It is seen that depending on the compactness of the mixed object, minimum fluxes of the pulse profiles would be altered significantly.

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Quark stars in massive gravity might be candidates for the mass gap region objects

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The gravitational wave (GW) events offer new insights into compact stars. The binary merger GW170817 and its electromagnetic counterpart have led to new constraints on the maximum mass of neutron stars (NSs). Based on GW170817, the upper bound of MTOV for NSs is predicted as (2.3-2.4)M☒. However, there are other observations of pulsars and binary mergers consisting of components or remnants with masses more than this value which fall within the unknown mass gap region (2.5-5M☒). For example, PSR J0952-0607, the secondary component of GW190814, and the remnants of GW170817 and GW190425 have masses more than the maximum mass predicted for NSs. For two important reasons, the possibility of such massive NSs seems very unlikely. Firstly, for non-rotating NSs, the equation of state (EOS) must be very rigid to get such massive objects. This contrasts the tidal deformability constraint, which requires softer EOSs. Secondly, for a rotating NS, the rotation rate should be close to the Keplerian limit. Now, the question arises whether these objects are the smallest black holes or other forms of compact stars like hybrid stars and self-bounded strange quark stars.
My research findings indicate that by using a modified version of the Nambu-Jona-Lasinio model and a modified theory of gravity (massive gravity), it is possible to obtain quark stars that not only have masses fall in the mass gap region but also satisfy the GW observational constraints well.

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Covariant density functionals for compact star studies

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I will present recent work on covariant density functionals which include hyperonic and delta-resonance degrees of freedom. I will discuss (a) the construction of new density functionals with varying slope of symmetry energy and skewness; (b) the composition and equation of state of hot hypernuclear, delta-resonance-admixed matter; (c) universal relations for cold and hot compact stars.

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New vortices in two-flavor dense quark core of compact star

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Quark hadron continuity with two- flavor quarks connects hadronic matter with neutron 3P2 superfluidity and two-flavor dense quark matter. This two- flavor dense quark phase consists of the coexistence of the 2SC diquark condensate of ud - quarks and P –wave diquark condensate of d – quarks , which gives rise to color superconductivity as well as superfluidity. The stable vortices are non-Abelian Alice strings, which are superfluid vortices with fractional circulation and non-Abelian color magnetic fluxes therein. A single Abelian superfluid vortex is unstable against decay into three non-Abelian Alice strings. Three neutron vortices connect at the border with three non-Abelian

Alice strings with different color magnetic fluxes forming boojum. 2SC condensate is a type II superconductor and magnetic field penetrates into quark core in the form of quark vortices.

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Role of Strangeness in Neutron Stars

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The standard model of fundamental particles has revealed the existence of particles that we were less familiar with and their appearance needs extreme conditions of density and temperature. The most compacted matter on the earth is found in heavy nuclei which can be studied in heavy-ion collision (HIC) experiments. These high densities are interesting to investigate because exotic forms of matter and particles with one or two strange quarks can potentially appear while they are not found in ordinary matter. Therefore, the standard model, by proposing a surprising quantum number, strangeness, made it possible for us to have other states of the hadron classification called hyperons that open new windows for our understanding of matter at higher energy. Recent astrophysical observations have shown us signatures for the appearance of hyperon in the core of Neutron Stars (NS)s, which are the only natural laboratory for such extreme conditions. In the core of NS, not only the appearance of substantial amounts of hyperons is expected but also there is evidence for appearing strange quark matter accompanied by a phase transition from hadronic to deconfined quark matter when the density increases. Using experimental data from HIC, more accurate information for hyperons will be provided. Those data will be employed in many-body approaches to obtain the equation of state (EoS) of hypernuclear matter. Microscopic calculations of the EoS of dense matter profoundly affect our understanding of the origin and the thermodynamic properties of matter. During this talk, I will present my results based on constructing the EoS for hypernuclear matter and will discuss some roles played by hyperons in hypernuclear Physics.

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Boundary-induced effects for the scalar current density in de Sitter spacetime with compact dimensions

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The vacuum expectation value of the current density for a charged scalar field with general curvature coupling is investigated in locally de Sitter spacetime with toroidally compactified spatial dimensions and in the presence of boundaries. In addition, the presence of a classical constant gauge field is assumed. General quasiperiodic boundary condition are imposed along compact dimensions and on the boundaries the field obeys Robin conditions. For the Bunch-Davies vacuum state the contribution of the boundaries is separated in the total current density and its behavior is studied in various asymptotic regions.

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LOCV –Metamodel approach and the equation of state of neutron stars crust

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Anisotropic Collective Flow at High Baryon Density

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The anisotropic collective flow is one of the important observable sensitive to the equation of state (EOS) and transport properties of the strongly interacting matter created in relativistic heavy-ion collisions. In this work we discuss the recent flow measurements from the Beam Energy Scan programs at
SIS, SPS and RHIC and anticipated performance of the BM@N and MPD experiments at Nuclotron-NICA.

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Accelerated Expansion of the Universe in Terms of the Jordan-Brans-Dicke Theory

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The origin and formation of the Universe is always one of the most discussed and researched topics of all time. It is relevant and several theories have been developed to explain the evolution of the Universe, such as the standard, De Sitter , Alven-Klein and other models. The Big Bang was immediately followed by an inflationary phase lasting 10-34 second, as confirmed by experimentally polarized relict radiation studies, after which the highly accelerated expansion began. Accelerated expansion implies the presence of a "repulsive force", which we call Dark Energy, and it makes up about 70% of the Universe.
Considering this fact, the work considers the scalar field dominating the model of the Universe with the presence of vacuum energy in the "Einsteinian" conception of the Jordan-Brans-Dickey theory. Two problems are studied in the work.
In the first problem, the case with the existence of a non-minimally connected scalar field and a gravitational constant was considered within the framework of the theory of the JBD, which, as a result of conformal transformations, becomes a constant in Einstein's image, which results in acceleration. In the second problem, the theory of JBD was considered in Einstein's framework. The case described by the equation of state of matter $P=\alpha E$ with the presence of a scalar field and a cosmological constant is discussed. whose existence when q=-1/2 leads to Einstein's theory.
The analysis of the reveal that when the contribution of scalar field and its impact of parameter Λ

coincide under the condition q =-1/2. They effectively cancel each other, resulting in a theoretical framework consistent with Einstein's theory of gravity. To substantiate these findings, the study conducts numerical computations across an interval of dimensionless coupling constants, enriching our understanding of the behaviors of the models.

1 R. Avagyan, G. Harutyunyan, A. Kotanjyan, N. Saharyan, Dynamics of the Quasi-de Sitter Model of the Early Universe, 2018 Physics of Atomic Nuclei 81(6):894-898, DOI:10.1134/S1063778818060236

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Casimir Wormholes in Modified Gravity theories

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Static traversable wormhole solutions within extended gravity theories have been obtained by exploring the Casimir energy. The shape function and the associated energy conditions are obtained. Also, the concept of minimal length leading to the generalized uncertainty principle (GUP) is used to assess the effect of GUP correction on the wormhole geometry and the exotic matter content of the traversable wormholes.

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Gravitational Waves from Isolated Magnetized Neutron Stars

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The detections of gravitational waves (GWs) have significantly influenced physics and astrophysics since the analysis and interpretation of data from merger events constrain the equation of state (EoS) of the neutron stars.
In this work, we explore gravitational waveforms of magnetized rotating neutron stars. For this aim, we use realistic EoS for rotating magnetized neutron stars and calculate the EoS of magnetized neutron star matter by employing the variational method for the least energy. Then we fit the parameters of polytrope EoS on this realistic EoS and by solving the hydrostatic equilibrium equations, we find the deformation of spherical stars. After that, by finding the distortion and eccentricity of the star, we calculate the amplitude of the gravitational waveforms and by comparing them with the observed data of LIGO-Virgo detectors, we can check out our EoS.