# The Modern Physics of Compact Stars and Relativistic Gravity 2019

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# Book of Abstracts

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# Hybrid Star Properties within the Nambu - Jona-Lasinio (NJL) Model for Quark Matter and Relativistic Mean Field (RMF) Model for Hadronic Matter

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We study the properties of compact stars by taking into account the hadron-quark phase transition, as a result of which a quark matter core is formed in the central part of the star. In order to describe the quark matter, the local version of three-flavor Nambu-Jona-Lasinio (NJL) model is used. The thermodynamic characteristics of the hadronic matter are calculated within the framework of the extended version of the relativistic mean field (RMF) model, in which the contribution of the scalar-isovector $\delta$-meson effective field is also taken into account. To determine the parameters of the phase transition, both the Maxwell and the Gibbs constructions are applied. It is shown that in case of the equation of state considered by us, the narrow central density interval, $\rho_c \in (1.71 \div 1.73]10^{15} g/cm^3$, corresponds to stable neutron stars with a deconfined quark matter core. Our study showed that compact stars of masses of $2M_\odot$ are compatible with possible existence of deconfined quark matter in their core.

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# Third family of compact stars within a nonlocal chiral quark model equation of state

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A class of hybrid compact star equations of state is investigated that joins by a Maxwell construction a low-density phase of hadronic matter, modeled by a relativistic meanfield approach with excluded nucleon volume, with a high-density phase of color superconducting two-flavor quark matter, described within a nonlocal covariant chiral quark model. We find the conditions on the vector meson coupling in the quark model under which a stable branch of hybrid compact stars occurs in the cases with and without diquark condensation. We show that these hybrid stars do not form a third family disconnected from the second family of ordinary neutron stars unless additional (de)confining effects are introduced with a density-dependent bag pressure. A suitably chosen density dependence of the vector meson coupling assures that at the same time the 2 M⊠ maximum mass constraint is fulfilled on the hybrid star branch. A twofold interpolation method is realized which implements both, the density dependence of a confining bag pressure at the onset of the hadron-to-quark matter transition as well as the stiffening of quark matter at higher densities by a density-dependent vector meson coupling. For three parametrizations of this class of hybrid equation of state the properties of corresponding compact star sequences are presented, including mass twins of neutron and hybrid stars at 2.00, 1.39 and 1.20 M⊠, respectively. The sensitivity of the hybrid equation of state and the corresponding compact star sequences to variations of the interpolation parameters at the 10% level is investigated and it is found that the feature of third family solutions for compact stars is robust against such a variation. This advanced description of hybrid star matter allows to interpret GW170817 as a merger not only of two neutron stars but also of a neutron star with a hybrid star or of two hybrid stars.

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# Formation of Galaxies, Black Holes, Stars and SNs In scope of Non-Inflationary Cosmology

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Since the mechanisms of compact objects' formation in the framework of alternative new theory of cosmology (called as "Non-Inflationary Cosmology" (NIC), to distinguish from the Inflation theory of Modern Cosmology (MoC)) is essentially correlated with the galaxies' generation scenario, this thesis is designed in the form of compressed review on the new cosmological and astrophysical scenarios concerning the formation of galaxies and its compounds – SMBHs, stars and SNs. The investigations of compact objects (especially, stars ranging from Sun's mass to massive one, black holes from intermediate- to super-massive one, and supernovas, probably not standard candles, in contrary to MoC) have been initiated from the conceptual new view on the evolution problem of the Universe, as well as on cosmological original principles and hypotheses disclosed within NIC. During the evolution of the Universe, the original cosmological phenomena and processes have been disclosed in the threshold of Matter Era (ME) stage and further period [1,2], being very abundant by new and unique events. First of all, these are the Cosmological Small Bang (CSB) (local explosion within the galactic scale) and its direct consequence – Strong Shock Waves (SSW), and the new effect – the "induced gravitational collapse". Together these phenomena have initiated the IMBH and SMBH generation in the core of galaxy, formation of stars and SNs from the fragmentations of initial self-collapsing Bose-configuration after local explosion. The main hypothesis of NIC is Planck's constant time-variation phenomenon [3], which substituted the "explanation" of cosmological redshift, accepted in MoC via Doppler Effect. This hypothesis step-by-step is relieving the cosmology from the "necessity" of the hypothetical Dark-Energy, suggesting instead it the phenomenon of CSB as a possible source of energetic activity of galaxies [4,7] (caused by the sharp phase transition process from the initial Bose-statistics into Fermi one within the surrounding zone of CSB). Thus, being forced to revise once more the basics of MoC, one has deepening into its physical foundations, as well as cosmological and quantum-mechanical essence of Planck scales, disclosing disagreements between the basics of MoC and requests of fundamental physics. Leaving aside our detailed arguments on the physical-epistemological confusion, hidden in the physical essence of Planck scales, here I just mention the most prominent argue: the appearance of any fundamental particle in Nature, especially the Planck's particle, earlier than the Higgs boson, is contradicting the main concept of Standard Model. So, the next requirement of NIC has been the problem of new fundamental scales, naturally using the mass of Higgs boson as an etalon for ME. First and foremost, the experimental proof of Higgs Boson's existence has confirmed our earlier prediction about Higgs bosons' possible participation in large-scale Bose-condensate state, as a more broadened cosmological model of galaxy [1,2,6]. Moreover, as the Higgs boson was labeled "God's Particle", then it had to have an essential cosmological mission also in the "construction scenario of fundamental cosmological scales in ME" [5,6]. Thus the theory of NIC has succeed in design of original scales and corresponding scenarios for generation of various types of galaxies and massive BHs in their cores, as well as low- and high-mass stars and variable SNs within the disk, bulge and halo of the galaxy. In addition, let note that the theory of NIC is able to explain also the morphological types of galaxies (starting from dwarf galaxies with IMBH in their core till the giant ones with SMBH), especially, the generation of rotation curve of disk-galaxies without resorting to the help of hypothetical Dark-Matter [7]. In fact, within the NIC the step-by-step accumulation of the rotating momentum of disk has been realized due to symmetry breakdown of CSB with further action of SSW. As the formation of rotating disc likely has been formed as direct result of galactic interior processes, the requirement of MoC– the necessity of Keplerian law for the explanation of rotation curve of disk – already is groundless as a factor from "outside", so the CSB and SSW phenomena are able to adopt the main cosmological mission of Dark-Matter. The theory of NIC is able to resolve also the following enigma: "is the merging-galaxy realistic or the single galaxy with own double SMBHs in core"? The further investigations on the problem of high-energy phenomena around the SMBH revealed new alternative mechanism for the Gamma-astronomy in scope of NIC, disclosing the origin of new astrophysical phenomenon as a possible source for HE-, even VHE-gamma quanta [8,9]. Thus, one may manifest the so called "coherent drop of bi-component Bose-condensate within the galactic IMBH or SMBH" as a new unique phenomenon in role of real candidate for the energetic source and engine in the

new model of galactic jet.

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[7] A. K. Avetissian, Reports of National Academy of Sciences RA, 119, 142 (2019).
[8] A. K. Avetissian, In book: Proceedings of MePHi 4th International Conference, Moscow (2019).
[9] A. K. Avetissian, Proceedings of Int. Conf. on VHE Phenomena around SMBH, Yerevan (2019).

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## Bayesian Analysis for Extracting Properties of the Nuclear Equation of State

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We perform a Bayesian analysis for selecting the most probable equation of state under a set of constraints from compact star physics, which now include the tidal deformability from GW170817. It was considered a two-parameter family of hybrid equations of state, which produces a third family of hybrid stars in the mass-radius diagram. We present the corresponding results for compact star properties like mass, radius and tidal deformabilities and use empirical data for them in Bayesian analysis method to obtain the probabilities for the model parameters within their considered range.

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## Vacuum currents in braneworlds with compact dimensions

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We investigate the vacuum expectation value (VEV) of the current density for charged quantum fields in background of locally AdS spacetime with an arbitrary number of toroidally compact dimensions and in the presence of a constant gauge field. Along compact dimensions the field operator obeys quasiperiodicity conditions with arbitrary phases. The VEVs for the charge density and the components of the current density along uncompact dimensions vanish. The components along compact dimensions are decomposed into the brane-free and brane-induced contributions. The behavior of the vacuum currents in various asymptotic regions of the parameters is investigated. Applications are given to braneworld mpdels of the Randall-Sundrum type with compact dimensions. In the special case of three-dimensional spacetime, the corresponding results are applied for the investigation of the edge effects on the ground state current density induced in curved graphene tubes by an enclosed magnetic flux.

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## Quark-hadron pasta phases for two-phase approaches and the third family of compact stars

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The effect of pasta phases on the quark-hadron phase transition is investigated for a set of relativistic mean-field equations of state for both hadron and quark matter. The results of the full numerical solution with pasta phases are compared with those of an interpolating construction used in previous works, for which we demonstrate an adequate description of the numerical results. A one-to-one mapping of the free parameter of the construction to the physical surface tension of the quark-hadron interface is obtained for which a fit formula is given. For each pair of quark and hadron matter models the critical value of the surface tension is determined, above which the phase transition becomes close to the Maxwell construction. This result agrees well with earlier theoretical estimates. The study is extended to neutron star matter in beta equilibrium with electrons and muons and is applied to investigate the effect of pasta phases on the structure of hybrid compact stars and the robustness of a possible third family solution.
[1] K. Maslov et al., Phys. Rev. C 100, 025802 (2019)

**27**

## Potentially observable cylindrical wormholes without exotic matter in general relativity

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All known solutions in GR describing rotating cylindrical wormholes lack asymptotic flatness in the radial directions and thus cannot describe wormhole entrances as local objects in our Universe. To overcome this difficulty, wormhole solutions are joined to flat asymptotic regions at some cylindrical surfaces on both sides of the throat. The whole configuration thus consists of three regions, the internal one containing a wormhole throat, and two flat external ones. It remains to find such solutions where the matter content of the internal region and both junction surfaces respect the weak energy condition. Two examples of such configurations have been found, in one of which the internal matter is represented by a stiff perfect fluid and another one with a special kind of anisotropic fluid. In both examples, the resulting configurations do not contain closed timelike curves.

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## Time-Dependent Density Functional Theory for Fermionic Superfluids: from Cold Atomic Gases, to Nuclei and Neutron Stars Crust

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In cold atoms and in the crust of neutron stars the pairing gap can reach values comparable with the Fermi energy. While in nuclei the neutron gap is smaller, it is still of the order of a few percent of the Fermi energy. The pairing mechanism in these systems is due to short range attractive interactions between fermions and the size of the Cooper pair is either comparable to the inter-particle separation or it can be as big as a nucleus, which is still relatively small in size. Such a strong pairing gap is the result of the superposition of a very large number of particle-particle configurations, which contribute to the formation of the Copper pairs. These systems have been shown to be the host of a large number of remarkable phenomena, in which the large magnitude of the pairing gap plays an essential role: quantum shock waves, quantum turbulence, Anderson-Higgs mode, vortex rings, domain walls, soliton vortices, vortex pinning in neutron star crust, unexpected dynamics of fragmented condensates and role of pairing correlations in collisions on heavy-ions, Larkin-Ovchinnikov phase as an example of a Fermi supersolid, role pairing correlations control the dynamics of fissioning nuclei, self-bound superfluid fermion droplets of extremely low densities.

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# Hydrostatic equilibrium and stellar structure in Extended Gravity

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We investigate the hydrostatic equilibrium of stellar structure by taking into account the modified Lane'-Emden equation coming from Extended Theories of Gravity. Such an equation is obtained in metric approach by considering the Newtonian limit of Extended Gravity, which gives rise to a modified Poisson equation, and then introducing a relation between pressure and density with polytropic index n.The modified equation results an integro-differential equation, which, in the limit of General Relativity becomes the standard Lane'-Emden equation. We find the radial profiles of gravitational potential by solving for some values of n. The comparison of solutions with those coming from General Relativity shows that they are compatible and physically relevant. A comparison with observational data of some peculiar objects is presented.

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# Small Anisotropy in Stellar Objects in Modified Theories of Gravity

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Interior structures of stellar objects might have small pressure anisotropy due to several reasons, including rotation and the presence of magnetic fields. Here, retaining the approximation of spherical symmetry, we study the possible role of small anisotropy in stellar interiors in theories of modified gravity, that are known to alter the hydrostatic equilibrium condition inside stars. We show how anisotropy may put lower and upper bounds on the modified gravity parameter depending on the

polytropic equation of state, and determine them numerically. We also study the mass of stellar objects in these theories, assuming such equations of state, and find that the Chandrasekhar mass limit in white dwarf stars gets substantially modified compared to the isotropic case, even without assuming the presence of extreme magnetic fields. Effects of small pressure anisotropy on the Hydrogen burning limit in low mass stars are also briefly commented upon. It is shown that here the isotropic case can predict a theoretical lower bound on the scalar tensor parameter, in addition to a known upper bound.

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## The neutron star crust: Elasticity, breaking strength, durability and enhancement of the thermonuclear reaction rates

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In this talk I briefly review material properties of the neutron star crust and the plasma screening effects on the nuclear reaction rates. I start from elastic properties. In particular, I demonstrate that for pure Coulomb crystals the elasticity tensor has additional symmetry, which do not depend on the actual crystalline structure and composition. As a particular result of this symmetry, the effective (Voigh averaged) shear modulus of the polycrystalline matter can be derived from the lattice (Madelung) energy. It leads to universal upper limit for the effective shear modulus of polycrystalline or disordered neutron star crust. At the second part of the talk, I discuss current constraints on the maximal elastic deformation of the neutron star crust, crust durability at the maximal deformations and possibility of the plastic motions. The final part of the talk is devoted to plasma screening enhancement of the nuclear reaction rates, focusing attention on the requirement of the consistency with the detailed balance principle.

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## Modeling anisotropic magnetized white dwarfs with $\gamma$ metric

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The effect of magnetic fields in the equations of state (EoS) of compact objects is the splitting of the pressure in two components, one parallel and the other perpendicular to the magnetic field. This anisotropy suggests the necessity of using structure equations considering the axial symmetry of the magnetized system. In this work, we consider an axially symmetric metric in spherical coordinates, the

$\gamma$

-metric, and construct a system of equations to describe the structure of spheroidal compact objects. In addition, we connect the geometrical parameter

$\gamma$

linked to the spheroid's radii, with the source of the anisotropy. So, the model relates the shape of the compact object to the physics that determines the properties of the composing matter. To illustrate how our structure equations work, we obtain the mass-radii solutions for magnetized white dwarfs. Our results show that the main effect of the magnetic field anisotropy in white dwarfs structure is to cause a deformation of these objects. Since this effect is only relevant at low densities, it does not affect the maximum values of magnetized white dwarf's masses, which remain under Chandrasekhar limit.

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## Scalar Field and Quintessence in Gauge Symmetry Group $SU(2) \otimes U(1)$

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We consider the formation of structured and massless particles with spin 1 (vector boson), by using the Yang-Mills like stochastic equations system for the group symmetry $SU(2) \otimes U(1)$ without taking into account the nonlinear term characterizing self-action. We prove that, in the first phase of relaxation, as a result of multi-scale random fluctuations of quantum fields, massless particles with spin 1, further referred as \emph{hions}, are generated in the form of statistically stable quantized structures, which are localized on 2D topological manifolds. We also study the wave state and the geometrical structure of the \emph{hion} when as a free particle and, accordingly, while it interacts with a random environment becoming a quasi-particle with a finite lifetime. In the second phase of relaxation, the vector boson makes spontaneous transitions to other massless and mass states. The problem of entanglement of two \emph{hions} with opposite projections of the spins $+1$ and $-1$ and the formation of a scalar zero-spin boson are also thoroughly studied. We analyze the properties of the scalar field (dark energy-quintessence) and show that it corresponds to the Bose-Einstein (BE) condensate. The scalar boson decay problems, as well as a number of features characterizing the stability of BE condensate, are also discussed. Then, we report on the structure of empty space-time in the context of new properties of the quantum vacuum, implying on the existence of a natural quantum computer with complicated logic, which manifests in the form of dark energy. The possibilities of space-time engineering are also discussed.

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## Some aspects of the cooling of neutron stars

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Measurements of the low masses for the pulsar PSR J0737-3039B, for the companion of PSR J1756-2251 and for the companion of PSR J0453+1559 on the one hand and of the high masses for the pulsars PSR J1614-2230 and PSR J0348-0432 on the other demonstrate the existence of compact stars with masses in a broad range from 1.2 to 2 Msun. We show that for realistic stellar matter EoS it is possible to explain the whole set of cooling data within "nuclear medium cooling" scenario for compact stars by a variation of the star masses. We select appropriate proton gap profiles from those exploited in the literature and allow for a variation of the effective pion gap controlling the efficiency of the medium modified Urca process. Using the set of existing observational temperature-age data for neutron stars one can also extract their possible mass distribution from the cooling model, because for each of observed compact object its mass can be predicted from the model. Such analyses has been performed for a particular EoS - DD2 model and shown that indeed the interval of masses from 1.2 to 2 Msun should be equally populated.

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## Electrodynamics of axion-active system: polarization and stratification of plasma in an axionic dyon magnetosphere.

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The state of a static spherically symmetric relativistic axionically active multi-component plasma in the gravitational, magnetic and electric fields of an axionic dyon is studied in the framework of the Einstein - Maxwell - Boltzmann - axion theory. We assume that the equations of axion electrodynamics, the covariant relativistic kinetic equations, and the equation for the axion field with modified Higgs-type potential are nonlinearly coupled; the gravitational field in the dyon exterior is assumed to be fixed and to be of the Reissner-Nordstrom type. We introduce the extended Lorentz force, which acts on the particles in the axionically active plasma, and analyze the consequences of this generalization. The analysis of exact solutions, obtained in the framework of this model for the relativistic Boltzmann electron-ion and electron-positron plasmas, as well as, for degenerated zero-temperature electron gas, shows that the phenomena of polarization and stratification can appear in plasma, attracting the attention to the axionic analog of the known Pannekoek-Rosseland effect.
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[2] Rosseland, S.: 1924, Monthly Notices Roy. Astron. Soc. 84, 720728.

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## Decrease in Mass of the Protoquark Stars During their Cooling

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The change in mass of the protoquark stars during their cooling is studied. When a supernova explodes, its central part shrinks so quickly that the lepton charge due to weak processes does not have time to change. Therefore, the chemical equilibrium is established after the formation of the protoquark star with a temperature of 1012 K, when the star's matter is opaque to neutrinos. It is shown that in this state the thermal energy reserves of the hot quark matter are huge: up to 20-40 percent of the total energy. This state of the star does not last long, but it can play a crucial role in the future fate of the star. When it cools down, all this energy leaves the star. Therefore the mass of the cooled quark star will be less than the mass of the original protoquark star by 20−40 percent too. The maximum masses of cold and hot quark stars differ slightly. Consequently, among the existing quark stars, the number of massive stars will be relatively less. This may also be for protoneutron stars too.

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## Bulk viscosity of baryonic matter with trapped neutrinos

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We study bulk viscosity arising from weak current Urca processes in dense baryonic matter at and beyond nuclear saturation density. We consider the temperature regime where neutrinos are trapped and therefore have non-zero chemical potential. We model the nuclear matter in a relativistic density functional approach, taking into account the trapped neutrino component. We find that the resonant maximum of the bulk viscosity would occur at or below the neutrino trapping temperature, so in the neutrino trapped regime the bulk viscosity decreases with temperature as $T^{-2}$, this decrease being interrupted by a drop to zero at a special temperature where the proton fraction becomes density-independent and the material scale-invariant. The bulk viscosity is larger for matter with lower lepton fraction, i.e., larger isospin asymmetry. We find that bulk viscosity in the neutrino-trapped regime is smaller by several orders than in the neutrino-transparent regime, which implies that bulk viscosity in neutrino-trapped matter is probably not strong enough to affect the evolution of neutron star mergers.

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## More on Complexity in Finite Cut Off Geometry

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It has been recently proposed that late time behavior of holographic complexity in a uncharged black brane solution of Einstein-Hilbert theory with boundary cut off is consistent with Lloyd's bound if we have a cut off behind the horizon. Interestingly, the value of this new cut off is fixed by the boundary cut off. In this paper, we extend this analysis to the charged black holes. Concretely, we find the value of this new cut off for charged small black hole solutions of Einstein-Hilbert-Maxwell theory, in which the proposed bound on the complexification is saturated. We also explore this new cut off in Gauss-Bonnet-Maxwell theory

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## Affine Gravity: From vacuum to matter in affine spacetime

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In this talk we firstly explore the theoretical aspects of purely affine gravity in the presence of scalar fields, and reveal the intimate connection between vacuum state and metric structure. In a second stage, cosmological inflation will be studied in view of cosmological observations and unavoidable frame dependence occurring in general relativity. We show that affine geometry, based solely on geodesics with no a priori notion of lengths and angles, leads to general relativity dynamically and may clear away frame ambiguity in inflationary dynamics.

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## Investigations of region of extended radio source 3C315

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The 3C315 galaxy and its surroundings were examined. According to galaxies and quasars, there is a lack of galaxies and quasars in that domain. Only 4 of these 35 domains have a lack of quasars and galaxies. The deficit of galaxies and quasars is the reason why there is empty space around the 3C315 galaxie.

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## Second look to the Polyakov Loop Nambu-Jona-Lasinio model at finite baryonic density

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We revisit the Polyakov Loop coupled Nambu-Jona-Lasinio model that maintains the Polyakov loop dynamics at zero temperature, which is the most interesting for astrophysical applications. For this purpose we re-examine potential for the deconfinement order parameter at finite baryonic densities. Secondly, and the most important, we explicitly demonstrate that naive modification of this potential at any temperature is formally equivalent to assigning a baryonic charge to gluons. We develop a general formulation of the present model which is free of the discussed defect and is normalized to asymptotic of the QCD equation of state given by $\mathcal{O}(\alpha_s^2)$ perturbative results. We also demonstrate that incorporation of the Polyakov loop dynamics to the present model sizably stiffens the quark matter equation of state supporting an existence of heavy compact stars with quark cores.

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## Influence of strong magnetic field on the equation of state and the structure properties of strange quark stars

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We investigate the thermodynamic properties of strange quark matter under the strong magnetic field in the framework of the MIT bag model with the density-dependent bag constant. We consider two cases of the magnetic field, the uniform magnetic fields, and the density-dependent magnetic field to calculate the equation of state of strange quark matter. For the density-dependent magnetic field case, we use a Gaussian equation with two free parameters β and θ and use two different sets of the parameters for the magnetic field changes (a slow and a fast drop of the magnetic field from the center to the surface). Our results show that the energy conditions based on the limitation of the energy-momentum tensor are satisfied in the considered conditions. We also show that the equation of state of strange quark matter becomes stiffer by increasing the magnetic field. In the current paper, we also calculate the structure parameters of a pure strange quark star using the equation of state. We investigate the compactness of strange quark star by the compactification factor and the surface redshift. The results show that the strange quark star is denser than the neutron star. In addition, it is more compact in the presence of the stronger magnetic field. As another result, the compactness increases when we use a slow increase of the magnetic field from the surface to the center. Eventually, we compare our results with the observational results for some strange star candidates, and we find that the structure of the strange star candidates is comparable with that of the star in our model.

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## Astrophysical aspects of general relativistic mass twin stars

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An effective, multi-polytope equation of state (EoS) model is used to study the so-called "mass twins" scenario, where two compact stars have approximately the same mass but (significant for observation) quite different radii. Stellar mass twin configurations are obtained if a strong first-order phase transition occurs in the interior of a compact star. In the mass-radius diagram of compact stars, this leads to a third branch of gravitationally stable stars with features that are very different from those of white dwarfs and neutron stars. Rotating hybrid star sequences are discussed in the slow rotation approximation and in full general relativity and conclusions are drawn [1] for an upper limit on the maximum mass of nonrotating compact stars that has recently been deduced from the observation of the merger event GW170817.

[1] D. Blaschke et al., arXiv:1906.02522 (2019)

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## Delineating the properties of matter in cold, dense QCD

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The properties of dense QCD matter are delineated through the construction of equations of state which should be consistent with QCD calculations in the low and high density limits, nuclear laboratory experiments, and the neutron star observations. These constraints, together with the causality condition of the sound velocity, are used to develop the picture of hadron-quark continuity in which hadronic matter continuously transforms into quark matter (modulo small 1st order phase transitions). The resultant unified equation of state at zero temperature and beta - equilibrium, which we call Quark-Hadron-Crossover (QHC18 and QHC19), is consistent with the measured properties of neutron stars and in addition gives us microscopic insights into the properties of dense QCD matter.

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## Some Quantum Effects in de Sitter Spacetime with Compact Dimensions

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We investigate the effects of background curvature, nontrivial topology and of a planar boundary on the properties of the vacuum state for a charged scalar field. The background geometry is locally dS with an arbitrary number of toroidally compact dimensions. The planar boundary is perpendicular to one of infinite dimensions and on it the charged scalar field obeys the Robin boundary condition. Along compact dimensions general quasiperiodicity conditions are imposed and, in addition, the presence of a constant gauge field is assumed. The latter induces Aharonov-Bohm-type effect on the vacuum expectation values (VEVs) of physical observables. The periodicity conditions imposed on fields along compact dimensions give rise to the modification of the spectrum for normal modes and, related to this, the expectation values of physical observables are changed. As important local characteristics of the vacuum state we consider the VEVs of the field squared, energy-momentum tensor and of the current density.

**35**

## Implications of Binary Neutron Star and Black Hole-Neutron Star Mergers for Neutron Stars and Dense Matter

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Newly discovered binary neutron star and black hole-neutron star mergers via gravitational waves can offer interesting constraints on the properties of dense matter. There are also important implications for the structure and composition of neutron stars. In the case of black hole-neutron star mergers, it is shown how to infer information about the components from GCN announcements, long before the LIGO/VIRGO collaboration publishes their results. New information from X-ray observations of neutron stars, such as from the Neutron Star Interior Composition ExploreR (NICER), can be combined with the gravitational wave data to further constrain these properties.

**20**

## High-Density Nuclear Symmetry Energies from Observations of Neutron Stars and Gravitational Waves

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The high-density behavior of nuclear symmetry energy is the most uncertain part of the Equation of State (EOS) of dense neutron-rich nucleonic matter [1]. It has significant ramifications in understanding properties of nuclear reactions induced by rare isotopes, neutron stars and gravitational waves from various sources. Using a new technique of inverting numerically the Tolman-Oppenheimer-Volkov (TOV) equation and Bayesian inferences, we show that a firmly restricted EOS parameter space is established using observational constraints on the radius, maximum mass, tidal deformability and causality condition of neutron stars [2,3,4]. The constraining band obtained for the pressure as a function of energy (baryon) density is in good agreement with that extracted recently by the LIGO and Virgo Collaborations from their improved analyses of the tidal deformability of neutron stars involved in the GW170817 event. Rather robust upper and lower boundaries on nuclear symmetry energies are extracted from the observational constraints up to about twice the saturation density of nuclear matter. Moreover, by studying variations of the causality surface where the speed of sound equals that of light at central densities of the most massive neutron stars within the restricted EOS parameter space, the absolutely maximum mass of neutron stars is found to be about 2.40 Msun. Implications of these findings on the recently reported mass 2.17 Msun of PSR J0740+6620 [5,6], calculations of the EOS of dense neutron-rich matter, heavy-ion reactions in terrestrial laboratories as well as the frequencies and damping times of oscillating modes of neutron stars are discussed [7].

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**16**

## Electromagnetic vacuum densities around a cosmic string in de Sitter spacetime

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We evaluate the vacuum expectation values (VEVs) of the electric and magnetic fields squared and of the energy-momentum tensor for the electromagnetic field around a cosmic string on the background of (D+1)-dimensional locally de Sitter spacetime. It is assumed that the field is prepared in the Bunch-Davies vacuum state. The topological contributions in the VEVs are explicitly separated. It is shown that in spatial dimensions other than 3 the part of the vacuum energy-momentum tensor induced by the cosmic string, in addition to the diagonal components, has a nonzero off-diagonal component corresponding to the energy flux along the radial direction. The asymptotic behavior of the VEVs is discussed near the string and at proper distances larger than the curvature radius of the de Sitter spacetime.

**36**

## Cosmological models with variable anisotropic hyperbolic parameter in modified gravity

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The cosmological models of the universe with an anisotropic variable parameter has been constructed. The field equations for Bianchi type I space-time have been derived in $f(R,T)$ gravity for the functional relationship $f(R,T) = R + 2f(T)$, where $R$ is the Ricci scalar and $T$ is the trace of the energy momentum tensor. Two different models are constructed with respect to the scale factors, such as Power law scale factor and Hybrid scale factor. Moreover, the anisotropic parameter taken here in the form of hyperbolic function that further gives clarity on the behaviour of Equation of State (EOS) parameter. The models can be reduced to isotropic universe when the coefficient constant vanishes. For both the cases the deceleration parameter, state finder diagnostic pairs and energy conditions have been obtained and analyzed which provide physical plausibility of the models.

**1**

## Investigation of Neutron stars structure using Energy-momentum squared gravity

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The structural properties of neutron stars, namely, maximum mass is a subject that theoretical astrophysicists have desired to study. Theoretically, investigation of structure for neutron stars necessities obtaining the perfect hydrostatic equilibrium equations. Up to now, different models and metrics have been used to calculate these equations. It is expected higher order energy-momentum gravity plays crucial role in the investigation of neutron stars structure due to high density cores of neutron stars. Recently, the energy-momentum squared gravity (EMSG) is exposed [1].
In this paper, we will compute mass-radius relation for neutron stars using EMSG and employing realistic equations of state (EOS). We have obtained the EOS of neutron star matter using the lowest order constrained variational (LOCV) formalism as a microscopic approach [2, 3]. The LOCV method is a powerful tool for determination of the properties of the nucleonic matter at zero and finite temperatures [4-5].

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**56**

## The universe acceleration in modified gravity: an overview

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General introduction to cosmology of modified gravity is given. It is shown that different forms of modified gravity are possible: many of them being consistent with Solar system tests and cosmological bounds. Special attention is paid to F(R) gravity. It is shown that such theory may naturally describe the early-time inflation with late-time acceleration (dark energy epoch). Realistic versions of F(R) gravity are proposed. The inflationary indices are shown to be consistent with Planck experiment. New ghost-free versions of modified gravity are introduced and their cosmological evolution is studied. It is shown that it may naturally give the unification of inflation with dark energy while scalar field which appears there plays the role of dark matter.

**38**

## Merger of compact stars in the two-families scenario

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I will discuss the phenomenological implications of the two-families scenario on the merger of compact stars. After reviewing the main properties of this scenario, which is based on the coexistence of hadronic stars (HSs) and quark stars (QSs), I will present results of population synthesis analyses for the estimates of the rate of events associated with the merger of two HSs, two QSs or a HS and a QSs. I will move then to the results obtained by numerical simulations of HS-HS mergers concerning the threshold mass for the prompt collapse, the postmerger GW signal and the mass dynamically ejected. Finally, after discussing the interpretation of GW170817 as due to the merger of a HS-QS system, I will argue that the specific signature of our scenario is the observation of cases of prompt collapses even for systems with a mass smaller than 2.74 m_sun (i.e. the mass of the source of GW170817).

**7**

## Quantum effects for a spherical shell in the Milne universe

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The influence of a spherical boundary on the vacuum fluctuations of a massive scalar field is investigated in background of $(D+1)$-dimensional Milne universe, assuming that the field obeys Robin boundary condition on the sphere. The normalized mode functions are derived for the regions inside and outside the sphere. For the interior region, the boundary-induced contribution is explicitly extracted in the Wightman function with the help of the generalized Abel-Plana summation formula. The vacuum expectation values (VEVs) of the field squared and of the energy-momentum tensor are investigated for the conformal vacuum. They are decomposed into the boundary-free and boundary-induced contributions. For the latter, rapidly convergent integral representations are provided. In addition to the diagonal components, the vacuum energy-momentum tensor has an off-diagonal component that describes energy flux along the radial direction.

**11**

## Searching for new physics with future CMB experiments

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Large scale B-mode patterns in CMB polarization, if detected, would constitute a "smoking gun" signature of primordial gravitational waves generated during an inflationary phase in the early universe. In this talk, I will discuss other sources of B-modes, such as primordial magnetic fields, axion-like fields and cosmic strings, and prospects of isolating their distinguishing features with future CMB measurements.

**6**

## Tachyonic DGP cosmological model with an exponential potential: Dynamical System approach

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In this work we use the dynamical system approach to study the stability of a normal DGP model in which we assume that a tachyon scalar field plays the role of dark energy. We consider an exponential potential ($V_0 e^{\alpha\phi}$) for the tachyon field. We write the main equations of the model. Then, with attention to these equations, we introduce a set of new dimensionless dynamical variables and obtain their evolutionary equations. Putting these equations equal to zero and solving them simultaneously, we find three critical points for the model. Using linear perturbation theory, we calculate corresponding eigenvalues and discuss about the stability conditions of them and also respective cosmological epochs. One of the most interesting features of this work is that one of these critical points depends on a new variable $() = -V/V^{3/2}$. By assuming this point moves slowly enough, we can consider this dynamical critical point as an instantaneous fixed critical point and see how the universe tends to evolve for different values of parameter $\lambda$.

**15**

## Dynamics of anisotropic dark energy universe embedded in one-directional magnetized fluid

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This work discovers few extraordinary features of an anisotropic dark energy cosmological model in a two fluid situation such as the usual dark energy and the electromagnetic fluid. We have assumed

the dark energy pressure to be anisotropic in spatial directions in terms of skewness parameters and have been studied their behavior through cosmic evolution. In order to yield a healthy mathematical formalism of the model, we have considered the scale factor as hybrid scale factor; a combination of both power law and volumetric (de Sitter) expansion law, showing a transitional phase in between. The physical parameters are derived, analyzed and found to be in agreement with recent observational data. The evolution of Equation of State parameter obtained here, presents a scenario which is consistent with three different stages of evolutionary universe, namely; radiation dominated, matter dominated and dark energy dominated era. Also this work clearly compares the effect of magnetized fluid over other cosmic fluids (discussed in our earlier works) along with dark energy fluid. Moreover, we observed that electromagnetic fluid extremely dominates the early phase of evolution than any other cosmic fluids. Whereas, the late cosmic epoch is completely filled and driven by dark energy fluid. Also, we diagnosed the model through state-finder parameters and compared with Λ CDM model to convey the physical acceptability of it.

**13**

# Vacuum polarization by cosmic strings

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We investigate the polarization of the vacuum for scalar, fermionic and electromagnetic fields induced by cosmic strings. Locally Minkowski, de Sitter and anti-de Sitter background geometries are considered. As local characteristics of the vacuum the expectation values of the field squared and of the energy-momentum tensor are considered. The contributions induced by the nontrivial topology of a cosmic string are explicitly extracted. The asymptotic behavior of the vacuum expectation values is discussed near the string and at large distances. For the de Sitter and anti-de Sitter geometries the influence of the gravitational filed on the vacuum characteristics is essential at proper distances from the string larger than the curvature radius of the background spacetime.

**8**

# Cosmological constant induced by a bulk scalar in braneworlds with compact dimensions

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We investigate the vacuum expectation value (VEV) of the surface energy-momentum tensor for a charged scalar field in a higher dimensional locally anti-de Sitter spacetime with two parallel branes and with a compact dimension (generalized Randall–Sundrum model). The presence of a constant background gauge field is assumed. The latter gives rise to Aharonov-Bohm type effect on the characteristics of the scalar vacuum. The problem is reduced to the investigation of the VEV of the field squared on the branes. It is shown that the VEV can be decomposed into three contributions representing the VEV in the brane-free geometry, the VEV in a single brane geometry, and the contribution due to the second brane. The latter is investigated, and it is shown that this gives rise to a cosmological constant on the visible brane (our universe). The behavior of the cosmological constant is studied as a function of the locations of the branes, of the length of the compact dimension and of the magnetic flux enclosed by the compact dimension. In particular, it is shown that the cosmological constant is a periodic function of the magnetic flux with the period equal to the flux quantum. Depending on the parameters of the problem it can be either negative or positive.

**41**

## On the role of fluctuations in compact objects

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NA

**59**

## On the role of fluctuations in compact objects

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One of the pending challenges of modern physics is to probe the microscopic equation of state (EoS) of cold and dense matter to constraint macroscopic neutron star observations such as the masses and radii. Still, unanswered issues concern the detailed composition of matter in the core of neutron stars at high pressure or the possible presence of strange quarks or hyperons in neutron stars (hyperon puzzle).

Different matter phases with accompanying transitions are most likely to appear whose details, particularly in the vicinity of their criticality, are triggered by quantum and thermal fluctuations. In this talk, a non-perturbative functional renormalization group approach is employed in order to investigate the influence of quantum and thermal fluctuations on the EoS for beta stable quark matter. The findings are confronted to results obtained with common mean-field approximations where usually important fluctuations are ignored.

**54**

## The fourth family of compact stars

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I will discuss the features pertaining to the new family of compact stars that are denser than the hybrid stars and arises if multiple phase transitions take place in the dense quark matter. The mass, radius, deformability and internal structure of these new objects will be discussed and confronted with the constraints from astrophysics.

**12**

## Cosmic matter in the laboratory- The Compressed Baryonic Matter experiment at FAIR

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The Compressed Baryonic Matter (CBM) experiment is of the major scientific pillars of the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt. In collisions between heavy nuclei at FAIR energies, it is expected that the matter in the reaction zone is compressed to more than five times saturation density, corresponding to the density in the core of a massive neutron star. This offers the unique opportunity, to study in the laboratory the high-density equation-of-state (EOS) of nuclear matter, and to search for new phases of QCD matter at large baryon chemical potentials. Promising experimental observables sensitive to the EOS and to possible phase transitions will be discussed, together with the expected performance of the CBM experiment, and the status of the FAIR project.

**42**

## Time-dependent Ginzburg-Landau equations for interacting neutron-proton superfluid in neutron stars

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We discuss a time-dependent generalization of the stationary Ginzburg-Landau theory for interacting neutron superfluid and proton superconducting condensates and its modification in the presence of rotation.

**60**

## First-order phase transition from hypernuclear matter to deconfined quark matter obeying new constraints from compact star observations

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We reconsider the problem of the hyperon puzzle and its suggested solution by quark deconfinement within the two-phase approach to hybrid compact stars with recently obtained hadronic and quark matter equations of state. For the hadronic phase we employ the hypernuclear equation of state from the lowest order constrained variational method and the quark matter phase is described by a sufficiently stiff equation of state based on a color superconducting nonlocal Nambu-Jona Lasinio model with constant (model A) and with density-dependent (model B) parameters. We provide for the first time a hybrid star EoS with an intermediate hypernuclear matter phase for which the maximum mass of the compact star reaches 2.2 solar mass.

**2**

## LOCV calculation of equation of state and binary neutron stars

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The binary system of neutron stars (NSs) has drawn a lot of astrophysicists' attention in past years. Discovery of the gravitational wave (GW) signal from GW170817, the compact binary inspiral event, has resulted in the multi-messenger astronomy which indeed provides substantial data about the interior of dense matter. In addition, they have the potential of elucidating the information about the equations of state (EOSs) of NS matter.
Structural and tidal parameters of NSs in the observed binary neutron star merger are studied employing the realistic equations of state. It is notable to mention that we use the same EOS for each component of the merger in the case of low spin prior. The value of dimensionless tidal deformability $\Lambda$ is calculated as $216 < \Lambda < 314$ regarding 1.4 $M_{\odot}$ configuration of NS with the EOSs of Argonne family potentials in addition to the UV14 accompanied by TNI and applying the LOCV method [1]. Fixing the chirp mass at 1.188 $M_{\odot}$, the mass ratio of components, q, is set as the recent results obtained by the PhenomPNRT wave model: (0.73, 1) for the low spin case. Therefore, our results for weighted dimensionless tidal deformability $\widetilde{\Lambda}$ agree well with the recent constraints on its lower limits: $300^{+420}_{-230}$ [2]. Moreover, it is found that some EOSs with Argonne family potentials such as AV6' and AV8' can be ruled out due to their consequences that are far away from the credible intervals. We have also investigated the impact of quark core and the van der Waals equation of state on the tidal deformability of neutron stars in a binary system.

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**49**

## Vacuum fluxes from a brane in de Sitter spacetime with compact dimensions

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We investigate the vacuum expectation value of the energy flux density for a complex scalar field in de Sitter spacetime with an arbitrary number of toroidally compact spatial dimension and in the presence of a brane. Quasiperiodicity conditions with arbitrary phases are imposed along compact dimensions and on the brane the field obeys Robin boundary condition. Depending on the values of the parameters in the problem, the flux can be directed from the brane or to the brane. The behavior of the flux density in various asymptotic regions is investigated. It has been shown that the energy flux density is an even periodic function of magnetic fluxes enclosed by compact dimensions with the period equal to flux quantum.

**43**

## Young magnetars with fracturing crusts as fast radio burst repeaters

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Fast radio bursts (FRBs) are short (duration ~ ms) but intense (flux ~ Jy) flashes, generally believed to be of extragalactic origin due to their high dispersion measures, which appear in the GHz-band. Currently, there are two sources which are known to repeat, thereby suggesting that there may be at least a subclass of FRBs resulting from transient outbursts of a young, compact object. We discuss some of the statistics surrounding the repeating bursts, and explore what this might indicate about the progenitors. We consider the possibility that FRBs are instigated by crustal fractures in young (~ 100 yrs) magnetars, whose crust yields due to strong, and topologically complicated, magnetic stresses, which build up as the field evolves rapidly due to Hall drift and ambipolar diffusion.

**57**

## Study of surface and volume coefficients of the nuclear symmetry energy

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Nuclear symmetry energy plays a key role in both nuclear physics and nuclear astrophysics. It is important to studying the equation of state of neutron star matter and also estimating the core-crust interface density. In order to calculate symmetry energy we have used the lowest-order constrained variational (LOCV) method. In this work, the volume(a_A^V) and surface(a_A^S) components of the nuclear symmetry energy and their ratio(�κ=a�_A^V/a_A^S) obtained for the Zr, Mo, and Sn isotopic chains. Our results for the values of the ratio ,κ, are about the range of 0.3 ≤ � ≤ 1.3, 0.4 ≤ � ≤ 1.6 and 0.3 ≤ � ≤ 0.7 respectively. The symmetry energy s for finite nuclei is obtained to be infinite superposition of the corresponding asymmetric nuclear matter (ANM) symmetry energy for each isotopic chains. The results are compared with experimental data and also with those of other theoretical methods.

Keywords: LOCV method, volume and surface components of symmetry energy

**44**

## Dynamical aspects of the magnetized anisotropic cosmological model in extended gravity

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In this paper, we have investigated the extended gravity particularly the f(R,T) gravity in Bianchi �VI�*(h=-1) space time filled with magnetized anisotropic matter contents. We have explored the field equations and obtain the solution with power law function. The kinematical and geometrical parameters are derived and analyzed in detail. The effect of energy conditions is also studied. It is found that the extended gravity induced by f(R)=R and f(T)=2Λ*{0}+2βT, where Λ_{0} and β are respectively denotes the cosmological constant and coupling constant, are likely to experience an expansion at late time of cosmic acceleration.

**61**

## Transport properties in magnetized compact stars

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Nowadays strong magnetic field has been observed or expected in compact stars or during relativistic heavy-ion collisions. In particular, magnetars may have a huge magnetic field of O(10 15 G) at the surface. We here consider the transport properties of Dirac particles in the presence of a strong magnetic field. As a phenomenological implication, the heat conductivity is interesting and important in the context of the thermal evolution of magnetars: The heat conductivity is, in general, a tensor in the coordinate space,$\kappa_{ij}$ (I,j=x,y,z); the off-diagonal components represent the thermal Hall conductivity.
First, we discuss the electron contribution in the crust of magnetars, since the main mechanism of thermal transport is responsible for conducting electrons. The diagonal components give the thermal currents proportional to the gradient of temperature. It comes from some dissipative effects for electron propagation and has a classical analogy to the Drude-Zener formula. On the other hand, the off-diagonal components consist of two parts $\kappa_{ij}$ =$\kappa_{ij}$ I + $\kappa_{ij}$ II ($i \neq j$), where the first term represents the dissipative contribution similar to the diagonal components and has been studied by many authors [1]. However, there is a little study about the second term, which is a genuine quantum effect and gives a non-dissipative contribution. It comes from the field-dependent level density and has no classical analogy [2]: the Landau levels become essential in the strong magnetic field and the density of states (DOS) is a field-dependent quantity, while DOS is not field dependent in the classical limit. Sometimes $\kappa_{ij}$ II has been missed in the literature. We elucidate its contribution by way of the Kubo formula and estimate its importance.
Next, we discuss the anomalous thermal Hall effect in quark matter, which may develop in the core of compact stars. Recently we have shown a possibility of the anomalous Hall effect in dense QCD matter by the use of the Kubo formula [3], where inhomogeneous chiral phase (DCDW phase) is realized [4]. The important consequence is that the Hall conductivity $\kappa_{ij}$ becomes nonvanishing even in the absence of the magnetic field. It has a geometrical origin and modifies the Maxwell equation as in the Weyl semimetal [5]: the energy spectrum exhibits asymmetry with respect to the zero energy to produce a kind of "magnetization" in the DCDW phase, and the Hall current flows in the direction perpendicular to the magnetization. Since thermal conductivity is closely related to conductivity $\kappa_{ij}$, we can expect the anomalous thermal Hall effect there as well [6]. It then should give another contribution to the thermal conductivity independent of the magnetic field. We discuss the interplay of these terms in the non-dissipative contribution $\kappa_{ij}$ II .
Finally, we briefly discuss some implications of the non-dissipative thermal Hall conductivity $\kappa_{ij}$ II , in the context of thermal evolution of magnetars.

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**45**

## Massive bosonic conformal zero mode in the spatially compactified FRW spacetimes and its detection

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N. A.

**5**

## Cosmological Models with Hybrid Scale Factor

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We construct some cosmological models in an extended gravity theory. The gravitational action of the extended gravity theory contains a term proportional to the trace of the energy momentum tensor in addition to the usual Ricci scalar. Keeping in view the cosmic transit behavior from a decelerated universe to an accelerated one, we have employed a hybrid scale factor (HSF) to study the cosmic dynamics. The parameters of the HSF have been constrained from some Physical basic and Hubble parameter data. The viability of the models has been tested through some diagnostic analysis. The model parameters substantially affect the dynamical properties.

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## Cosmological models with a Hybrid Scale Factor

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We construct some cosmological models in an extended gravity theory. The gravitational action of the extended gravity theory contains a term proportional to the trace of the energy momentum tensor in addition to the usual Ricci scalar. Keeping in view the cosmic transit behavior from a decelerated universe to an accelerated one, we have employed a hybrid scale factor (HSF) to study the cosmic dynamics. The parameters of the HSF have been constrained from some Physical basic and Hubble parameter data. The viability of the models has been tested through some diagnostic analysis. The model parameters substantially affect the dynamical properties.

**47**

## Low-mass stellar objects in modified gravity

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I will demonstrate how the minimum main sequence mass of the low-mass stars is affected by the Palatini gravity: it turns out that such objects, whose the internal structure is known better in comparison to compact stars, can be used to test modified theories of gravity.

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# Magnetic deformations of neutron stars

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In this work, we review the formalism which would allow us to model magnetically deformed neutron stars. We study the effect of different magnetic field configurations on the equation of state (EoS) and structure of such stars. In this study, the EoS of magnetars is acquired by using the lowest order constraint variational (LOCV) method and the upper limit of the magnetic field is derived based on our EoS for magnetized neutron matter.
We introduce two different exponential and polynomial density-dependent prescriptions for the magnetic field profiles and check the divergence-free constraint of these profiles in the neutron stars. It can be concluded that the exponential profile violates Gauss law, while the polynomial prescription fulfills Gauss law.
For obtaining macroscopic properties of magnetars, the magnetic pressure as well as the metric are expanded as multipoles in spherical harmonics up to the quadrupole term. Solving the Einstein equations, one acquires the excess mass and deformation of the star due to the magnetic field.