56th Karpacz Winter School in Theoretical Physics 2020

Students' talks

Thomas Celora

The effect of non-linear mutual friction on pulsar glitch sizes and rise times

Observations of pulsar glitches have the potential to provide constraints on the dynamics of the high-density interior of neutron stars. However, to do so, realistic glitch models must be constructed and compared to the data. In this paper, we take a step towards this goal by testing non-linear models for the mutual friction force, which is thought to be responsible for the exchange of angular momentum between the neutron superfluid and observable normal component in a glitch. In particular, we consider the full non-linear dependence of the drag force on the relative velocity between superfluid vortices and the normal component, in which the contributions of both kelvin and phonon excitations are included. We find that our model produces qualitatively new features and that we are able to reproduce the observed bimodal distribution of glitch sizes in the pulsar population. The model also suggests that the differences in size distributions in individual pulsars may be due to the glitches being triggered in regions with different pinning strengths, as stronger pinning leads to higher vortex velocities and a qualitatively different mutual friction coupling with respect to the weak pinning case. Glitches in pulsars that appear to glitch quasi-periodically with similar sizes may thus be due to the same mechanisms as smaller events in pulsars that have no preferred glitch size but simply originate in stronger pinning regions, possibly in the core of the star.

Geraint Evans

Magnetic flux tubes in colour-superconducting quark matter

I will give a report on an ongoing project regarding magnetic defects in 2SC and CFL quark matter, including effects of a non-zero strange quark mass. By constructing the phase diagram in the presence of an external magnetic field, I will discuss critical magnetic fields and identify the type-II regime, which contains flux tubes and is possibly realised in the interior of compact stars.

Lorenzo Gavassino

Universality of the relativistic correction to glitch rise-times

Despite its importance in determining the interior structure of neutron stars has been universally acknowledged, Einstein's theory of General Relativity has been up to now mostly neglected in the study of pulsar glitches. Its inclusion into the existing Newtonian models seems to be too expensive, compared to the moderate qualitative gain in accuracy and comprehension it gives. However, as the resolution of pulsar timing techniques increases, it will be soon important to be able to isolate the relativistic contributions to the glitch amplitude and rise-time, for a reliable quantitative comparison with observations. We will present, here, a simple universal formula for the relativistic correction to the glitch rise-time, given as a pure function of the compactness of the neutron star. It has been derived directly from Carter's multifluid hydrodynamics and can be easily employed to correct, a posteriori, any Newtonian estimation for the coupling time scale, without any computational expense.

Davide De Grandis

The effects of localized heating in the crust of a neutron star

In neutron stars, the magnetic field is believed to be mostly confined into the crust. Its topology strongly influences the surface temperature distribution, and hence the star observational properties. In this contribution, I will present some of the first simulations of the coupled crustal magneto-thermal evolution in three dimensions. In particular, I will discuss how the crust reacts to episodes of localised energy injection. This directly bears to the evolution of outbursts in magnetars, as well as to the surface temperature map of rotation powered pulsars. Simulations show that the surface temperature distribution can have non-trivial patterns, as a consequence of the driving of transport properties by the magnetic field. A remarkable result is that the hottest region on the star surface may drift while cooling.

Arus Harutyunyan

Bulk viscosity of dense baryonic matter in neutron star mergers

We study bulk viscosity arising from weak interaction processes in dense baryonic matter for temperature-density range relevant to neutron star mergers. We consider two compositions of baryonic matter: a) pure nucleonic matter, where the main source of bulk viscosity are weak current direct Urca processes – neutron decay and electron capture; b) hypernuclear matter, where the bulk viscosity arises from non-leptonic weak interaction processes involving Λ and Σ hyperons. We model the nuclear matter in relativistic density functional approach, taking into account the trapped neutrino component. We find that the resonant maximum of bulk viscosity would occur below the neutrino trapping temperature, therefore, in the neutrino trapped regime the bulk viscosity decreases with temperature as T^{-2} , this decrease being interrupted by a drop to zero at a special temperature (for fixed density) where the neutron fraction becomes density-independent and the material scale-invariant. We further investigate the oscillation damping timescales by bulk viscosity of a post-merger object and identify regimes where these timescales are comparable to the merging timescales $\sim$10 ms.

Fatemeh Kayanikhoo
Structure properties of strange quark stars

Like white dwarfs, neutron stars, and black holes, strange quark stars (SQS) are compact objects, created at the end of the life of the massive stars. The SQS is made up of strange quark matter. We usually consider two kinds of stars as SQS: Hybrid stars (the neutron stars with the quark core) and pure strange quark stars.
I am investigating the structure of pure magnetized SQS. I have used the MIT bag model to calculate the equation of state of SQM and calculated the maximum gravitational mass and the radius of SQS using TOV equations.

Andrew Kozhberov
Elastic properties of crystals in neutron stars crust

Elastic properties play an important role in neutron stars and white dwarfs. They are crucial for modeling stellar oscillations and different processes in magnetars and in degenerate stars which enter compact binary systems. Using electrostatic energy of deformed lattices, we calculate elastic moduli of different one-component and binary lattices. We also study screening corrections and discuss
stability of crystals.

Hao-Jui Kuan
Inverse-Chirp Imprint of Gravitational Wave Signals in Scalar Tensor Theory

The scalar tensor theory contains a coupling function, which is constrained to have the equivalence between the Jordan and Einstein frames. We simulate the supernovae core collapse with different choices of coupling functions defined over the viable region of the parameter space and find that a generic inverse-chirp feature of the gravitational waves in the scalar tensor scenario.

Swagata Mallik
Unified modelling for intermediate energy heavy ion reaction and supernova matter

Based on the similarity of several thermodynamic conditions, heavy ion reactions at intermediate energies are very important for extrapolating nuclear properties of supernova matter. A grand canonical model for intermediate energy heavy ion reaction [1, 2] is extended to study the properties of stellar matter and nuclear equation of state at high temperature and sub-saturation densities. In this model, cluster functional from simple liquid drop formula is replaced by recent metamodelling equation of state [3] and consistent mean field for free nucleon gas is introduced. Preliminary results of different observables related to free nucleon gas and clusters for different baryonic densities, temperatures and proton fractions will be discussed.

[1] C. B. Das, S. Das Gupta et. al. Phys. Rep. 406, 1 (2005)
[2] S. Mallik and G. Chaudhuri, Phys. Lett. B 718, 189 (2012)
[3] J. Margueron, R. H. Casali and F. Gulminelli, Phys. Rev. C 97, 025805 (2018)

Michal Marczenko

The role of repulsive quark-vector interactions in the phenomenology of neutron stars

We extend the recently developed hybrid quark-meson-nucleon (QMN) model by augmenting a vector-isoscalar and vector-isovector coupling to quarks and investigate the consequences for neutron-star sequences in their mass-radius profiles. The model has a unique feature that the chiral symmetry is restored within the hadronic phase by lifting the mass splitting between chiral partner states, before the deconfinement to quark matter takes place, leaving the two transitions well separated. We investigate the role of repulsive vector interactions among the quarks and explore whether or not quark deconfinement may occur in high-mass neutron stars.

Alessandro Montoli

Crust and core contributions in overshooting pulsar glitches

During a pulsar glitch the angular velocity of the neutron star may overshoot, namely reach values greater than that of the new post-glitch equilibrium. Fitting the data of the 2016 glitch of the Vela pulsar, it is possible to obtain estimates for the moments of inertia of the internal superfluid components involved in the glitch. Preliminary results imply a reservoir of angular momentum extending beyond the crust. The talk will be based on: https://arxiv.org/abs/1910.00066

Yuliya Mutafchieva

Magnetic field influence on magnetar crusts – a unified description of the crust

Magnetars – a class of neutron stars associated with ultra-strong magnetic fields, offer unique possibilities to study matter under extreme conditions that cannot be reproduced in the laboratory. We have studied the effects of the magnetic field on the equilibrium properties of magnetar crusts. We have determined the composition and equation of state of the outer and inner crust for a wide range of magnetic-field strengths. Both regions of the crust were treated consistently within the framework of the nuclear-energy density functional theory using functionals that were precision-fitted to theoretical and experimental data.

Valeriya Mykhaylova
Quark-flavor dependence of the transport parameters of the quark-gluon plasma

We study the quark-flavor dependence of the shear and bulk viscosities, as well as electrical conductivity, calculated in the relaxation time approximation combined with the quasiparticle model. The dynamical masses of the QGP constituents carry a non-trivial temperature dependence encoded in the effective coupling extracted from the lattice simulations for pure SU(3) theory and for QCD with 2+1 quark flavors.

Duncan Neill
Investigating resonant shattering flares by modelling the vibrational modes within neutron stars
Neutron star mergers are thought to be the progenitors of short gamma ray bursts (SGRBs). However, some time before main SGRB a smaller 'precursor' burst is sometimes detected. These precursor bursts may be caused by a resonance between the orbit of the binary stars and their vibrational modes depositing a large amount of energy into the crust, causing it to shatter. In particular the interface mode between the core and crust of the neutron star is a candidate for resonant excitation. In my project I aim to calculate the frequency of the interface mode for various equations of state and use this to model resonant shattering flares.

Daniel Pęcak
Modeling superfluidity in neutron stars with Brussels-Montreal functionals

We use microscopic description to provide a solid underpinning of the so-called vortex filament model, the mesoscopic approach used to model vortex dynamics in neutron star crust. From fully microscopic simulations, employing Time-Dependent Density Functional Theory (TDDFT), it is possible to extract various parameters of the filament model, including vortex-impurity interactions and dissipation coefficients. For microscopic TDDFT calculations, we use BSk type energy density functional, which is a very accurate nuclear functional designed to agree with existing astrophysical constraints. Using this state-of-the-art functional we try to narrow down the range of values of parameters of VFM which may also affect, in principle, the parameter space of hydrodynamical models. Here, I will present the properties of a vortex in superfluid neutron matter.

Violetta Sagun
Dark matter effect on the neutron star properties

We study an impact of asymmetric dark matter on properties of the neutron stars and their ability to reach the two solar masses limit, which allows us to present a new upper constraint on the mass of dark matter particle. Our analysis is based on the observational fact of existence of three pulsars reaching this limit and on the theoretically predicted reduction of the neutron star maximal mass caused by accumulation of dark matter in its interior. Using modern data on spatial distribution of baryon and dark matter in the Milky Way we found out an upper constraint on the mass of dark matter particles. We also demonstrate that light dark matter particles with masses below 0.2 GeV can create an extended halo around the neutron star leading not to decrease, but to increase of its visible gravitational mass. Furthermore, we predict that high precision measurements of the neutron stars maximal mass near the Galactic center, will put a stringent constraint on the mass of the dark matter particle. This last result is particularly important to prepare ongoing, and future radio and X-ray surveys.

Nikolay Shchechilin

The crust of accreting neutron stars within simplified reaction network

abstract: Transiently accreting neutron stars in low mass X-ray binaries are generally believed to be heated up by nuclear reactions in accreted matter during hydrostatic compression. Detailed modeling of these reactions is required for the correct interpretation of observations. We construct a simplified reaction network, which can be easily implemented and depends mainly on atomic mass tables as nuclear physics input. We show that it reproduces the results of the detailed network by Lau et al. (2018, ApJ, 859, 62) very well if one applies the same mass model. However, the composition and the heating power are shown to be sensitive to the mass table used and treatment of mass tables boundary, if one applies several of them in one simulation. In particular, the impurity parameter Qimp at density ρ=2×10^12 g cm^–3 can differ for a factor of few, and even increase with density increase. The profile of integrated heat release shown to be well confined between results by Fantina et al. (2018, A&A, 620, 19) and Lau et al. (2018, ApJ, 859, 62). Detailed analysis of results allows us to reveal a hint of inconsistency in implicit assumptions, which are traditionally applied in models of accreted crust.

Aurélien Pascal

Modeling the cooling phase of young proto-neutron stars

The modelisation of protoneutron stars cooling is still a computational challenge due to the very different physical processes and timescales at stake, such as acoustic oscillations, hydrodynamic convection, neutrino transport and Kelvin-Helmholtz contraction. In order to deal efficiently with these various timescales, we need to use a set of consistent approximations such as a quasi-stationary hydrodynamics, a stationary radiation transfert and find a way to model the convective motion without being limited by the acoustic timescale.
In this talk I will make a brief review of previous works focused on PNS cooling. Then I will introduce the model that I am developing and the current state of my work.

Allard Valentin

Entrainment effects in neutron-proton mixtures within the nuclear energy-density functional theory (at low-temperature limit)

Mutual entrainment effects in cold neutron-proton mixtures are studied in the framework of the self-consistent nuclear energy-density functional theory. Exact expressions for the mass currents, valid for both **homogeneous** and inhomogeneous systems, can be directly derived from the time-dependent Hartree-Fock equations with no further approximation. Focusing on neutron-star cores, a convenient and simple analytical formulation of the entrainment matrix in terms of the isovector effective mass is found, thus allowing one to relate entrainment phenomena in neutron stars to isovector giant dipole resonances in finite nuclei. Results obtained with different functionals are presented. These include the Brussels-Montreal functionals, for which unified equations of state of neutron stars have been recently calculated.