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Book of Abstracts

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EoS for neutron stars and core-collapse supernovae

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Modelling compact stars is a complex task which depends on many ingredients, among others the properties of dense matter. In this talk I will discuss models for the equation of state (EoS) of dense matter, relevant for the description of core-collapse supernovae, compact stars and compact star mergers. Such EoS models have to cover large ranges in baryon number density, temperature and isospin asymmetry. The characteristics of matter change dramatically within these ranges, from a mixture of nucleons, nuclei, and electrons to uniform, strongly interacting matter containing nucleons, and possibly other particles such as hyperons or quarks. I will highlight some implications for compact star astrophysics.

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Neutron Star physics with X-ray observations of accreting systems

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X-ray observations of neutron stars in many cases give information directly from the neutron star surface. I will review methods that have been used to constrain key neutron star physics using X-ray observations, including studies of X-ray bursts, quiescent neutron stars in globular clusters, X-ray pulse profiles (see also S. Guillot's talk on NICER), and crust cooling observations.

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Continuous Gravitational Waves from Neutron Stars: questing for the missing signals

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The recent sensitivity improvements of the worldwide advanced gravitational-wave detector network has allowed us to detect the first transient gravitational-wave signal, marking thus the official beginning of the gravitational-wave astronomy. We have then started to hone the comprehension of some of the objects populating our Universe. A broader picture would be however provided by the detection of continuous-wave signals, which are emitted by rotating neutron stars with a non-axisymmetric deformation.
I will present the prospects for detecting continuous gravitational waves by mainly exploiting innovative strategies to search for such types of signals. In proceeding, I will also focus on what information can be attained on neutron-star physics from a continuous-wave detection.

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Gravitational waves from newly born neutron stars: emission mechanisms and methods for detection

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Newly born neutron stars are potential sources for current and future generation gravitational wave experiments. Detections of such a signal could allow for, among other things, precision measurements of the equation of state. But there are many uncertainties in the emission mechanism, which leads to uncertainties in the gravitational-wave signal. I will review such emission mechanisms, their gravitational and electromagnetic signatures, and the prospects and methods for detecting such signals with ground-based gravitational-wave interferometers.

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Crystallography of neutron-star crusts

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The outer crust of a neutron star has been generally assumed to be stratified into different layers, each of which consists of a pure body-centred cubic ionic crystal in a charge compensating electron background. The validity of this assumption is examined by analysing the stability of multinary ionic compounds in dense stellar matter. It is shown that their stability against phase separation is uniquely determined by their structure and their composition irrespective of the stellar conditions. However, equilibrium with respect to weak and strong nuclear processes imposes very stringent constraints on the composition of multinary compounds, and thereby on their formation. By examining different cubic and noncubic lattices, it is found that substitutional compounds having the same structure as cesium chloride are the most likely to exist in the outer crust of a nonaccreting neutron star. The formation of binary and ternary compounds in accreted crusts will be also discussed.

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Probing pulsar interiors via timing measurements

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Pulsar timing provides a probe of the state of matter at high densities. Some pulsars have been observed to display quasi-periodicities in their spin-down rates, while others have displayed sudden steps in spin frequency, known as glitches. In this talk I will discuss what we can learn about neutron star interiors from those (very few systems) where *both* sorts of timing irregularities have been observed.

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Light curve modelling of millisecond pulsars: Measuring the neutron star radius with NICER

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Rotation-powered millisecond pulsars offer a unique method to obtain constraints on the dense matter equation of state. Modelling the spin-modulated thermal X-ray pulsations from MSPs permit measurements of their radius and mass. Such modelling includes the atmospheric emission from MSPs as well as relativistic effects present in the environment of such a fast-spinning compact object. On behalf of the NICER Science Team, I will present an overview of the mission, a brief description of the modelling, and the expected results from the observations of targeted MSPs. If time permits, I will also rapidly discuss additional neutron star science enabled by NASA's Neutron Star Interior Composition ExploreR.

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QCD phase transitions in Hybrid Quark-Nucleon-Meson model at finite density

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Coalescing Binary Black Holes From Globular Clusters

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In 2015 gravitational wave observatories LIGO detected two binary black hole systems. In one of them measured masses of both objects exceeded 25 Msol each. This may imply the formation of the binary in a low metalicity environment. Globular clusters are highly probable to generate such kind of binaries. In our work we analyse evolutionary simulations of globular clusters made with MOCCA code and calculate the event rate of compact binary mergers.

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Properties Of Differentially Rotating Neutron Stars And Strange Stars

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We present the results of the effect of the differential rotation and the Equation of State on the main astrophysical properties of Neutron Stars and Strange Stars. Calculations were performed for broad ranges of the degree of differential rotation, maximum densities and different stiffness of the EoS. Additionally we discuss the stability of those objects.

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Properties of the nuclear matter liquid-gas phase transition within the DD-NLD model with energy dependent self-energies

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The equation of state (EOS) of dense matter is essential for modeling compact astrophysical objects and sets the conditions for the creation of chemical elements in the universe. To provide it, we use the generalized relativistic mean-field model (RMF) with density-dependent (DD) nucleon-meson couplings and higher-order derivative couplings (NLD) between nucleons and mesons (DD-NLD model). The model is extended to describe the properties of homogeneous nuclear matter at finite temperatures, covering the full range of isospin asymmetries from neutron matter to symmetric and proton matter. The properties of the liquid-gas phase transition for subsaturation densities and not too high temperatures are studied in comparison to the standard RMF descriptions. We investigate the evolution of spinodals and binodals, i.e. boundaries of local and global stability regions, with increasing temperature. Furthermore critical lines and points in the phase diagram are extracted, and the general features of the phase transitions are explored.

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f(R) gravity: application to stellar dynamics and to fundamental plane of elliptical galaxies

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The role of f(R) gravity, as well as the other modifications of standard Einstein's gravity, is to explain the accelerated expansion, structure formation of the Universe, and some other phenomena at extragalactic scales (such as e.g. flat rotation curves of spiral galaxies) without adding unknown forms of dark energy or dark matter [1]. In f(R) model, the Ricci scalar in the Einstein-Hilbert action is replaced by a general function of it. Its power-law form R, here is analyzed using observed orbits of S-stars around Galactic Center and also their computer simulations. We review the various consequences of the Rˆn gravity parameters (rc - characteristic radius i.e. scale length depending on the gravitating system properties and β - universal constant) on stellar dynamics and investigate their constraints from the observed S - star orbits. The presented results show that these observations could put reliable constraints on the parameters of Rˆn gravity [2]. Also, other aim of this investigation is to show the connection between the half-light radius, central velocity dispersion, and mean surface brightness of elliptical galaxies and the parameters of Rˆn gravity potential. We also want to show that Rˆn gravity fit the observations of fundamental plane of elliptical galaxies very well [3], without adding unknown forms of dark energy or dark matter.

[1] S. Capozziello and M. de Laurentis, Extended Theories of Gravity, Physics Reports 509, (2011) 167. [2] D. Borka, P. Jovanović, V. Borka Jovanović and A. F. Zakharov, Constraints on Rˆn gravity from precession of orbits of S2-like stars, Physical Review D 85 (2012) 124004-1-11.

[3] V. Borka Jovanović, S. Capozziello, P. Jovanović and D. Borka, "Recovering the fundamental plane of glaxies by f(R) gravity", Physics of the Dark Universe 14 (2016) 73.

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Hyperons, Delta baryons and rho-mesons in neutrons stars

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Knowledge of the equation of state of the baryon matter plays a decisive role in the description of neutron stars. With an increase of the baryon density the filling of Fermi seas of hyperons and Delta-isobar becomes possible. The inclusion of hyperons and Delta resonances into standard relativistic mean-field models results in a strong softening of the equation of state and a lowering of the maximum neutron star mass below the measured values. We extend a relativistic mean-field model with scaled hadron masses and coupling constants developed in our previous works and take into account both hyperons and Deltas isobars. We analyze available empirical information to put constraints on coupling constants of Deltas to mesonic mean fields. Also we argue that if rho mesons are included in the relativistic mean-field model as non-Abelian gauge bosons and the rho meson mass decreases with a density increase, then there is could appear a mean-field of the charged rho meson (rho-meson condensate). We show that the resulting equation of state satisfies majority of presently known experimental constraints.

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Outer crust structure and the spin parameter of neutron stars

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All the existing studies indicates that observed neutron stars are rotating namely millisecond pulsars (MSPs). Such rotation affects the global attributes of the neutron stars. The study of structural properties of these objects specifically maximum mass, radii and spin parameter has interested for theoretical astrophysicists over the last decades. The dimensionless spin parameter is important characteristic quantity for rotating neutron stars. Recently, this parameter for uniformly rotating compact stars have been studied in detail [1, 2]. Here, we have computed the structural properties of Keplerian rotating neutron star using of the numerical RNS code [3]. We have seen, the outer crust structure have crucial role in maximal spin parameter, jmax, and for neutron stars without outer crust jmax is larger than 0.7. This indicates that the central star in Circinus X-1 can be traditional neutron star. In this work, we have employed the equation of state (EOS) for neutron star matter by describing the neutron star outer crust, inner crust and the liquid core. For the inner crust, the EOS is calculated by Douchin and Haensel [4], and the Baym-Pethick-Sutherland EOS for outer crust [5] have been used. For neutron star liquid core, we have applied the lowest order constrained variational (LOCV) method to generate equation of state [6, 7].
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[1] K. W. Lo, L. M. Lin, Astrophys. J., 728 (2011) 12. [2] B. Qi, et al. RAA, 16 (2016) No 4. [3] http://www.gravity.phys.uwm.edu/rns/. [4] F. Douchin and P. Haensel, Astron. Astrophys., 380 (2001) 151. [5] G. Baym, C. Pethick and D. Sutherland, Astrophys. J., 170 (1971) 299. [6] M. Bigdeli, Phys. Rev. C, 82 (2010) 054312. [7] M. Modarres and G.H. Bordbar, Phys. Rev. C, 58 (1998) 2781.

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X-ray bounds on the r-mode amplitude in millisecond pulsars

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r-mode oscillations provide an important way to study the inner structure of compact stars. Because of their precisely measured, large spin frequencies, millisecond pulsars are the best sources to use these oscillations for astroseismology.r-mode oscillations can act as a heat source in the pulsar and X-ray observations of the thermal emission of millisecond pulsars can help us to understand the nature of this process. We have recently started a project to either determine the surface temperatures of millisecond pulsars, or set stringent bounds on them, by using direct spectral analyses of X-ray data as well as the large number of temperature and luminosity measurements given in the literature. This allows us constrain the amplitude of r-mode oscillations and thereby the internal composition of the star. In this poster, we will show the initial results of our work.

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Structure, Composition and Equation of State of Magnetar Crusts

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The constitution and the properties of the crust of a neutron star can be significantly modified by the presence of a high magnetic field due to Landau quantization of electron motion. The structure, the composition and the equation of state of both the outer and inner regions of magnetar crusts are calculated consistently using the same set of accurately calibrated Brussels-Montreal nuclear energy density functionals. This allows assessing the uncertainties associated with the lack of knowledge of high-density matter. Results obtained for different magnetic-field strengths will be presented.

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Microphysics in the gamma ray burst central engine

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We calculate the structure and evolution of a gamma ray burst central engine where an accreting torus has formed around the newly born black hole. We study the general relativistic,MHD models and we self-consistently incorporate the nuclear equation of state. The latter accounts for the degeneracy of relativistic electrons, protons, and neutrons, and is used in the dynamical simulation, instead of a standard polytropic -law. The EOS provides the conditions for the nuclear pressure in the function of density and temperature, which evolve with time according to the conservative MHD scheme. We analyze the structure of the torus and outflowing winds, and compute the neutrino flux emitted through the nuclear reactions balance in the dense and hot matter. We also estimate the rate of transfer of the black hole rotational energy to the bipolar jets. Finally, we elaborate on the nucleosynthesis of heavy elements in the accretion flow and the wind, through computations of the thermonuclear reaction network. We discuss the possible signatures of the radioactive elements decay in the accretion flow. We suggest that further detailed modeling

of the accretion flow in GRB engine, together with its microphysics, may be a valuable tool to constrain the black hole mass and spin. It can be complementary to the gravitational wave analysis, if the waves are detected with an electromagnetic counterpart.

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Is it possible to distinguish between neutron stars?

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Recent measurements of the high masses of neutron stars (NSs), like pulsars PSR J1614-2230 and PSR J0348+0432 with masses $M \approx 2M_{\odot}$, put a new constraints on the theories of the interiors of the compact objects. Future extraterrestial observatories, like Advanced Telescope for High ENergy Astrophysics (ATHENA) or Neutron star Interior Composition Explorer (NICER), will be dedicated to collect informations about global parameters of NSs, like their masses and radii, with accuracies of a few percent. There is a strong connection between mass-radius $M(R)$ relation and properties of the interiors of the NSs: cold matter equation of state (EOS) might be reconstruct from measured $M(R)$, by using inverted Tolman-Oppenheimer-Volkoff (TOV) equations. Distinction between NSs with similar $M(R)$ relation, but different interiors, using current and future missions and their observational errors, might be essential in understanding physics of the matter at supranuclear densities inside NSs.

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Hydrodynamics of superfluid vortex avalanches in neutron stars

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Neutron stars being a highly dense objects are natural laboratories for studying physical processes in matter in a state that can't be obtained on Earth. The data to interpret comes to us in the form of electromagnetic radiation, gravitational waves, high-energy particle flows and the product of their interaction with the interstellar medium. Even having a lot of data from isolated neutron stars and from pulsars and binaries in a different spectral range it's still not possible to solve some of the problems, connected with the interiors of these stars as well as with the exterior. One of the currently unsolved problem - is pulsar glitches. Pulsars emit pulses of wide-band electromagnetic radiation. The pulses of emitted radiations provide data about the rotation of NS as well as about the magnetic field on the surface. The timing of the typical profiles shows slowing down of pulsars due to emission and this slowing down is expected to be with a constant slope theoretically. But experimental data shows a lot of details and sometimes - glitching of a pulsar. Pulsar glitches are a sudden increase of rotational frequency of a star with further relaxation to a predicted values.
It's believed that glitches are connected with superfluid neutrons in the interior of NSs. One of the mechanisms, responsible for angular momentum exchange may be connected with vortices that are expected to exist in a superfluid condensate if the star rotates. Under some conditions vortices may be pinned on a crystalline lattice (or its imperfections) or superconducting flux-tubes in a core. Due to the difference of rotational velocity between the normal and the superfluid components, the Magnus force, acting on vortices may exceed the pinning force and an avalanche event can occur.

The aim of the present investigation is to simulate the propagation of vortices initially pinned and clustered together say in a crust using the multifluid conservative formalism [1]. The equations of motion and continuity equations may be simplified by considering two fluids - a charged and superfluid one. The charged fluid is strongly coupled to the electromagnetic field of the star. The superfluid component is a 1S0 neutron superfluid in the crust and 3P2 in the core. The final equations for the lag and fraction of pinned vortices are as follows: \begin{equation} \frac{\partial \Delta \Omega } {\partial t}=- \frac{\gamma \beta }{{x}{p}}\varpi \Delta \Omega \frac{\partial \Delta \Omega }{\partial \omega } - 2\omega \Delta \Omega \frac{\gamma \beta }{{x}{p}} (1) \end{equation} \begin{equation} \frac{\partial \gamma }{\partial t}=-\gamma \frac{\partial \gamma }{\partial \omega } (2) \end{equation} with $\Delta\Omega$ - the lag between two components, γ - the fraction of pinned vortexes, ω - cylindrical radius, β - a parameter, describing the local physics. It was established that an initially "flat" lag profile, physically representing a constant difference between the rotational frequency of two components, will relax to a minimum lag between the components in a point where vortices are pinned leading to a propagation of vortices in the outward direction possibly interacting with other vortices. Tracing these vortexes through a star will give one information about the total number of vortices that take part in this process and which are the favourable conditions for the formation of an avalanche.

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Horizon pressure from junction conditions for Schwarzschild and Rindler geometries

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We suggest a stress tensor is necessary on the event horizon of a Schwarzschild black hole or on the Rindler horizon for the Israel match- ing conditions to be satisfied. We found the surface energy density ρ_s is vanishing but the surface pressure p_s equals $1/16\pi l$ in both cases, where l is the proper distance from the horizon. The junction relations are applied both for r = const. and T = const. surfaces, with the same results for the surface quantities ρ_s and p_s. We emphasize the nonstatic feature of the spacetimes beyond the corresponding horizons.

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Properties of symbiotic X-ray binary GX 1+4

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We present unprecedented long optical light curve of the Symbiotic X-ray Binary GX 1+4 (V2116 Oph). This object represents small group of binaries containing red giant and the neutron star (7 objects confirmed). Our observations were made by OGLE IV project in I filter between July 8th 2010 and October 16th 2015 - total 1664 days. Optical light curve shows brightenings on every several dozen days (50-75 days). We interpret these brightenings as irregular pulsations of the red giant. Combination of X-ray and optical light curves reveal, that brightenings are almost simultaneous. This fact indicated, that we observe pulsating red giant, which control accretion rate in this binary system. The latter is responsible for brightenings in X-rays. Power spectrum analysis shows the period P = 1264±164 days, which confirms the orbital period obtained by Hinkle et al. (2006). Our 370±7 days periodicity is marginally consistent with the period obtained

by Pereira et al. (1999). We do not agree with interpretation of the latter period as the orbital period.

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Vortex buoyancy in superfluid and superconducting neutron stars

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Buoyancy of proton vortices is considered as one of the important mechanisms of magnetic field expulsion from the superconducting interiors of neutron stars. Here we show that the generally accepted expression for the buoyancy force is not correct and should be modified. The correct expression is derived for both neutron and proton vortices. It is argued that this force is already contained in the coarse-grained hydrodynamics of Bekarevich & Khalatnikov and its various multifluid extensions, but is absent in the hydrodynamics of Hall. Some potentially interesting buoyancy-related effects are briefly discussed.

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Supporting the existence of the QCD critical point by compact star observations

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In order to prove the existence of a critical end point (CEP) in the QCD phase diagram it is sufficient to demonstrate that at zero temperature $T = 0$ a first order phase transition exists as a function of the baryochemical potential μ, since it is established knowledge from ab-initio lattice QCD simulations that at $\mu = 0$ the transition on the temperature axis is a crossover.
We present the argument that the observation of a gap in the mass-radius relationship for compact stars which proves the existence of a so-called third family (aka "mass twins") will imply that the $T = 0$ equation of state of compact star matter exhibits a strong first order transition with a latent heat that satisfies $\Delta\epsilon/\epsilon_c > 0.6$. Since such a strong first order transition under compact star conditions will remain first order when going to symmetric matter, the observation of a disconnected branch (third family) of compact stars in the mass-radius diagram proves the existence of a CEP in QCD. Modeling of such compact star twins is based on a QCD motivated NJL quark model with high order interactions together with the hadronic DD2-MEV model fulfilling nuclear observables.
Furthermore we show results of a Bayesian analysis (BA) using disjunct M-R constraints for extracting probability measures for cold, dense matter equations of state. In particular this study reveals that measuring radii of the neutron star twins has the potential to support the existence of a first order phase transition for compact star matter.

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Mixing of charged and neutral Bose condensates at nonzero temperature and magnetic field

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It is expected that in the interior of compact stars a proton superconductor co- exists with and couples to a neutron superfluid. Starting from a field-theoretical model for two complex scalar fields – one of which is electrically charged – we derive a Ginzburg- Landau potential which includes entrainment between the two fluids and temperature ef- fects from thermal excitations of the two scalar fields and the gauge field. The Ginzburg- Landau description is then used for an analysis of the phase structure in the presence of an external magnetic field. In particular, we study the effect of the superfluid on the flux tube phase by computing the various critical magnetic fields and deriving an approximation for the flux tube interaction. As a result, we point out differences to the naive expecta- tions from an isolated superconductor, for instance the existence of a first-order flux tube onset, resulting in a more complicated phase structure including mixed phases in the region between type-I and type-II superconductivity.

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Modeling the X-ray variability of BH transients via Propfluc in the state transition

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The aim of this work is to test the condensation disk model by modeling the power spectrum of BH transients in their outburst rise and decay, using the PropFluc model which has never done before.
Outer and inner disk of Black Hole X-ray binaries are investigated in their outburst rise and decay in order to find the best model for hard state. Furthermore, state transition luminosities has also been calculated.
They key parameters of this model is truncation radius and inner radius of the flow. By observing the evolution of these parameters we can have an idea how disk and corona behave relative to each other.

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Neutron-drip transition in the crust of highly magnetised neutron stars

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The role of a high magnetic field on the neutron-drip transition marking the boundary between the outer and inner regions of the crust of a cold nonaccreting neutron star is studied. The equilibrium composition of the crust at the neutron-drip threshold is determined numerically for different magnetic field strengths using the Brussels-Montreal Hartree-Fock-Bogoliubov nuclear mass tables. As a result of the Landau quantization of electron motion, the neutron-drip transition is found to be shifted to either higher or lower densities depending on the magnetic field strength. These characteristic quantum oscillations are shown to be essentially universal and independent of the nuclear mass model employed. Numerical results and approximate analytical expressions valid in the strongly quantizing regime will be presented.

The crust-core transition and the stellar matter equation of state

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We calculate the stellar matter equation of state within two different frameworks: relativistic mean-field models and SU(2) extended Nambu–Jona-Lasinio models. For the RMF sets, the effect of the nonlinear $\omega\rho$ and $\sigma\rho$ coupling terms on the crust-core transition density and pressure, and on the macroscopic properties of some families of hadronic stars, is investigated. For that purpose, six families of relativistic mean field models, which differ in the symmetry energy behaviour, are considered. For the eNJL models, several parametrizations with different nuclear matter saturation properties are proposed. The effect on the star radius of the inclusion of a pasta calculation in the inner crust is discussed, for all the models considered. Stellar macroscopic properties are in accordance with some of the recent results in the literature.

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Exact Calculations for Effective Models of Cold Nuclear Matter

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Speaker: Péter Pósfay
Authors: P. Pósfay, G.G. Barnaföldi, A. Jakovác
Abstract:

We proposed a novel, more efficient technique to calculate the effect of quantum fluctuations using the Functional Renormalization Group (FRG) method at zero temperature and finite chemical potential. Within this framework we studied the effect of the running self interaction coupling in a simple model of Fermions coupled to a fluctuating scalar field. We calculated the phase diagram and the equation of state in this model, and compared the results to mean field and one-loop calculations [1]. We calculated the mass-radius relation for a static, spehrical symmetric compact star corresponding to our model, which was compared to other results as well. Here we present our results and the latest extended models from Refs. [1,2], on the effect of quantum fluctuations in neutron star mass and radii.

References:

[1] G.G. Barnafoldi, A. Jakovac and P. Posfay Phys.Rev. D95 (2017) no.2, 025004
[2] P. Posfay, G.G. Barnafoldi, and A. Jakovac The FRG Method as a Novel Technique for Calculating Superdense Nuclear Matter Equation of State in Compact Stars, (Submitted to PRC) arXiv:1610.03674 [hep-th]

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The effect of differential rotation on the maximum mass of strange quark stars

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Strange quark stars are considered as a possible alternative to neutron stars as compact objects. A hot compact star (a proto-neutron star or a strange star) born in a supernova explosion or a remnant of neutron stars binary merger are expected to rotate differentially. Rotating compact stars are considered as important sources of gravitational waves for Advanced Virgo/Ligo detectors. We present results of the first relativistic calculations of differentially rotating strange quark stars for broad ranges of degree of differential rotation and maximum densities, including all previously predicted types of solutions, and compare them with results for neutrons stars. Using a highly accurate, relativistic code we show that rotation may cause a significant increase of maximum allowed mass and can temporarily stabilise stars against prompt collapse into a black hole.

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Nuclear symmetry energy and properties of neutron stars

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Dense matter found in compact objects like neutron stars and supernovae is very neutron rich. Therefore, a correct description of the symmetry-energy contribution to the nuclear energy is of great importance.
We have studied the role of the symmetry energy on the neutron-drip transition and on the outer-crust composition in neutron stars. We have also studied the constraints on the symmetry energy obtained from both nuclear physics experiments (like mass measurements) and neutron-star observations. For these purposes, we have used a set of unified equations of state of cold dense matter, based on recent generalised Skyrme energy-density functionals from the Brussels-Montreal collaboration. We have also shown that, although some correlations between the properties of neutron stars at the neutron-drip transition and the symmetry energy coefficient J (or equivalently the slope of the symmetry energy L) are found, these correlations are radically different in nonaccreting and accreting neutron stars.

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Models of neutron stars with realistic EOS in a simple extended theory of gravity

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The well-known serious difficulties in numerical investigation of realistic models of neutron stars (NS) in the modified theories of gravity [1] are surmounted on a general basis. We present a review of the recent results of the authors [2-5] for realistic models of static spherically symmetric NS with AMP1, Sly, BSk19, BSk20 and BSk21 EOS using the correct boundary conditions at the center, at the edge and at the cosmological horizon of the de Sitter like Universe. The critical step is the introduction of new field variable for the scalar degree of freedom which we call "the dark scalar". The maximal mass or the NS turns to be around 2.2-2.7 solar masses and depends on the mass of the dark scalar. We present this dependence, as well as the influence of the dark scalar on the gravitational field inside the NS and its exponentially decreasing dark halo outside the star. The dark halo may give some 15 % of the total mass of the NS. The behavior of the

newly introduced pressure and mass density of the dark matter and dark energy are also studied and discussed. References:

1. E. Berti et al, Testing General Relativity with Present and Future Astrophysical Observations, TOPICAL REVIEW, Class.Quant. Grav. (2015); arXiv:1501.07274.
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Neutron star structure with chiral interactions

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Using two-nucleon and three-nucleon interactions derived in the framework of chiral perturbation theory (ChPT) with and without the explicit Δ isobar contributions, we calculate the energy per particle of symmetric nuclear matter and pure neutron matter employing the microscopic Brueckner–Hartree–Fock approach. In particular, we present nuclear matter calculations using the new fully local in coordinate-space two-nucleon interaction at the next-to-next-to-next-to-leading-order (N3LO) of ChPT with Δ isobar intermediate states (N3LOΔ) recently developed by M. Piarulli and collaborators. We compute the β-equilibrium equation of state and determine the neutron star mass-radius and mass-central density sequences. We find that the adopted interactions are able to provide satisfactory properties of nuclear matter at saturation density as well as to fulfill the limit of two-solar mass for the maximum mass configuration as required by recent observations.

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r-process nucleosynthesis from binary neutron star mergers

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The question of the origin of heavy elements has undergone a change in the last few years. Recent numerical simulations have demonstrated that binary neutron star mergers are the most likely progenitors of heavy elements in our galaxy instead of core-collapse supernova. This is due to a more neutron-rich environment that allows a more robust rapid neutron capture (r-process) nucleosynthesis. This change has also allowed for a multi-channel classification of ejecta to emerge: dynamical, neutrino driven wind, and viscous wind ejecta. Of these, the dynamical ejecta is the most amenable to numerical relativity simulations due to the shorter time scales. Furthermore, improved treatments of neutrino emission has improved the microphysics of the dynamical ejecta, which in turn provides a more robust environment for r-process nucleosynthesis. In this talk, we will discuss the dependence of the dynamical ejecta nucleosynthesis on the initial composition of the binary neutron star, such as equation of state, masses, and mass ratios.

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Accuracy of mass and radius determination of the neutron star in Athena and LOFT missions

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We present an accuracy of mass and radius determination of the neutron star for future Athena and LOFT missions, using our theoretical model atmosphere spectra. We simulated model X-ray spectra as seen by two detectors: WFI on board of Athena satellite and LAD on board of LOFT. Parameters of these spectra correspond to the compact star in a Type I X-ray bursters. We assumed for the neutron star $T_{eff} = 2.2 \times 10^7$ K, M = 1.64 $M_\odot$ and R = 11.95 km. Next we fitted our synthetic spectra by large grid of theoretical models with different parameters. In this manner we were able to reproduce assumed parameters with their errors. In case of LAD's spectrum these errors defined by 2-sigma confidence range are: M = $1.64^{+0.16}_{-0.02}\,M_\odot$ and R = $11.95^{+1.57}_{-0.4}$ km, whereas for WFI M = $1.64^{+0.13}_{-0.05}\,M_\odot$ and R = $11.95^{+0.64}_{-0.62}$ km. The errors for WFI are overestimated, because of too large step between subsequent parameters in our grid of models. Such very accurate mass and radius determination allow to constrain the equation of state of the dense matter.

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Determination of empirical parameters from nuclear observables using a model-independent unified Equation of State

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Neutron star properties crucially depend on the nuclear EoS (Equation of State), which is defined in terms of a set of empirical parameters (saturation density, compressibility, symmetry energy and its derivatives etc). In turn, these quantities are constrained through the comparison with experimental data on ground state nuclear properties. To achieve this, one requires a model that can describe both nuclear matter as well as finite nuclei within the same framework. The phenomenological models that are extensively employed in nuclear structure calculations have parameters that are fit to well determined empirical nuclear observables, and must be continuously updated with the improvement of experimental data. Further, they often introduce spurious correlations with the empirical quantities which are unphysical. In this work, we develop a model-independent unified description of nuclear matter, that can be related directly to empirical quantities specifically sensitive to the EoS. We then apply this model to study surface properties of finite nuclei and compare our results with well known experimental observables.

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Magnetars: physics and observations

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Soft gamma repeaters (SGRs) and anomalous X-ray pulsars (AXPs) are slowly-rotating, isolated neutron stars that sporadically undergo episodes of long-term flux enhancement (outbursts) generally accompanied by the emission of short X/gamma-ray bursts.
These peculiar X-ray sources are believed to be magnetars: ultra-magnetized neutron stars which emission is dominated by surface magnetic fields (with strenght often in excess of 1E14 G, i.e. well above the threshold at which QED effects become important).
Spectral analysis is an important tool in magnetar astrophysics since it can provide key information on the emission mechanisms. In this talk I will introduce the magnetar sources and their

phenomenology, from the quiescent emission to their spectacular bursting activity. I will review our interpretation of magnetar properties and discuss future perspectives in the field.

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Status of numerical relativity simulations of neutron stars

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I will review the rapid recent progress made in modelling these systems and show how the inspiral and merger of a binary system of neutron stars is more than a strong source of gravitational waves. Indeed, while the gravitational signal can provide tight constraints on the equation of state for matter at nuclear densities, the ejection of matter during the merger can shed light on the chemical enrichment of the universe.

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Long-lasting resistive, viscous MHD simulations of accretion disk around neutron star

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We performed long lasting resistive and viscous MHD simulations of a thin accretion disk around neutron star with magnetospheric outflow, capturing 500 rotations of the millisecond pulsar. We analyze the mass accretion flux and torques on the star from various components of the flow in the system.

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vBag - a bag model extension with non-perturbative corrections

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For studies of quark matter in astrophysical scenarios the thermodynamic bag model is commonly employed. Although successful, it does not account for dynamical chiral symmetry breaking and repulsions due to the vector interaction which is crucial to explain recent observations of massive, two solar mass neutron stars. We developed the novel vBag quark matter model which takes these effects into account and apply it at finite temperatures and isospin asymmetry. Another particular feature of vBag is the determination of the deconfinement bag constant Bdc from a given hadronic equation of state (EoS) in order to ensure that chiral and deconfinement transitions coincide. We discuss consequences of this novel approach for the phase transition construction and the phase diagram.

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Stellar electron capture rates on neutron-rich nuclei and their impact on core-collapse

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During the late stages of gravitational core-collapse of massive stars, extreme isospin asymmetries are reached within the core. Due to the lack of microscopic calculations of electron capture (EC) rates for all relevant nuclei, in general simple analytic parameterizations are employed. We study here several extensions of these parameterizations, allowing for a temperature, electron density and isospin dependence as well as for odd-even effects. The latter extra degrees of freedom considerably improve the agreement with large scale microscopic rate calculations. We find, in particular, that the isospin dependence leads to a significant reduction of the global EC rates during core collapse with respect to fiducial results, where rates optimized on calculations of stable fp-shell nuclei are used. Our results indicate that systematic microscopic calculations and experimental measurements in the $N \approx 50$ neutron rich region are desirable for realistic simulations of the core-collapse.

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X-ray observations as a probe of polar cap physics in pulsars

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The physics of the inner acceleration region in pulsars is yet another issue that is unresolved. The electron-positron pair plasma is polarised by the ultra-strong accelerating electric field. One species bombards the surface and heats the polar cap to MK temperatures, while the other one creates the secondary plasma in the magnetosphere. Thus, old cool pulsars should be detected in X-rays through thermal blackbody radiation from their hot polar cap, together with the nonthermal magnetospheric synchrotron radiation. We review the available X-ray data of old pulsars in order to characterize physical conditions at the polar caps of pulsars.

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Low-level accretion onto highly magnetized neutron stars

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In my talk I will consider the case of transient highly magnetized neutron stars accreting in a broad range of rates, focusing on their behaviour in the very end of the outbursts. At low mass accretion rates the centrifugal inhibition of the accretion (aka “propeller effect”, one of the most direct evidence of the ultra-strong magnetic field presented in the vicinity of the neutron stars) was discovered in a few systems. I will review observational manifestations of the propeller effect in X-ray pulsars with broad range of the magnetic fields from 10^8 to 10^14 G with main focus on our recent discoveries. In the second part of my talk I will introduce a model explaining the existence in some X-ray pulsars of an unexpected quasi-stable state characterized by the accretion rate of ∼10^14 – 10^15 g/s. We associate this state with the accretion from cold (non-ionised) disc with temperature below ∼6500 K. We argue that a transition to such accretion regime should be observed in all X-ray pulsars with certain combination of the rotation frequency and magnetic field strength. Moreover, the propeller effect should never be observed in such sources even for very low mass accretion rates.

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Electrical conductivity of a warm neutron star crust in magnetic fields

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We study the electrical conductivity of finite-temperature crust of a warm compact star which may be formed in the aftermath of a supernova explosion or a binary neutron star merger as well as when a cold neutron star is heated by accretion of material from a companion. We focus on the temperature-density regime where plasma is in the liquid state and, therefore, the conductivity is dominated by the electron scattering off correlated nuclei. The dynamical screening of this interaction is implemented in terms of the polarization tensor computed in the hard-thermal-loop effective field theory of QED plasma. The correlations of the background ionic component are accounted for via a structure factor derived from Monte Carlo simulations of one-component plasma. With this input we solve the Boltzmann kinetic equation in relaxation time approximation taking into account the anisotropy of transport due to the magnetic field. The electrical conductivity tensor is studied numerically as a function of temperature and density for carbon and iron nuclei as well as density-dependent composition of zero-temperature dense matter in weak equilibrium with electrons. We also provide accurate fit formulas to our numerical results as well as supplemental tables which can be used in dissipative magneto-hydrodynamics simulations of warm compact stars.

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Magnetically-driven failure of neutron-star crusts

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For many purposes, the crust of a neutron star is assumed to be strong enough to absorb any imposed stresses - either from the star's spindown or its evolving magnetic field. Equally, models of magnetar activity implicitly require the build-up and release of crustal stresses. Employing ideas from terrestrial elasticity, this talk will attempt to quantify when the crust can resist magnetic stresses, and when it fails. We derive a criterion for crustal failure due to an evolving magnetic field, and estimate the field strength required to induce plastic flow as a function of crustal depth. We speculate on the observational implications of crustal failure.

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Neutrino emissivity from the modified urca processes: nuclear correlations and kinematic effects

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The neutrino emissivity from both branches of the modified urca process (neutron and proton one) is calculated using nucleon-nucleon correlated state vectors to deal with nuclear correlation effects. This is done assuming the independent-pair approximation for nucleon quasiparticles. The realistic nuclear correlation functions are extracted from a modified extended version of the lowest-order constrained variational (LOCV) method in asymmetric nuclear matter in beta

equilibrium with electrons and muons that allows for three-body nucleon interactions and fits all semi-empirical saturation parameters of nuclear matter quite well. Two-body nucleon interaction is modelled by realistic Argonne AV18 potential and three-body potential is a phenomenological Urbana UIX type. Angular integrations in momentum space are performed numerically without recourse to widely used approximations. Limiting to the two-body forces only, we find that at fixed temperature, neutrino emissivity is a (weakly) decreasing function of density. However, inclusion of the modified three-body force effects changes this behaviour. We get different neutrino emissivity curves at densities higher than 2n0, obtained using different models all consistent with nuclear matter parameters at saturation density but predicting different results in superdense matter of neutron star core.

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General relativistic magnetohydrodynamic simulations of binary neutron star mergers forming a long-lived neutron star

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Recent observations indicate that in a large fraction of binary neutron star (BNS) mergers a long-lived neutron star (NS) may be formed rather than a black hole. Unambiguous electromagnetic (EM) signatures of such a scenario would strongly impact our knowledge on how short gamma-ray bursts (SGRBs) and their afterglow radiation are generated. Furthermore, such EM signals would have profound implications for multimessenger astronomy with joint EM and gravitational-wave (GW) observations of BNS mergers, which will soon become reality with the next science runs of the advanced LIGO/Virgo network of ground-based GW detectors. I will present recent BNS merger simulations involving long-lived NS remnants and discuss the results in the context of SGRBs and multimessenger astronomy.

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Magnetic field evolution in neutron stars

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The magnetic field in neutron stars evolves under the action of Ohmic dissipation, Hall drift and ambipolar diffusion. While Ohmic and Hall processes strongly influence the magneto-thermal evolution in the neutron star crust, ambipolar diffusion is expected to be relevant in the core. In this talk I will describe the recent developments of the magneto-thermal evolutions and discuss its physical implications.

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The Magnetic Field Profile in Strongly Magnetized Neutron Stars

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In this work, we report the first realistic calculation of the magnetic field profile for the microscopic description of matter inside strongly magnetized neutron stars. Unlike previous estimates, which are widely used in the literature, we find that magnetic fields increase relatively slowly with increasing baryon chemical potential (or baryon density) of magnetized matter. More precisely, the increase is polynomial instead of exponential, as previously assumed. Through the analysis of several different realistic models for the microscopic description of matter in the star (including

hadronic, hybrid and quark models) combined with general relativistic solutions endowed with a poloidal magnetic field obtained by solving Einstein-Maxwell's field equations in a self-consistent way, we generate a phenomenological fit for the magnetic field profile to be used as input in microscopic calculations.

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The freedom to choose neutron star magnetic field equilibria

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This talk addresses the following question: is one free to arbitrarily prescribe magnetic equilibria in neutron star models such that the fluid degrees of freedom can balance the equilibrium equations? We examine this question for various models for neutron star matter; from the simplest single-fluid barotrope to more realistic non-barotropic multifluid models with superfluid/superconducting components, muons and entropy. We do this for both axi- and non-axisymmetric equilibria, and in Newtonian gravity and general relativity. We show that, in axisymmetry, the most realistic model allows complete freedom in choosing a magnetic field equilibrium whereas non-axisymmetric equilibria are never completely arbitrary.

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Pulsar Magnetosphere: a New View from PIC Simulations

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Pulsar emission is produced by charged particles that are accelerated as they flow in the star's magnetosphere. The magnetosphere is populated by electrons and positrons while the physical conditions are characterized by the so called force-free regime. However, the magnetospheric plasma configuration is still unknown, besides some general features, which inhibits the understanding of the emission generation. Here we show the closest to force-free solution ever obtained with a particle-in-cell (PIC) code. The importance of obtaining a force-free solution with PIC is that we can understand how the different particle species support the corresponding magnetosphere structure. Moreover, some aspects of the emission generation are captured. These are the necessary steps to go toward a self consistent modeling of the magnetosphere, connecting the microphysics of the pair plasma to its macroscopic quantities. Understanding the pulsar magnetosphere is essential for interpreting the broad neutron star phenomenology (young pulsars, magnetars, millisecond pulsars, etc.). The study of these plasma physics processes is also crucial for putting limits on the ability of these objects to accelerate particles.

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Early evolution of newly born proto-neutron stars

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We evolve a proto-neutron star (PNS) with a nuclear many-body theory equation of state (EoS), for the first tens of seconds after the core bounce. In particular, we have determined the neutrino signal on terrestrial detectors and the frequencies of the gravitational waves due to stellar oscillations. We also determine the time variation of the rotation rate and the neutrino angular momentum loss of the PNS with the GM3 mean-field EoS, and determine the corresponding gravitational wave signal due to rotation as the PNS contracts. We find that the mass shedding limit restricts the initial angular momentum and consequently the final rotation rate must be smaller than about 300 Hz for a PNS of about 1.6 solar masses. These results are obtained using a new code we have developed which describes the PNS evolution. This code integrates the neutrino number and energy transport equations together with the relativistic stellar structure equations by iteration. The neutrino cross sections are determined consistently with the underlying EoS. To include the many-body EoS in the evolution, we have find and tested a new fitting formula for the interacting part of the baryon free-energy, valid at finite temperature.

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Formation of Double Neutron Star Systems

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In recent years, the discovery rate of double neutron star (DNS) systems has increased rapidly and the coming decade will greatly enhance the number of both radio pulsar DNS systems, with the completion of the Square-Kilometre-Array, and DNS mergers from detections of high-frequency gravitational waves using LIGO. This calls for a new investigation of the formation and evolution of DNS systems. In this talk, I will summarise the exotic journey of binary stars leading to the production of DNS systems and discuss correlations between spin period (of the first-formed, mildly recycled NS), orbital period and eccentricity, based on theoretical modelling. Finally, I will discuss NS kicks and present a large set of Monte Carlo simulations of the second SN in order to extrapolate the pre-SN stellar properties and probe the explosions.

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Binary Neutron Star Mergers: Effects of Magnetic Fields in the Post-Merger Evolution

Mr. ENDRIZZI, Andrea[1]

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I will present results from recent general relativistic magnetohydrodynamic simulations performed by our numerical relativity group in Trento. We investigated the effects of magnetic fields on binary neutron star (BNS) mergers, and in particular on their gravitational wave (GW) and electromagnetic (EM) emission. In the first part I will describe simulations of "high-mass" systems that collapse promptly into a black hole (BH) surrounded by an accretion disk. I will discuss in particular their correlation with the short Gamma Ray Bursts (sGRB) standard scenario, which requires the launch of a relativistic jet during the post-merger phase of the evolution. In the second part of my talk, I will instead discuss "low-mass" binaries, that result into long-lived remnants, namely supramassive neutron stars (SMNS). I will show the results we obtained regarding the magnetic field evolution throughout all our models and comment on similarities and differences between our and other groups simulations.

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Searches for Gravitational Waves Associated with Gamma-Ray Bursts in the Advanced Detector Era

Dr. PANNARALE, Francesco[1]

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Gamma-ray bursts are the most luminous electromagnetic events in the universe. They fall into two, broad categories: long-duration ($\geq$2 s) bursts, which are powered by the core collapse of rapidly rotating massive stars, and short-duration ($\leq$2 s) bursts, for which binary neutron star and neutron star-black hole mergers are the leading progenitor candidates. In both scenarios, gravitational waves are expected to accompany the gamma-ray burst, making these transient phenomena promising events for gravitational-wave follow-up. I will review the status of targeted searches for gravitational waves in association with gamma-ray bursts and I will present the results of these searches obtained during the first Advanced LIGO observing run, which was carried out between September 2015 and January 2016.

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The Origin of heavy elements – the puzzle at low metallicity

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The production of heavy elements beyond iron in the universe poses sever challenges to our current understanding of explosive cosmic events. In particular during the early evolution of the galaxy are explosions of massive stars the major site, if not the only one. Even though the heaviest elements with mass number up to A˜195 are robustly produced in neutron star mergers, associated with the main component of the r process, they can have no contribution to the chemical enrichment of the galaxy at vanishing metallicity. It leaves massive star explosions as only site, for which I will review in this talk our current picture of the associated nucleosynthesis, which canonically yields the production of light neutron-capture elements with atomic numbers only up to $32<Z<50$. It emphasizes the puzzle of the observed r-process enrichment of metal-poor stars, simultaneously pointing to few rare events associated with massive star explosions that enriched the galaxy with r–process elements at low metallicity. Their origin and nature is yet to be discovered.

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Weak reactions in binary neutron Star mergers: status and challenges

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Binary neutron star mergers produce copious amounts of neutrinos, due to the high densities and temperatures that characterize the coalescence and its aftermath. The inclusion of weak reactions in sophisticated hydrodynamical simulation is a crucial step to accurately model the merger and to robustly predict all the relevant observables, including gravitational waves, relativistic jets and electromagnetic transients. In this talk, I will discuss the present status of the modeling of weak reactions in numerical models of binary mergers, showing some of the many ways in which neutrinos can influence the system dynamics and the ejecta properties. After that, I will critically discuss the uncertainties, the challenges and the future strategies to sharpen our understanding of the role of weak reactions and its implications for the multi-messenger detection of compact binary mergers.

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"Follow the cosmic chirps and roars: characterising gravitational wave and electromagnetic compact object mergers”

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Dense QCD - A lattice perspective

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Magnetic fields in neutron stars: from radio pulsars to magnetars

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Neutron star magnetic fields

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Asteroseismology and gravitational wave afterglow of binary neutron star merger remnants

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We will focus on the gravitational wave afterglow of supramassive neutron stars formed after binary neutron star mergers. These objects are extremely massive and rotating close to their Kepler limit and that is why they are prone to secular instabilities that can lead to the emission of strong gravitational radiation. An important question we will address is how to relate the neutron star parameters, such as mass, radius and rotational rate, to the observed gravitational wave frequencies. The proper choice of such relations can help us constrain the neutron star models and thus the equation of state when gravitational waves by oscillating neutron stars are observed in the future.

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Towards the first coincident detection of gamma ray bursts and gravitational waves from binary neutron star mergers

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With the discovery of the first gravitational waves (GWs) from a binary black hole merger in 2015, it is expected that the first neutron star mergers will be detected by aLIGO in the next observation runs. Significantly, the discovery of short gamma ray bursts by satellite detectors could be the smoking gun for the existence of binary neutron star mergers. This has yet to be proven, and coincident GW and electromagnetic (EM) observations will provide unequivocal proof of this association, and offer a unique probe of the physics of compact object mergers from the dynamic strong gravity regime, through to the relativistic gamma-ray emission and optical/radio afterglow. This new era of multi-messenger transient source astronomy poses particularly daunting challenges for EM follow-up, such as the large GW error boxes, and optimising (matching) telescope facilities to specific search strategies. This presentation highlights key issues that need to be addressed to obtain a first coincident EM and GW observation of a binary neutron star merger.

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Can we Measure the Effect of Compactified Extra Dimension by a Gravitational Wave Detectors?

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Recently we have explored the properties of an interacting fermionic compact star in a 1+4 dimensional Kaluza–Klein-like spacetime, where an extra microscopical spacelike dimension was introduced. This theory led us to check gravitational theories beyond the post-Newtonian case. Here, we present whether we would be able to measure the effect of these extra dimensions by gravitational wave detectors in the future.

2

Dynamics of spinning bodies in GR

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I present a new formulation of the gravitational dynamics of compact objects with intrinsic angular momentum and its application to extreme mass-ratio binary stars. It is shown how to obtain constants of motion, and this is applied to get exact expressions for the energy and angular momentum of spinning bodies on circular orbits in spherically symmetric space-times. I develop a perturbative treatment for non-circular orbits and obtain precise results for the radius of the last stable circular orbit for spinning bodies. Finally I present a modification of the dynamics to include gravitational Stern-Gerlach type interactions.

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Ultraluminous X-ray sources - a new channel of pulsar formation

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The discovery of three pulsars in ultra-luminous X-ray sources (ULXs), changes the paradigm of ULXs and reveals a new channel of neutron star spin-up. Much of the phenomenology of the the three sources, as reported e.g. for NuSTAR J095551+6940.8, and M82 P13, can be understood in terms of a model (published recently with King and Lasota) of a superEddington accretion disk and a run-of-the-mill neutron star. However, the extremely high spin-up rates observed in these sources suggest that some ULXs may be progenitors of millisecond pulsars. On the other hand, given the extremely high inferred mass transfer rate from the binary companion, some ULX pulsars may be on their way to gravitational collapse.

3

Entropy-limited hydrodynamics: a novel approach to relativistic hydrodynamics

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We present entropy-limited hydrodynamics (ELH): a new approach for the computation of numerical fluxes arising in the discretization of hyperbolic equations in conservation form. ELH is based on the hybridisation of an unfiltered high-order scheme with the first-order Lax-Friedrichs method. The activation of the low-order part of the scheme is driven by a measure of the locally generated entropy inspired by the artificial-viscosity method proposed by Guermond et al. Here, we present ELH in the context of high-order finite-differencing methods and of the equations of general-relativistic hydrodynamics. We study the performance of ELH in a series of classical astrophysical tests in general relativity involving isolated, rotating and nonrotating neutron stars, and including a case of gravitational collapse to black hole. We present a detailed comparison of ELH with the fifth-order monotonicity preserving method MP5, one of the most common high-order schemes currently employed in numerical-relativity simulations. We find that ELH achieves comparable and, in many cases, better accuracy than more traditional methods at a fraction of the computational cost. Given its accuracy and its simplicity of implementation, ELH is a promising framework for the development of new special- and general-relativistic hydrodynamics codes well adapted for massively parallel supercomputers.

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A curious case of 4U 1700-37

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4U 1700-37 is an eclipsing High Mass X-ray binary in a short orbital period of 3.412 days. In the absence of detectable pulsations, the orbital evolution is determined from the eclipse timing measurements, both from archival measurements as well as new measurements from long-term light curves obtained with the all sky monitors RXTE-ASM, Swift-BAT and MAXI-GSC. The orbital period decay rate of the system is estimated to be 10^{−7} /yr, smaller compared to its previous estimates. The mid-eclipse times and the eclipse duration measurements obtained from 10 years long X-ray light curve with Swift-BAT are used to separately put constraints on the eccentricity of the binary system and measure any apsidal motion. We carry out a deepest search for pulsations and Cyclotron Resonance Scattering Feature (CRSF) using a 40 kilosec ASTROSAT LAXPC observation. We also investigate the orbital parameters of the system by the

radial velocity measurements of the optical companion star HD 153919 with a SALT observation. These results will provide some newer insights into the nature of the compact object, which is either a very high mass neutron star or a very low mass black hole.

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Role of correlations on spin-polarized neutron matter

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Using the Hellmann–Feynman theorem we analyze the contribution of the different terms of the nucleon-nucleon interaction to the spin symmetry energy of neutron matter. The analysis is performed within the microscopic Brueckner–Hartree–Fock approach using the Argonne V18 realistic potential plus the Urbana IX three-body force. The main contribution to the spin-symmetry energy of neutron matter comes from the S=0 channel, acting only in the non-polarized neutron matter, in particular the $^1S_0$ and the $^1D_2$ partial waves. By evaluating the kinetic energy difference between the correlated system and the underlying Fermi sea to estimate the importance of correlations in spin-polarized neutron matter, we conclude that non-polarized neutron matter is more correlated than totally polarized one.

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Advances in our understanding of the free-precession candidate PSR B1828-11

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The quasi-periodic modulations of PSR B1828-11 provide a way to probe the physics of neutron stars. In this talk, I will outline the recent advancements we have made in understanding these modulations as evidence of precession, their utility in placing constraints on the mutual friction coupling, and the surprising discovery that the period of the modulations is getting shorter.

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Gravitational collapse to a Kerr-Newman black hole

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We present a systematic study of the gravitational collapse of rotating and magnetised neutron stars to charged and rotating (Kerr-Newman) black holes. In particular, we consider the collapse of magnetised and rotating neutron stars assuming that no pair-creation takes place and that the charge density in the magnetosphere is so low that the stellar exterior can be described as an electrovacuum. Under these assumptions, which are rather reasonable for a pulsar that has crossed the "death line", we show that when the star is rotating, it acquires a net initial electrical charge, which is then trapped inside the apparent horizon of the newly formed back hole. We analyse a number of different quantities to validate that the black hole produced is indeed a Kerr-Newman one and show that, in the absence of rotation or magnetic field, the end result of the collapse is a Schwarzschild or Kerr black hole, respectively. We discuss possible association with fast radio bursts.

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Hydrodynamic instabilities in dissipative two-fluid systems

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I will discuss relativistic two-fluid systems in the presence of a counterflow between them. Energetic and dynamic instabilities occur at certain critical velocities, and I will show how energetic instabilities can be turned into dynamic ones by dissipation. The results can be applied to two-fluid systems in compact stars, possibly playing a role in the mechanism for pulsar glitches, or, in their non-relativistic limit, to laboratory systems of ultracold atomic gases. I will also point out an instructive analogy of certain modes in two-fluid systems to r-modes and their instability.

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Holographic quark matter and neutron stars

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I will discuss recent developments in the description of strongly interacting quark matter using holographic methods. In particular, I demonstrate that contrary to standard lore, it is possible to construct asymptotically AdS geometries, corresponding to strongly coupled field theories with UV fixed points, where the speed of sound exceeds the conformal value of 1/Sqrt[3]. I shall further argue that although related to theories different from QCD, such calculations can shed important light on the properties of strongly interacting quark matter exactly in the density region that remains inaccessible for both nuclear physics and perturbative QCD methods.

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GRRMHD simulations of super-Eddington accretion onto a hard surface

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We perform general relativistic radiation magnetohydrodynamic simulations of super-Eddington accretion flows onto a hard surface. We attempt to mimic the effect of accretion onto a neutron star by forcing the gas to reach zero or near zero velocity as it reaches the surface. We measure the effects on outflows, luminosity, efficiency, and other quantities as compared to that of a black hole accretion disk with the same accretion rate. We draw comparisons to observations of ultra-luminous X-ray sources, some of which have already been shown to originate from accreting neutron stars.

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Fast radio bursts from collapsing neutron stars

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Fast Radio Bursts are short emissions of extragalactic origin with an energy of $\sim 10^{38-40}$ erg. Although several theoretical models exist, the exact mechanism of their production is still unknown. This talk investigates the possibility of modelling Fast Radio Bursts with the gravitational collapse of magnetised neutron stars through resistive general relativistic magnetohydrodynamic (GRMHD) simulations. The electromagnetic emission is studied using several initial neutron star models with rotation periods ranging from $1.5 - 100$ ms and it is shown that the emitted electromagnetic energy exhibits a maximum for the dimensionless spin parameter $J/M^2 \approx 0.17$. This is then contrasted with the energy emitted in gravitational waves.

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Bright X-ray pulsars and ultraluminous X-ray sources

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X-ray pulsars (XRPs) form special class in family of accreting NSs. They stand out from the other classes due to their strong magnetic field, which typically exceed 10^{12} G and affects even fundamental properties of matter. Magnetic field funnels the accretion flow and the gravitational energy of matter is released in the form of X-rays coming from the compact area on the NS surface. Resent discoveries of pulsations from ultra-luminous X-ray sources - ULXs - have open a new chapter in studies of XRPs. The discovery of pulsations from ULXs shows that some of these sources are powered by accreting NSs. It is a challenge for modern astrophysics. I will discuss the basic properties of bright X-ray pulsars and features which become essential at extreme mass accretion rate: accretion columns and optically thick envelopes around ULXs powered by accreating NSs.

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High-mass twin stars with a multi-polytrope EoS

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We show that in the 3-polytropes model of Hebeler et al. [1] for the neutron star equation of state at supersaturation densities a third family of compact stars can be obtained which confirms the possibility of high-mass twin stars [2] that have coincident masses M1 = M2 ˜ 2 M and significantly di fferent radii |R1 - R2| > 2 - 3 km. We consider a scenario of a first order phase transition which eliminates one of the three polytropes from the star structure and results in a sharp boundary between a high-density and low-density phase. We review other, microscopic hybrid equation of state models that describe high-mass twin stars and discuss their characteristics [3].

[1] K. Hebeler, J. M. Lattimer, C. J. Pethick and A. Schwenk, Astrophys. J. 773, 11 (2013).
[2] S. Benic, D. Blaschke, D. E. Alvarez-Castillo, T. Fischer and S. Typel, Astron. Astrophys. 577, A40 (2015).
[3] D. Alvarez-Castillo, S. Benic, D. Blaschke, S. Han and S. Typel, Eur. Phys. J. A 52, no. 8, 232 (2016).

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Pulsars probe the low-frequency gravitational sky: Pulsar Timing Arrays

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Pulsars are invaluable laboratories to test gravity theories. The aim of Pulsar Timing Array (PTA) experiments is to exploit the clock-like behaviour of an array of carefully selected millisecond pulsars to detect gravitational waves at low frequencies. In the last decade, three PTA experiments were started. These three experiments, based on the most sensitive radiotelescopes in the world, developed detection algorithms and refined the timing precision pushing the sensitivity of PTAs lower and lower. Although no gravitational wave detection has been made to date, the future perspectives are more than exciting thanks to new, futuristic radiotelescopes coming online in the next years, such as the Five hundred Aperture Spherical Telescope and, in particular, the Square Kilometre Array.

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Neutron stars in the laboratory

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Neutron stars are nature's own extreme physics laboratories, allowing us to probe aspects that cannot be tested on Earth. The connection with nuclear physics, both theory and experiment, is well established. The overlap with low-temperature physics less so. Yet, we know that issues involving superfluidity/superconductivity (are likely to) play key roles for neutron star phenomenology. In this talk, I will provide a survey of recent developments in low-temperature physics experiments, with particular focus on results that may progress our understanding of neutron stars.

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Constraints on the equation of state at nuclear saturation density and below

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The equation of state (EoS) for astrophysical applications describes the properties of strongly interacting matter at extreme conditions of baryon number density, temperature and isospin asymmetry. Phenomenological models for the EoS can be constrained with experimental data from nuclear structure physics, heavy-ion collisions, ab-initio nuclear theory and astrophysical observations. In this contribution, constraints that apply to densities at and below nuclear saturation are reviewed.

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Constraints on the equation of state of dense matter from experiments and observations

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Constraints on the equation of state set by experiments, observations and theoretical calculations above saturation density or at finite temperatures, including new degrees of freedom such as hyperons, kaons, quarks and possible phase transitions will be discussed.

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Nonlinear Inter-glitch Dynamics and the Braking Index of the Vela Pulsar

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Determination of the braking index characterizing the external torque of a pulsar requires taking account of the effects of internal torques as glitches and inter-glitch relaxation in particular. The inter-glitch timing behaviour of the Vela pulsar is characterised by recovery at constant second derivative of the rotation rate correlating with glitch properties. This behaviour takes over after the early post-glitch linear response, i.e. exponential relaxation, is over, and extends to the next glitch. The vortex creep model explains the second derivatives and the steps in terms of the nonlinear response of the creep process to offsets introduced by the glitch. We present inter-glitch timing fits with constant second derivatives to the present sample covering 16 large glitches. Part of the step in spin-down rate in each Vela glitch may involve a "persistent shift", which does not relax back, as observed in the Crab pulsar's glitches. Modifying the expression for the time between glitches with this hypothesis leads to better agreement with the observed inter-glitch time intervals of the Vela pulsar. We extrapolate the inter-glitch model fits to obtain spin-down rates just prior to each glitch, and use these to calculate the braking index $n = 2.81$.

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Unitary Gas Constraints on Nuclear Symmetry Energy

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We argue that the ground state energy per particle in the unitary gas, i.e. the gas of fermions interacting via pairwise s-wave interactions with an infinite scattering length, provides the lower bound of the energy per nucleon in pure neutron matter. This suggests a lower bound on the volume symmetry energy parameter S0. We demonstrate that values of S0 above this minimum imply upper and lower bounds on the symmetry energy parameter L describing its lowest-order density dependence. The bounds are found to be consistent with both recent calculations of the energies of pure neutron matter and constraints from nuclear experiments. However, many equations of state in active use for simulations of nuclear structure, heavy ion collisions, supernovae, neutron star mergers, and neutron star structure violate these constraints.

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Superfluid density functional theory as a source of microscopic input for pulsar glitch models

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Pulsar glitches, sudden jumps in rotation period, are regarded as macroscopic manifestation of superfluid dynamics on the microscopic scale. Despite of considerable theoretical effort, accurate large scale models of this phenomena still awaits for implementation. These effective models (typically based on multifluid hydrodynamics) require microscopic input from underlying theory. As an example of microscopic input, that is crucial for any standard glitch model, one can list vortex-nucleus interaction or vortex tension coefficient. In my talk, I will demonstrate that the valuable microscopic information can be extracted from the approach based on time-dependent density functional theory. As example I show fully microscopic real time evolution of the quantized vortex in presence of nuclear impurity immersed in the neutron matter background. I will discuss also how the microscopic information can be transfered to the large scale models of the neutron start glitch.

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Role of differential rotation in the evolution of CFS-unstable neutron stars

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I analyze CFS instability of rapidly rotating relativistic stars within the multipolar expansion for gravitational radiation by Thorne (1980). It allows to derive evolution equations for a star, affected by CFS instability, without appeal to the canonical energy formalism by Friedman & Schutz (1978) and analyze the effects of differential rotation, which can be associated with development of CFS instability [e.g., Levin & Ushomirsky (2001), Friedman et al. (2016)]. I argue that the latter effects are not important for a long-term evolution (when spin frequency changes significantly) and obtain a simple equation describing spin evolution of the star on a long timescale. This equation, applicable at arbitrary spin rate, describes stellar evolution along the sequence of thermally equilibrium states and has no explicit dependence on the instability growing timescale. In contrast, on a short timescale differential rotation can affect the observed spin frequency. I analyze this possibility, taking r-mode instability in slowly rotating Newtonian stellar models as an example and demonstrate that the equations governing evolution of the *observed* spin frequency can differ from the widely accepted equations by Owen et al. (1998) and Ho & Lai (2000). Namely, emission of gravitational waves directly affects the observed spin frequency [but not through dissipation of r-modes], in line with the arguments of Levin & Ushomirsky (2001). This difference does not influence long-term evolution, but can be important on a short timescales, provided that the r-mode amplitude is varied strongly and rapidly. I discuss the possibility to observe this effect.

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Equation of State for Neutron Stars with Mass and Radius Constraints

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We obtain a new equation of state for the nucleonic and hyperonic core of neutron stars that fulfills the 2 Msun observations as well as the recent determinations of radii below 13 km. The nucleonic equation of state is obtained from a new parametrization of the FSU2 functional that satisfies these latest astrophysical constraints as well as reproduces the properties of nuclear matter and

finite nuclei while fulfilling the restrictions imposed by heavy-ion collisions on high-dense matter. By a slight modification of the parametrization, we also find that the constraints of 2 Msun with radii around 13 km are satisfied when hyperons are considered. In particular, hyperonic magnetars with magnetic fields in the surface of ˜10^{15} G and with values of ˜10^{18} G in the interior can reach maximum masses of 2 Msun with radii in the 11-13 km range.
Laura Tolos, Mario Centelles and Angels Ramos, Astrophys.J. 834 (2017) no.1, 3

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The appearance of non-spherical systems. Application to LMXB

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We study the appearance of the neutron star - accretion disk system as seen by a distant observer in the UV/X-ray domain. The observed intensity spectra are computed assuming non-spherical geometry of the whole system, in which outgoing spectrum is not represented by the flux spectrum, the latter being valid for spherically symmetric objects. Intensity spectra of our model display double bumps in UV/X-ray energy domains. Such structure is caused by the fact that the the source is not spherically symmetric, and the proper integration of intensity over emitted area is needed to reproduce observed spectral shape. Relative normalization of double bump is self consistently computed by our model. X-ray spectra of such a type were often observed in LMXB with accretion disk, ultra luminous X-ray sources, and accreting black hole systems with hot inner compact corona. Our model naturally explains high energy broadening of the disk spectrum observed in some binaries. We attempted to fit our model to X-ray data of XTE˜J1709-267 from {\it XMM-Newton}. Unfortunately, the double intensity bump predicted by our model for LMXB is located in soft X-ray domain, uncovered by existing data for this source.

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Light dark matter scattering in outer neutron star crusts

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We calculate for the first time the phonon excitation rate in the outer crust of a neutron star due to scattering from light dark matter (LDM) particles gravitationally boosted into the star. We consider dark matter particles in the sub-GeV mass range scattering off a periodic array of nuclei through an effective scalar-vector interaction with nucleons.We find that LDM effects cause a modification of the net number of phonons in the lattice as compared to the standard thermal result. In addition, we estimate the contribution of LDM to the ion-ion thermal conductivity in the outer crust and find that it can be significantly enhanced at large densities. Our results imply that for magnetized neutron stars the LDM-enhanced global conductivity in the outer crust will tend to reduce the anisotropic heat conduction between perpendicular and parallel directions to the magnetic field.

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Constraints on pulsar masses from large gltiches

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Pulsar glitches, sudden jumps in frequency in otherwise steadily spinning down pulsars, offer a glimpse into the superfluid interior of neutron stars. We propose a method to estimate the mass of glitching pulsars, using observations of the maximum glitch observed in a star, together with state of the art microphysical models of the pinning interaction between superfluid vortices and ions in the crust. By using a simplified but consistent model (detailed here) for the angular momentum reservoir of pinned vorticity we find a general inverse relation between size of the maximum glitch and the pulsar mass. This procedure procedure will allow current and future observations of glitching pulsars to constrain the physics of glitch models and pinning forces.

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MHD simulations of oscillating cusp-filling tori around neutron stars

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We performed axisymmetric, grid-based, ideal magnetohydrodynamic (MHD) simulations of oscillating cusp-filling tori orbiting a non-rotating neutron star. A pseudo-Newtonian potential was used to construct the constant angular momentum tori in equilibrium. The inner edge of the torus is terminated by a "cusp" in the effective potential. The motion of the torus was perturbed by uniform diagonal and vertical velocity fields. As the configuration evolved in time, we measured the mass accretion rate ($\dot{M}$) on the surface of neutron star and obtained the power spectrum of $\dot{M}$. The prominent mode of oscillation in the cusp torus is the radial epicyclic mode. We infer that the mass accretion rate carries a modulation imprint of the oscillating torus from our analysis. Our results may be of interest in the context of quasi-periodic oscillations (QPOs) observed in low mass X-ray binaries (LMXBs). The astronomy satellite ASTROSAT is expected to provide better opportunities to investigate the neutron star QPOs, and results of our simulations may be of immediate astronomical significance.

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Spontaneous scalarization of neutron stars in the unconstrained parameter regime of Scalar-Tensor theories

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We use numerical simulations to study the evolution of neutron stars in the context of scalar-tensor theories of gravity, in the yet unconstrained parameter regime of $\beta_0 > 0$, where β_0 measures the linear effective coupling between the scalar field and regular matter. We focus on initial data corresponding to equilibrium configurations with unstable scalar modes, and investigate the nonlinear development of this instability for some representative coupling functions with $\beta_0 > 0$. We find that, contrary to the well-understood $\beta_0 < 0$ case, the final state of the instability is highly sensitive to the details of the coupling function, varying from gravitational collapse to spontaneous scalarization. In particular, this is the first demonstration of spontaneous scalarization in the case of $\beta_0 > 0$, which could unveil novel astrophysical tests for this theories.

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Rotating neutron stars in massive scalar-tensor theories and universal relations

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In the scalar-tensor theories with a massive scalar field the coupling constants, and the coupling functions in general, which are observationally allowed, can differ significantly from those in the massless case. This fact naturally implies that the scalar-tensor neutron stars with a massive scalar field can have rather different structure and properties in comparison with their counterparts in the massless case and in general relativity. In the talk we will present rotating neutron stars in scalar-tensor theories with a massive gravitational scalar. It turns out that mass, radius and moment of inertia for neutron stars in massive scalar-tensor theories can differ drastically from the pure GR solutions if sufficiently large masses of the scalar field are considered. The universal relations between the normalized moment of inertia and quadrupole moment are also investigated both for the slowly and rapidly rotating cases. The results show that these relations are still EOS independent up to a large extend and the deviations from pure general relativity can be large. This places the massive scalar-tensor theories amongst the few alternative theories of gravity that can be tested via the universal I-Love-Q relations.

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Puzzles from the Old Story: Glitches with External Torque Variation

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Glitches provide with us unique opportunity to probe into neutron star internal structure. In general, glitches are explained in terms of a two component model with dominant contribution is resulting from neutron superfluid within the crust. However, in recent years there is growing evidence that glitches from magnetars, high magnetic field pulsars and in some cases canonical radio pulsars are accompanied by bursting activity and in particular strong variations in the observed spin-down rates, on observational timescales, indicating time dependent variability in the external torque as well as increased timing noise. In this work, we assess the contribution of external torque variation to glitches and provide the relative importance of external torque to internal superfluid torques in some special cases.

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The glitch-dominated rotation of PSR J0537-6910

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Rotational glitches, i.e. sudden spin-ups of a neutron star, are thought to be a manifestation of the internal superfluid dynamics. Testing theoretical glitch models against observations is crucial to extract information about the star's interior, and the X-ray pulsar J0537-6910 is an ideal test source for this, since it demonstrates large glitches more frequently than any other pulsar. Because of its high glitching rate, the rotation of PSR J0537-6910 is dominated by the glitch events and their recovery. This results in a rather unusual spin-down evolution characterised by a well-defined negative braking index.

We analysed all 12 years of RXTE data for this pulsar and identified a total of 45 glitches. Inferred glitch parameters are sensitive to the measuring method one uses and in the case of this pulsar the discrepancies can be significant, mostly due to the small inter-glitch time intervals. For this reason we used representative fake datasets to test several measuring techniques before adopting the most reliable one to consistently derive the spin and glitch parameters. In this talk, I will discuss the methods used, the properties of the resulting glitch set and the possible constraints they imply for the basic ingredients of the glitch mechanism.

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Spectral representation of nonperturbative quark propagators

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We consider a fermion propagator possessing a spectral representation enabling positivity violation of spectral densities. In such a case there is no Källén–Lehmann representation, whereby the corresponding states cannot appear in the spectrum of physical particles. This is very suitable for representing quark propagators in the nonperturbative regime of QCD, where confinement is essential. Phenomenological consequences of this propagator are investigated for the lightest quark-antiquark composites - the charged and neutral pions. This representation of fermion propagators is applicable also at finite densities.

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Partial accretion regime of rotating magnetized objects

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The inner parts of the disks around magnetized objects such as neutron stars may become geometrically thick due to inhibition of accretion at the disk mid-plane when the central object is rotating rapidly. In such a case matter inflowing through the disk may keep accreting onto the poles of the magnetized object from the parts of the disk away from the disk mid-plane while the matter is propelled at the disk mid-plane. An important ingredient of the evolution of magnetized objects is then the fraction of the inflowing matter that can accrete onto the poles in the fast rotation regime depending on the fastness parameter, the rotation rate of the object in units of Keplerian rotation rate at the inner radius of the disk. I will present analytical solutions that represent disks with partial accretion and argue that this “soft” propeller regime may be associated with the rapid decay stage observed in the light curves of several accreting millisecond pulsars.