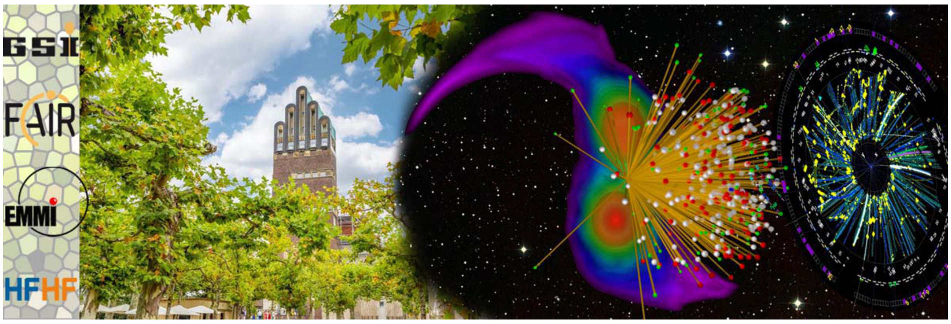
NuSym23, XIth International Symposium on Nuclear Symmetry Energy

Montag, 18. September 2023 - Freitag, 22. September 2023

GSI Darmstadt, Germany



Buch der Abstracts

Contents

Nuclear Symmetry Energy from Quantum Skyrmion Crystals 1

Equation-of-state studies with CBM (perspectives) and RHIC data 1

Systematic analysis of the impacts of symmetry energy parameters on neutron star properties 1

Studying the effects of the symmetry energy in hybrid stars 2

New Equation of State for Supernova and Binary Neutron Star Merger Simulations . . . 2

Astro multi-messenger, theory of compact stars, bayesian analysis 3

Bayesian inference of dense matter equation of state. Simplified covariant density functionals model. 3

Production of nuclei via correlated decay of nuclear sources in local equilibrium 3

Systematics of the dipole polarizability 4

Effects and relevance of off-shell transport 5

HADES data benchmarking with PHQMD and other models 5

Experimental investigation of cluster production at Fermi energies in excited light systems 5

Plans for symmetry energy research in INDRA-FAZIA 6

Overview of heavy-ion collisions program at FRIB 6

Dense matter within relativistic Hartree-Fock approaches 6

Nuclear equation-of-state studies with INDRA-FAZIA: status and perspectives 7

Extracting the nuclear equation-of-state from heavy ion collisions with transport simulations 7

Equation of state of nuclear matter from collective flows in intermediate energy heavy-ion collisions 8

Box study with momentum-dependent mean fields and threshold effects 9

In-medium Δ related cross sections 9

Combining nuclear physics and multi-messenger observations 9

Perspectives with SMASH 10

Direct comparisons of isospin diffusion measurements with transport models at Fermi energies 10

Extracting the high-density symmetry energy with pion and subthreshold hyperon production in heavy-ion collisions 10

Nuclear equation-of-state and nuclei in core-collapse supernovae 11

Order-by-order convergence of chiral nuclear forces in neutron matter (online) 11

Tidal heating as a direct probe of Strangeness inside Neutron stars 11

Nuclear models based on energy density functional for astrophysics applications 12

Current status of NICER's measurements of the neutron star masses and radii (online) . 13

Dynamics of cluster production in heavy-ion collisions 13

Nuclear EOS for arbitrary proton fraction and temperature based on chiral EFT and a Gaussian Process Emulator 14

Nuclear theory 14

Status and future scientific program of RAON 14

Impact of the momentum dependence of the neutron and proton potentials on pion production in heavy-ion collisions 15

Neutron stars to finite nuclei : A direct mapping 15

Flow phenomena at high nuclear densities with HADES 16

How meson crossing terms reconcile the recent observational data. 16

Robust universal relations in neutron star asteroseismology 17

Directed and elliptic flow observations in Sn+Sn collisions with radioactive beams at 270 MeV/u 17

Constraining the nuclear equation of state using Coulomb excitation of neutron-rich tin isotopes 18

Toward a quantitative evaluation of the nuclear equation of state 18

Equation-of-state studies with HADES (perspectives) 19

Heavy-ion collisions 19

Constraining the Equation of State of Nuclear Matter (Overview) 19

What are true ab initio calculations of neutron-rich matter? 20

Nuclear symmetry energy and neutron stars 20

Towards constraints on the Equation of State with SMASH 20

Searching for isospin drift sites in heavy dissipative nuclear systems 21

Probing neutron stars with resonant shattering flares and gravitational waves 21

Inferring the symmetry energy by combining nuclear and astrophysical data using a consistent model of nuclear matter 22

Neutron stars: probing ultra dense (and hot) matter (online) 22

When and where are clusters formed in expanding systems? (online) 23

What If the Nuclear Symmetry Energy is Larger than Expected? 23

Implications of CREX and PREX for energy density functionals 24

Constraining Neutron-Star Matter with Microscopic and Macroscopic Collisions 24

Precise Measurement of Total Interaction Cross Sections of 12C+12C with R3B 25

Bayesian inference of the dense matter equation of state built within mean field models . 25

Self-energy of pion and its impact on equation of state 26

Nuclear equation-of-state in neutron star mergers 26

Extreme matter with gravitational wave observations 27

Binary Neutron Stars: from macroscopic collisions to microphysics 27

The symmetry energy from ground and excited state properties of atomic nuclei 28

ASY-EOS II –observable and expectations 28

The Symmetry Energy: Current Status of Ab Initio Predictions vs. Empirical Constraints 28

Impact of symmetry energy on heavy baryon formation in neutron stars 29

Nuclear pastas in neutron stars: role of the symmetry energy 29

Multi-messenger astrophysics and the nuclear symmetry energy (online) 30

The equation of state of symmetric nuclear matter from heavy-ion collisions 30

Transport models of heavy-ion collisions 30

Neutrino emission in (proto-)neutron star matter 31

The Nuclear Equation of State from Experiments and Astronomical Observations 31

Using Multimessenger Observations of Neutron Star Mergers to Probe Symmetry Energy 32

Nuclear structure, short-range correlations 32

Future facilities and experiments 32

Nuclear symmetry energy from isobar collisions at RHIC 32

Kinetic approach of light-nuclei production in intermediate-energy heavy-ion collisions 33

Nuclear matter and neutron stars from the relativistic Brueckner-Hartree-Fock theory in the full Dirac space . . . 33

Nuclear equation-of-state studies with the compact spectrometer for heavy-ion experiment (CSHINE) . . . 34

Transport Model Evaluation Project (TMEP): Status and Future Directions . . . 34

Studies of nuclear equation of state with the HIRFL-CSR external target experiment (CEE) 35

Probing neutron skin with free spectator nucleons in ultracentral relativistic heavy-ion collisions . . . 35

Recent progress of nuclear matter EOS and cluster studies via direct nuclear reactions (online) . . . 36

Impact of Symmetry Energy on Sound Speed and Spinodal Decomposition in Dense Neutron-Rich Matter . . . 36

Refinements of the transport models and the constraints on symmetry energy . . . 37

KRAB detector for the ASY-EOS II experiment . . . 37

Microscopic calculations of neutron-rich, dense nuclear matter / 12

Nuclear Symmetry Energy from Quantum Skyrmion Crystals

Autor Christoph Adam[1]

[1] *University of Santiago de Compostela and IGFAE*

Korrespondenzautor: christoph.adam@usc.es

Recently, quite significant progress has been made in the description of nuclear matter and, in particular, its symmetry energy, at sufficiently high densities using skyrmion crystals and their semiclassical quantization. We briefly review these recent results and describe the challenges which still must be mastered in order to establish the Skyrme model framework as a reliable tool for the description of nuclear matter at intermediate and high densities.

Investigations at existing and future accelerator facilities and detectors / 77

Equation-of-state studies with CBM (perspectives) and RHIC data

Autor Kshitij Agarwal[1]

[1] *Eberhard Karls Universität Tübingen(UT-PIT)*

Korrespondenzautor: kshitij.agarwal@uni-tuebingen.de

The investigation of the nuclear equation of state (EoS) has been fundamental to the exploration of the QCD phase diagram at non-zero baryonic densities. This has garnered multi-messenger interest from nuclear theory, astrophysics, and heavy-ion collisions, especially due to its potential synergy with astrophysical objects and events, such as binary neutron mergers. At densities greater than twice the nuclear saturation density ($\rho > 2\rho_{sat}$), the nuclear EoS is primarily constrained by astrophysical observations. Therefore, heavy-ion collisions at corresponding energies ($E_{beam} \approx 2 - 10$ AGeV), accessible at the currently operating Relativistic Heavy Ion Collider (RHIC) and forthcoming Facility for Antiproton and Ion Research (FAIR), offer a complementary source to study the nuclear EoS. This contribution will talk about the EoS perspectives with the flagship heavy-ion collision experiments at aforementioned facilities, namely the Solenoidal Tracker at RHIC (STAR) and Compressed Baryonic Matter (CBM) at FAIR.

Combined analysis of nuclear and astrophysics information, Bayesian approach, and machine learning / 34

Systematic analysis of the impacts of symmetry energy parameters on neutron star properties

Autoren Bijay Kumar Agrawal[1]; N Patra[2]; A Venneti[3]; SK. Adil Imam[None]; A Mukherjee[None]

[1] *Saha Institute of Nuclear Physics*

[2] *BITS -Pilani Goa Campus*

[3] *BITS-Pilani Hyderabad*

Korrespondenzautor: bijay.agrawal@saha.ac.in

The impacts of various symmetry energy parameters on the properties of neutron stars have been recently investigated, and the outcomes are at variance. Results obtained from systematic analysis

of the correlations of slope and curvature parameters of symmetry energy at the saturation density with the tidal deformability and stellar radius of non-spinning neutron stars in the mass range of 1.2–1.6M⊙ will be discussed.

Theory of supernovae and neutron stars / 15

Studying the effects of the symmetry energy in hybrid stars

Autor David Alvarez Castillo[1]

[1] *Institute of Nuclear Physics Polish Academy of Sciences*

Korrespondenzautor: dalvarez@ifj.edu.pl

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

Poster flash talks / 78

New Equation of State for Supernova and Binary Neutron Star Merger Simulations

Autoren Debades Bandyopadhyay[1]; TUHIN MALIK[2]; Sarmistha Banik[3]

[1] *Aliah University*

[2] *CFisUC, Department of Physics, University of Coimbra, 3004-516 Coimbra, Portugal*

[3] *BITS Pilani, Hyderabad, India*

Korrespondenzautor: debades.bandyopadhyay@saha.ac.in

Recently, we constructed a new equation of state (EoS) table including the Bose-Einstein condensate of negatively charged kaons for core collapse supernova and binary neutron star merger simulations. The nuclear statistical equilibrium model including excluded volume effects was used to describe the matter below the saturation density whereas the uniform matter composed of neutrons, protons, electrons and K^- condensate at higher densities was treated in the relativistic hadron field theory with density dependent couplings. The equation of state table was generated for a wide range of density (10^{-12} to ~ 1 fm^{-3}), positive charge fraction (0.01 to 0.60) and temperature (0.1 to 158.48 MeV). As soon as the threshold condition of the Bose-Einstein condensate was reached, electrons were replaced by the negatively charged kaons in the condensate. The impact of antikaon condensate was investigated on different thermodynamic quantities. The charge neutral and beta-equilibrated matter with the condensate made the EoS softer compared to that without the condensate resulting in the reduction of the maximum neutron star mass but it was above the 2 solar mass benchmark. This softening in the EoS might be attributed to the equal number of neutrons and protons after the appearance of the condensate. This implies zero symmetry energy contribution in the EoS. It would be worth investigating the impacts of the antikaon condensate on the evolution of core collapse supernovae

and binary neutron star mergers particularly on the
ejected matter and nucleosynthesis in binary neutron mergers.

International long-range plan round-table / 83

Astro multi-messenger, theory of compact stars, bayesian analysis

Korrespondenzautoren: j.margueron@ip2i.in2p3.fr, diet.tim@gmail.com, a.bauswein@gsi.de

Poster flash talks / 41

Bayesian inference of dense matter equation of state. Simplified covariant density functionals model.

Autoren Mikhail Beznogov[1]; Adriana R. Raduta[2]

[1] *National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)*

[2] *IFIN-HH, Bucharest*

Korrespondenzautor: mikhail.beznogov@nipne.ro

A simplified version of the density dependent covariant density functional model is employed in a Bayesian analysis to determine the equation of state (EOS) of dense matter. Various constraints from nuclear physics; ab initio calculations of pure neutron matter (PNM); a lower bound on the maximum mass of neutron stars (NSs) are imposed in the order to investigate the effectiveness of their progressive incorporation as well as their compatibility. We demonstrate the importance of the constraints on PNM and show explicitly that correlations among parameters of nuclear matter and properties of NSs are model and setup dependent. Only nucleonic degrees of freedom are considered.

Constraints from heavy-ion collisions at Fermi energies / 19

Production of nuclei via correlated decay of nuclear sources in local equilibrium

Autor Alexander Botvina[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Korrespondenzautor: a.botvina@gsi.de

The statistical approaches were previously successfully applied
for the description of the disintegration of excited nuclear sources.
Such single sources in equilibrium with the temperature around
6-8 MeV (also with smaller temperatures) can be produced both
from spectator residues in peripheral collisions of nuclei and
after the fusion of nuclei in central collisions at Fermi energy.
We generalize this approach [1,2] and demonstrate that the new
conception of local equilibrium can be used to explain the
fragment formation in quickly expanding nuclear matter under
very high excitation energy. In this case we consider the matter

subdivided into several excited clusters. For the first time our approach is able to describe consistently the FOPI experimental data measured in central collisions, in particular, yields and kinetic energies of nuclei, and the modification of the nuclear isotope yields with increasing the beam energy. In peripheral collisions of Fermi energy we are able to explain [3] the projectile-like and neck-like fragment emission (in FAZIA experiment) by separating two local sources in the reaction. Relation to the symmetry energy during the statistical fragment formation is discussed. We have obtained the limitation on the temperature of such local sources which determines the statistical nucleation process.

[1] A.S. Botvina, et al., Phys. Rev. C103, 064602 (2021).

[2] A.S. Botvina, et al., Phys. Rev. C106, 014607 (2022).

[3] R. Ogul, et al., Phys. Rev. C107, 054606 (2023).

Nuclear structure, short-range correlations and direct reactions / 48

Systematics of the dipole polarizability

Autoren Isabelle Brandherm[1]; Peter von Neumann-Cosel[1]; Atsushi Tamii[2]

Co-Autoren: Gianluca Colò [3]; Tobias Klaus [1]; Hiroaki Matsubara [2]; Norbert Pietralla [1]; Paul-Gerhard Reinhard [4]; Xavier Roca-Maza [5]

[1] *Technische Universität Darmstadt*

[2] *Research Center for Nuclear Physics, Osaka University, Japan*

[3] *Dipartimento di Fisica, Università degli Studi di Milano, Italy*

[4] *Institut für Theoretische Physik, Universität Erlangen, Germany*

[5] *Dipartimento di Fisica, Università degli Studi di Milano, Italy*

Korrespondenzautor: ibrandherm@ikp.tu-darmstadt.de

The electric dipole polarizability is a key observable for the understanding of nuclear matter. Strong correlations between the neutron skin thickness, the dipole polarizability and the parameters of the symmetry energy term in the equation of state of neutron rich matter have been found within the framework of energy density functional theory [1].
The polarizability is experimentally accessible by a measurement of the full electric dipole strength distribution of atomic nuclei. A well suited technique for this purpose is inelastic proton scattering at relativistic velocities. At extreme forward angles Coulomb excitation dominates over the nuclear interaction. Such experimental conditions can be realized at the Research Center for Nuclear Physics in Osaka, Japan. There, the dipole response of various nuclei has been explored in the last decade. The scattered protons were measured with the Grand Raiden (GR) magnetic spectrometer, which can be placed at extreme forward angles up to 0° [3]. Measured spectra are deconvoluted into the contributions of different multipolarities by performing a multipole decomposition analysis based on DWBA calculations [2].
In this talk new results on the dipole polarizability of ^{58}Ni and ^{90}Zr will be presented. Also the now available systematics of the dipole polarizability will be discussed: from light and medium-mass to heavy nuclei [4,5,6,7,8,9].

[1] P.-G. Reinhard and W. Nazarewicz, Phys. Rev. C 81, 051303(R) (2010)
[2] P. von Neumann-Cosel and A. Tamii, Eur. Phys. J. A55, 110 (2019)
[3] A. Tamii et al., Nucl. Instrum. Meth. A 605, 326 (2009)
[4] A. Tamii et al., Phys. Rev. Lett. 107, 062505 (2011)
[5] J. Birkhan et al., Phys. Rev. Lett. 118, 252501 (2017)
[6] S. Bassauer et al., Phys. Lett. B 810, 135804 (2020)
[7] R. Fearick et al., Phys. Rev. Res. 5, L022044 (2023)

[8] J. Ahrens et al., Nucl. Phys. A 251, 79 (1975)
[9] D. M. Rossi et al., Phys. Rev. Lett. 111, 242503 (2013)

Supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) –Project-ID 279384907, SFB 1245.

Transport model simulations of heavy-ion reactions / 64

Effects and relevance of off-shell transport

Autor Elena Bratkovskaya[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Korrespondenzautor: e.bratkovskaya@gsi.de

The heavy-ion experimental program at SIS and the future FAIR facility explore nuclear matter at extreme conditions of large densities and temperatures where according to many-body theory a strong modification of hadron properties occurs. An understanding of the properties of strongly-interacting hadronic and partonic matter - created in heavy-ion collisions - from a microscopic point of view is a challenging task. This requires to go beyond the semi-classical BUU and QMD type of approaches, which are based on on-shell degrees-of-freedom, and to employ the off-shell transport theory based on Kadanoff-Baym equations, which allow to also propagate broad states with spectral functions that change their properties dynamically according to the environment.
We discuss the basic ideas of such an off-shell microscopic transport approach - Parton-Hadron-String Dynamics (PHSD) - and illustrate the importance of off-shell dynamics by some examples. We also show the impact on observables for the description of vector mesons - via dilepton decay spectra - as well as for strange degrees of freedom such as anti-kaons and phi-mesons.

Transport Model Evaluation Project / 91

HADES data benchmarking with PHQMD and other models

Korrespondenzautor: e.bratkovskaya@gsi.de

Constraints from heavy-ion collisions at Fermi energies / 24

Experimental investigation of cluster production at Fermi energies in excited light systems

Autor Alberto Camaiani[1]

[1] *INFN Sez. Firenze*

Korrespondenzautor: alberto.camaiani@fi.infn.it

Four different reactions, ^{32}S+^{12}C and ^{20}Ne+^{12}C at 25 and 50 MeV/nucleon, have been measured with the FAZIA detector, isotopically resolving the systems. Events have been well classified and fragment properties have been compared with AMD simulation coupled with the HFl afterburner, dedicated to light nuclei de-excitation. Here we report on a first comparison, shown in C. Frosin et al. PRC 107, 044614 (2023), where we obtained an explicit confirmation of the role of cluster aggregation in the reaction dynamics. Moving from this point, preliminary results on a second Bayesian analysis

will be also presented, to link the clusterization probability to other key parameters, such as the in-medium nucleon-nucleon cross-section.

Investigations at existing and future accelerator facilities and detectors / 58

Plans for symmetry energy research in INDRA-FAZIA

Autor Giovanni Casini[1]

[1] *INFN Firenze*

Korrespondenzautor: casini@fi.infn.it

Since 2020 the FAZIA detector performs experiment at GANIL coupled with the large acceptance INDRA array. This combined detector for charged reaction products represents one of the most advanced tools to study the details of the reaction mechanisms at the Fermi energies, with special attention to the role of the symmetry energy term of the EOS. The combinations of beams and energies available at GANIL or at similar facilities allow to mainly investigate systems formed at high temperatures and at relatively low densities. The experimental and theoretical community investigating the EOS is recently focussing the interest on suprasaturation densities, achievable with beam energies above 100AMeV, where the EOS parameters are much less constrained and the experimental data are relatively scarce. In the talk I will shortly present the mid-term programs of the FAZIA-INDRA collaboration towards possible experiments at higher beam energy facilities as RAON and FRIB.

Investigations at existing and future accelerator facilities and detectors / 80

Overview of heavy-ion collisions program at FRIB

Autor Zbigniew Chajecki[1]

[1] *Western Michigan University*

Korrespondenzautor: zbigniew.chajecki@wmich.edu

The equation of state (EOS) is a fundamental property of nuclear matter, important for studying the structure of systems as diverse as the atomic nucleus and neutron stars. Understanding the physics of neutron stars is becoming even more important recently because of the observation of gravitational waves from the neutron star merger. Nuclear reactions involving heavy-ion collisions in the laboratories can produce the nuclear matter similar to those contained in neutron stars and allow the exploration of the equation of state of nuclear matters over a wide range of densities and temperatures. The current status of the experimental constraints and future prospects from the experiments at FRIB will be presented.

Poster flash talks / 31

Dense matter within relativistic Hartree-Fock approaches

Autoren Mohamad Chamseddine[1]; Guy Chanfray[2]; Jerome Margueron[2]; Hubert Hansen[2]; Rahul Somasundaram[3]

[1] *IP2I-Lyon*

[2] *IP2I*

[3] *Syracuse U. and Los Alamos Natl. Lab.*

Korrespondenzautor: m.chamseddine@ip2i.in2p3.fr

In this talk, I will address the question of the understanding of dense matter from a model incorporating properties from quantum chromodynamics (QCD). QCD is a fundamental theory that poses challenges when applied to low-energy nuclear physics, such as finite nuclei and neutron star matter, due to its non-perturbative nature. While solving QCD numerically on a lattice is possible, it currently lacks the capability to handle large finite densities.
I am developing a model which captures some important aspects of the fundamental theory. I will present a relativistic mean field approach that incorporates two key features of low-energy QCD: chiral symmetry breaking and color confinement. I will show that by including effects beyond the simplest Hartree mean field, e.g. Fock terms, nucleon finite size and short range effects via the Jastrow ansatz, the model predictions get closer to the empirical properties of dense matter around saturation density. The value of the spin-isospin parameter g'is also improved. In this way, I will show that considering a Lagrangian with nucleons and interactions fields, the careful treatment of many-body terms provides a satisfying approach.

Constraints from heavy-ion collisions at Fermi energies / 56

Nuclear equation-of-state studies with INDRA-FAZIA: status and perspectives

Autor Caterina Ciampi[1]

[1] *GANIL*

Korrespondenzautor: caterina.ciampi@fi.infn.it

In the framework of heavy ion collisions, isospin transport phenomena can be used as a tool to gather information on the properties of nuclear matter far from equilibrium conditions. The INDRA-FAZIA apparatus, operating in GANIL, is particularly well suited to investigate such kind of phenomena; it exploits the best characteristics of FAZIA (covering the forward polar angles and providing isotopic identification also for heavy quasiprojectile-like fragments) and INDRA (providing a large angular coverage).

In this talk, the most recent results from the INDRA-FAZIA apparatus will be presented, with a special focus on its first experiment, carried out in 2019. Coherent indications of the isospin transport effects have been obtained by studying the neutron content of both light and heavy fragments belonging to the quasiprojectile phase space. The setup performance also allowed an in-depth analysis of the quasiprojectile breakup channel, leading to novel results that add valuable information for a comprehensive view of such process: AMD calculations have been used to extract the information on the relevant timescales of the interaction process, thus helping with the interpretation of the new experimental observations. An overview of the future perspectives offered by the apparatus will be also given.

Transport model simulations of heavy-ion reactions / 68

Extracting the nuclear equation-of-state from heavy ion collisions with transport simulations

Autor Maria Colonna[1]

[1] *Istituto Nazionale di Fisica Nucleare - LNS*

Korrespondenzautor: colonna@lns.infn.it

Recent results connected to nuclear collision dynamics, from Fermi up to intermediate energies, will be reviewed.
Dissipative heavy ion reactions offer the unique opportunity to probe the complex nuclear many-body dynamics and to explore, in laboratory experiments, transient states of nuclear matter under several conditions of density, temperature and charge asymmetry.
Transport models are an essential tool to undertake the latter investigations and make a connection between the nuclear effective interaction and sensitive observables of experimental interest.
In this talk, I mainly focus on the description of a selection of reaction mechanisms, also considering comparisons of predictions of different approaches. This analysis can help understanding the impact of the interplay between mean-field and correlation effects, as well as of in-medium effects, on reaction observables, which is an essential point for extracting information on the features of the nuclear effective interaction and the nuclear Equation of State.

Transport model simulations of heavy-ion reactions / 49

Equation of state of nuclear matter from collective flows in intermediate energy heavy-ion collisions

Autor Dan Cozma[1]

[1] *IFIN-HH (Bucharest, Romania)*

Korrespondenzautor: dan.cozma@theory.nipne.ro

The equation of state of nuclear matter, momentum dependence of the effective interaction and in-medium modification of elastic nucleon-nucleon cross-sections are studied by comparing theoretical predictions for collective flows in intermediate energy heavy-ion collisions to experimental data. To that end, the dcQMD transport model [1] is upgraded by implementing medium modifications of differential elastic cross-sections guided by microscopical model calculations [2,3] and allowing for a medium modification factor of elastic cross-sections that depends on the local density, isospin asymmetry and isospin projections of the scattering particles. The description of final state multiplicities of emitted clusters is significantly improved by incorporating the coalescence afterburner into the transport model, allowing for identification of clusters at the local freeze-out time rather than the final moment of the simulation. The impact of potential energy corrections to the collision term, which proved crucial for pion production in heavy-ion collisions close to threshold [4,5], is also investigated. Finally, model predictions are compared to experimental data for rapidity dependent transverse flow of protons, deuterons, A=3 clusters and alpha particles and transverse momentum dependent elliptic flow of protons, deuterons and tritons at mid-rapidity in mid-central AuAu collisions of impact energy between 150 and 800 MeV/nucleon [6]. A multivariate analysis employing these combined experimental data sets that takes into account a systematic uncertainty induced on model predictions by the coalescence afterburner [7] leads to the following constraint for the equation of state at 68 percent confidence level: compressibility modulus of isospin symmetric matter K_0=183±11 MeV and slope of the symmetry energy L=62±12 MeV. The momentum dependence of the isoscalar potential is found to be similar to that of the empirical optical potential, with an effective isoscalar mass m*=0.65±0.03, but slightly more repulsive at high momenta. The favored momentum dependence of the isovector potential is compatible with a positive neutron-proton effective mass difference Δm^*_{np}=(0.16±0.08)δ, close to the world average for this quantity [8]. An in-medium reduction of elastic cross-sections by about 25 percent in symmetric nuclear matter at saturation density is favored. The modification factor is reduced in isopin asymmetric nuclear matter of positive isospin asymmetry. Furthermore, a splitting of proton-proton and neutron-neutron elastic cross-sections $\sigma^*_{pp}>\sigma^*_{nn}$ is deduced, in qualitative agreement with microscopical model calculations [9,10].

1. M.D. Cozma and M.B. Tsang, Eur. Phys. J. A 57, 309 (2021);
2. G.Q. Li and R. Machleidt, Phys. Rev. C 48, 1702 (1993);
3. G.Q. Li and R. Machleidt, Phys. Rev. C 49, 566 (1994);
4. M.D. Cozma, Phys. Lett. B 166, 753 (2016);

5. J. Estee et al., Phys. Rev. Lett. 126, 162701 (2021);
6. W. Reisdorf et al. (FOPI Collaboration), Nucl. Phys. A 876, 1 (2012);
7. M.D. Cozma, in preparation;
8. B.A. Li and X. Han, Phys. Lett. B 727, 276 (2013);
9. H. Zhang et al., Int. Jour. Mod. Phys. E 19, 1788 (2010);
10. F. Sammarruca, Eur. Phys. Jour. A 50, 22 (2014);

Transport Model Evaluation Project / 89

Box study with momentum-dependent mean fields and threshold effects

Korrespondenzautor: dan.cozma@theory.nipne.ro

Poster flash talks / 14

In-medium Δ related cross sections

Autor Ying Cui[1]

[1] *China Institute of Atomic Energy*

Korrespondenzautor: cuiying@ciae.ac.cn

TThe ratio $Y(\pi^-)/Y(\pi^+)$ (π^-/π^+) of the yields of the different charge states of π is considered an important observable for determining the symmetry energy density in the high-density region. However, there remains much controversy in using it to constrain the resulting symmetry energy. This requires us to further explore the physical mechanisms associated with the production of π, i.e., the in-medium Δ and π production and propagation, which are the foundation for reliable determination of the symmetry energy in the future.
In this report, we will show the in-medium Δ related inelastic scattering in isospin asymmetric nuclear matter in frame work of the one-boson exchange model. Δ and isovector mesons, i.e., ρ, δ are included in order to reasonable describing the isospin asymmetric nuclear matter. Based on this model, we will perform the systemically study on in-medium $NN \to N\Delta$, $N\Delta \to NN$, $N\pi \to \Delta$ cross section and $\Delta \to N\pi$ decay width.

Combined analysis of nuclear and astrophysics information, Bayesian approach, and machine learning / 67

Combining nuclear physics and multi-messenger observations

Autor Tim Dietrich[1]

[1] *University of Potsdam and Max Planck Institute for Gravitational Physics Potsdam*

Korrespondenzautor: diet.tim@gmail.com

Our knowledge about dense matter explored in the cores of neutron stars remains limited. Fortunately, the detections of gravitational waves emitted from the merger of neutron stars and the corresponding electromagnetic signals provide a new way of studying supranuclear-dense material. Making use of the strength of multi-messenger astronomy, one can combine the information obtained from gravitational-wave observations, the electromagnetic counterparts of merging neutron stars with the information provided by NICER, radio pulsar observations, and heavy-ion collision experiments to derive new constraints on the neutron-star equation. We outline how the combination of current theoretical knowledge, astrophysical observatories, and experimental facilities helps us to improve our knowledge about the supranuclear-dense equation of state and what we can expect from the next generation of experiments.

Transport Model Evaluation Project / 90

Perspectives with SMASH

Korrespondenzautor: h.elfner@gsi.de

Constraints from heavy-ion collisions at Fermi energies / 60

Direct comparisons of isospin diffusion measurements with transport models at Fermi energies

Autor Quentin Fable[1]

[1] *L2IT - UT3 - CNRS/IN2P3*

Korrespondenzautor: quentin.fable@l2it.in2p3.fr

This work presents an investigation of isospin equilibration in cross-bombarding ^{48,40}Ca+^{48,40}Ca reactions at 35 MeV/nucleon, by comparing experimental data with filtered transport model calculations. In particular, isospin diffusion is studied from the evolution of the isospin transport ratio with centrality. The asymmetry $\delta = (N-Z)/A$ of the quasiprojectile residue is used as an isospin-sensitive observable, while a recent method for impact parameter distribution estimation is used for centrality sorting, proven to be suitable for the whole range of impact parameter.

Constraints from heavy-ion collisions at relativistic energies / 5

Extracting the high-density symmetry energy with pion and subthreshold hyperon production in heavy-ion collisions

Autoren Zhao-Qing Feng[1]; Heng-Jin Liu[1]; Hui-Gan Cheng[1]; Si-Na Wei[1]; Ban Zhang[1]

[1] *South China University of Technology*

Korrespondenzautor: fengzhq@scut.edu.cn

Within the framework of the quantum molecular dynamics transport model, the pion production and constraint of the high-density symmetry energy in heavy-ion collisions near threshold energy have been thoroughly investigated. The energy conservation in the decay of resonances and reabsorption of pions in nuclear medium are taken into account. The isospin and momentum dependent hyperon-nucleon potential and the threshold energy correction on the hyperon elementary cross section are included in the model. The density profile of pion production, energy conservation and pion potential are analyzed by the model. The isospin diffusion in the low-density region (0.2ρ_0 - 0.8ρ_0) and high-density region (1.2ρ_0 - 1.8ρ_0) is investigated by analyzing the neutron/proton and π^-/π^+ ratios in the isotopic reactions of ^{132}Sn + ^{124}Sn and ^{108}Sn + ^{112}Sn at the incident energy of 270

MeV/nucleon, in which the symmetry energy manifests the opposite contribution. The controversial conclusion of the π^-/π^+ ratio for constraining the high-density symmetry energy by different transport models is clarified. A soft symmetry energy with the slope parameter of $L(\rho_0) = 42 \pm 25$ MeV by using the standard error analysis within the range of 1σ is obtained by analyzing the experimental data from the SπRIT collaboration. The high-density symmetry energy is dependent on the isospin ratios Σ^-/Σ^+ and Ξ^-/Ξ^0, in particular in the domain of high kinetic energies. The isospin diffusion in heavy-ion collisions influences the neutron/proton ratio in the high-density region. The Σ^-/Σ^+ ratio depends on the stiffness of symmetry energy, in particular at the beam energy below the threshold value (E_{th}=1.58 GeV), i.e., the kinetic energy spectra of the single ratios, excitation functions and energy spectra of the double ratios in the isotopic reactions of ^{108}Sn + ^{112}Sn, ^{112}Sn + ^{112}Sn, ^{124}Sn + ^{124}Sn and ^{132}Sn + ^{124}Sn. The double strangeness ratio Ξ^-/Ξ^0 weakly depends on the symmetry energy because of the hyperon-hyperon collision mainly contributing the Ξ production below the threshold energy (E_{th} = 3.72 GeV).

Theory of supernovae and neutron stars / **46**

Nuclear equation-of-state and nuclei in core-collapse supernovae

Autor Shun Furusawa[1]

[1] *Kanto Gakuin University*

Korrespondenzautor: furusawa@kanto-gakuin.ac.jp

Core-collapse supernovae are one of the most fascinating phenomena in astrophysics but the explosion mechanism is not clearly understood yet because of their intricacies. I will give an overview about the role of nuclear equation-of-state (EOS) and nuclei in supernovae. I will also discuss key nuclei and their key information to be investigated for further supernova study, and introduce recent progress of the research on EOS for astrophysical simulations.

Microscopic calculations of neutron-rich, dense nuclear matter / **27**

Order-by-order convergence of chiral nuclear forces in neutron matter (online)

Autor Alexandros Gezerlis[1]

[1] *University of Guelph*

Korrespondenzautor: gezerlis@uoguelph.ca

Modern formulations of nuclear forces, such as pionless or chiral effective field theory, are typically based on a perturbative approach. Such interactions are then often employed by state-of-the-art nuclear many-body techniques (such as quantum Monte Carlo) which are non-perturbative in nature. The equation of state of a compact star is thus the result of this interplay of perturbative nuclear force and non-perturbative many-body method. Despite the centrality of this question to nuclear *ab initio* predictions, the perturbative use of nuclear interactions as input is still in its infancy (i.e., limited to first order). In this talk I will report on our recent work fusing non-perturbative approaches and second-order perturbation theory. Results will build up to the order-by-order convergence of chiral Effective Field Theory interactions for pure neutron matter.

Poster flash talks / **54**

Tidal heating as a direct probe of Strangeness inside Neutron stars

Autoren Suprovo Ghosh[None]; Bikram Keshari Pradhan[1]; Debarati Chatterjee[2]

[1] *IUCAA, Pune, India*

[2] *Laboratoire de Physique Corpusculaire de Caen*

Korrespondenzautor: suprovoghosh529@gmail.com

The cores of neutron stars (NS) reach densities several times the nuclear saturation density and could contain strangeness containing exotic particles such as hyperons. During the binary inspiral, viscous processes inside the NS matter can damp out the tidal energy induced by the companion and convert this to thermal energy to heat up the star. We demonstrate that the bulk viscosity originating from the non-leptonic weak interactions involving hyperons is several orders of magnitude higher than the standard neutron matter shear viscosity in the relevant temperature range of $10^6 - 10^9$K and for heavier mass NSs ($M \geq 1.6 M_\odot$) that contain a significant fraction of hyperons in their core, the bulk viscosity can heat up the stars upto $0.1 - 1$ MeV before the final merger. This "tidal heating" process also introduces a net phase shift of $10^{-3} - 0.5$ rad, depending on the component mass, in the gravitational wave (GW) signal that can potentially be detected using current and future generation GW detectors. Such a detection would be the direct confirmation of the presence of hyperons inside the NS core, having a great significance for the study of dense matter under extreme condition.

Microscopic calculations of neutron-rich, dense nuclear matter / 72

Nuclear models based on energy density functional for astrophysics applications

Autoren Guilherme Grams[1]; Wouter Ryssens[2]; Guillaume Scamps[3]; Stephane Goriely[4]; Nicolas Chamel[5]

[1] *Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles*

[2] *Université Libre de Bruxelles*

[3] *Department of Physics, University of Washington, Seattle, USA.*

[4] *???*

[5] *Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles, Belgium.*

Korrespondenzautor: guilherme.grams@ulb.be

Large-scale models of nuclear structure play an essential role in many astrophysics applications. Nucleosynthesis simulations of heavy elements, through the rapid neutron-capture process (or r-process), for example, require nuclear information inputs across the whole nuclear chart, far beyond the region where experimental data is available. Likewise, describing the extremely dense neutron-rich matter in neutron stars is a challenge for nuclear physics and astrophysics.
The Brussels-Montréal Skyrme (BSk-series) nuclear energy density functionals and associated nuclear mass models have been developed to this end. Based on the Hartree-Fock-Bogoliubov (HFB) method with a Skyrme interaction, their parameters have been fitted to essentially all experimental nuclear masses and constrained to reproduce various infinite nuclear matter (INM) properties (equation of state, effective masses, pairing gaps, …). Recently, the first Brussels-Skyrme-on-a-grid (BSkG) models have been developed. This series focuses on exploiting the powerful concept of symmetry breaking: BSkG1 [1] incorporates for the first time the possibility of triaxial deformation, BSkG2 [2] in addition, allows for the effects of time-reversal symmetry breaking. The latter enables us to access the spin and current densities in the ground states of odd-mass and odd-odd nuclei. These densities contribute to the total energy of such nuclei through the so-called 'time-odd' terms. Moving beyond ground-state properties, BSkG2 also includes information on fission barrier heights of actinide nuclei in the parameter adjustment.
We will present in this contribution the latest BSkG3 nuclear mass model, which brings important

improvements. To grasp further collective effects, we now break reflection symmetry, allowing for both triaxial and octupole-deformed ground states simultaneously. Moreover, we add to the description of finite nuclei improvements of relevance to the description of neutron star properties. We focus on rendering the predicted equation of state stiffer along the lines of Ref. [3], ensuring the model can accommodate the existence of heavy pulsars. We also replace the phenomenological pairing interaction of previous models by a more microscopically grounded interaction designed to match the 1S0 pairing gaps in INM deduced from ab-initio calculations. This is particularly important for describing superfluids in neutron stars. Reconciling the complexity of neutron stars with those of atomic nuclei establishes BSkG3 as a tool of choice for applications to nuclear structure, the nuclear equation of state, and nuclear astrophysics in general.

[1] G. Scamps et al., Eur. Phys. J. A 57, 333 (2021).
[2] W. Ryssens et al., Eur. Phys. J. A 58, 246 (2022).
[3] N. Chamel, S. Goriely and J. M. Pearson, Phys. Rev. C 80, 065804 (2009).
[4] G. Grams, W. Ryssens, G. Scamps, S. Goriely and N. Chamel, arXiv:2307.14276 [nucl-th] (2023).

Astrophysical, multi-messenger observations / 61

Current status of NICER's measurements of the neutron star masses and radii (online)

Autor Sebastien Guillot[1]

[1] *IRAP / CNRS*

Korrespondenzautor: sebastien.guillot@irap.omp.eu

The Neutron Star Interior Composition Explorer (NICER) has been in operation from the International Space Station for over 6 years now. By accurately modelling the phase-energy resolved light curves of millisecond pulsars (caused by their hot polar caps) and the effects of general relativity on these light curves, we can obtain measurements of the pulsars'masses and radii. NICER has accumulated over 16 Megaseconds of observational data for these millisecond pulsars, providing data sets of unprecedented quality. I will summarise the results for the two published pulsars and present the current status of the analyses. These published results have naturally sparked a lot of interest and have placed some constraints on the equation of state of dense matter. But they have also raised a lot of questions on our understanding of the surface emission of pulsars and their magnetospheres, and how we can interpret those to extract information on the masses and radii of pulsars. I will then conclude on future prospects from NICER and from future X-ray missions.

Constraints from heavy-ion collisions at Fermi energies / 22

Dynamics of cluster production in heavy-ion collisions

Autor Tom Génard[1]

[1] *GANIL*

Korrespondenzautor: tom.genard@ganil.fr

Collisions of heavy ions are the best tools at our disposal to probe nuclear matter. It allows us to reach extreme densities, giving us the possibility to constraint transport models. In particular, at incident energies around 100 MeV/nucleon, a participant zone is formed by a part of projectile and target nuclei.

The aim of this work is to characterize the participant zone. We will focus on the characteristics of cluster production (chemical composition, energy, angular distributions, multiplicities, and their correlations). These analyses reveal the neutron richness of the emitted particles, and their yield gives an insight on the mixing of target and projectile contributions. Furthermore, a systematic analysis of the transverse energy of the emitted clusters shows a link between incident energy, compression energy, and density during the reaction.

For this study, INDRA datasets for 124,129Xe+112,124Sn collisions at 100 AMeV have been used to study the effect of neutron richness on the production of light particles. The kinematic study was carried out using the datasets for 129Xe+124Sn collisions at 65, 80, 100 and 150 AMeV, and using the data set of 136Xe+124Sn collision at 32 and 45 AMeV. Densities of up to 1.7 of saturation density were deduced in agreement with previous pBUU calculations. The results of this analysis were compared to the semi-classical event generator ELIE.

Microscopic calculations of neutron-rich, dense nuclear matter / 62

Nuclear EOS for arbitrary proton fraction and temperature based on chiral EFT and a Gaussian Process Emulator

Autoren Jonas Keller[1]; Achim Schwenk[1]; Kai Hebeler[1]

[1] *TU Darmstadt*

Korrespondenzautor: kai.hebeler@physik.tu-darmstadt.de

We present results for the equation of state of asymmetric nuclear matter at finite temperature based on
chiral effective field theory interactions to next-to-next-to-next-to-leading order. Our results assess the theoretical uncertainties from the many-body calculation and the chiral expansion. Using a Gaussian process emulator for the free energy, we derive the thermodynamic properties of matter through consistent derivatives and use the Gaussian process to access arbitrary proton fraction and temperature. This enables a first nonparametric calculation of the equation of state in beta equilibrium, and of the speed of sound and the symmetry energy at finite temperature. Moreover, our results show that the thermal part of the pressure decreases with increasing densities.

International long-range plan round-table / 84

Nuclear theory

Korrespondenzautor: kai.hebeler@physik.tu-darmstadt.de

Investigations at existing and future accelerator facilities and detectors / 57

Status and future scientific program of RAON

Autor Byungsik Hong[1]

[1] *Korea University*

Korrespondenzautor: b.hong@gsi.de

A new radioactive-ion-beam (RIB) accelerator complex RAON is under construction in Korea. RAON will be equipped with both ISOL (Isotope Separation On-Line) and IF (In-flight Fragmentation) systems and explore the possibility to combine them to provide more neutron-rich ion beams than any single mode. The ISOL and low-energy systems were completed in 2022 and the high-energy section will be finished in around 2030. As the experimental setups for nuclear physics, KOBRA (KOrea Broad acceptance Recoil spectrometer and Apparatus) was constructed for nuclear structure and nuclear astrophysics using RIBs with a few tens MeV per nucleon. In addition, LAMPS (Large-Acceptance Multipurpose Spectrometer) is being constructed at the high-energy experimental area. In this presentation we summarize the status and prospects of the RAON facility. The status and research plan for KOBRA and LAMPS will be also described.

Transport model simulations of heavy-ion reactions / 36

Impact of the momentum dependence of the neutron and proton potentials on pion production in heavy-ion collisions

Autoren Natsumi Ikeno[1]; Akira Ono[2]

[1] *Tottori University*

[2] *Tohoku University*

Korrespondenzautor: ikeno@tottori-u.ac.jp

The momentum dependence of the nucleon mean-field potential in a wide momentum range can be an important factor to determine the Δ resonance and pion production in intermediate-energy heavy-ion collisions. In particular, in neutron-rich systems such as 132Sn+124Sn collisions, we need to carefully treat the momentum dependence because the neutron and proton potentials can have different momentum dependence, as characterized at low momenta by effective masses. We rigorously calculate the collision terms of $NN \leftrightarrow N\Delta$ and $\Delta \leftrightarrow N\pi$ processes with the precise conservation of energy and momentum under the presence of momentum-dependent potentials for the initial and final particles of the process. The potentials affect not only the threshold condition for the process but also the cross section in general as a function of the momenta of the initial particles, which is treated in a natural way in our work.

We calculate central 132Sn+124Sn collisions at 270 MeV/nucleon by combining the nucleon dynamics obtained by the antisymmetrized molecular dynamics (AMD) model with a newly developed transport code which we call sJAM. The calculated results clearly show that the momentum dependence of the neutron and proton potentials has a significant impact on the $NN \to N\Delta$ process, and this information is strongly reflected in the charged pion ratio (π^-/π^+). We also investigate the effects of the high-density symmetry energy and the isovector part of the potential of Δ resonances on pion production, which we find are relatively small compared to the effect of the momentum dependence of the neutron and proton potentials.

I will give a presentation based on Ref. [1].

[1] N. Ikeno and A. Ono, arXiv:2307.02395 [nucl-th].

Poster flash talks / 17

Neutron stars to finite nuclei : A direct mapping

Autoren Sk Md Adil Imam[1]; Bijay Kumar Agrawal[1]; Arunava Mukherjee[2]; Gourab Banerjee[2]

[1] *SAHA INSTITUTE OF NUCLEAR PHYSICS*

[2] *Saha Institute of Nuclear Physics*

Korrespondenzautor: skmdadilimam@gmail.com

The iso-scalar and iso-vector nuclear matter parameters (NMPs) are frequently used to characterise the equations of state (EoSs) that govern the properties of neutron stars (NSs). Recent attempts to relate the radius and tidal deformability of a NS to the individual NMPs have been inconclusive. These properties display strong correlations with the pressure of NS matter which depends on several NMPs. We systematically analyze to isolate the NMPs that predominantly determine the tidal deformability, over a wide range of NS mass. The tidal deformability of the NS with mass 1.2-1.8 M can be determined within 10% directly in terms of four nuclear matter parameters, namely, the incompressibility (K0)and skewness (Q0) of symmetric nuclear matter, and the slope (L0) and curvature parameter (Ksym,0) of symmetry energy

Constraints from heavy-ion collisions at relativistic energies / 51

Flow phenomena at high nuclear densities with HADES

Autor Behruz Kardan[1]

[1] *Goethe University Frankfurt (IKF)*

Korrespondenzautor: bkardan@ikf.uni-frankfurt.de

The study of strongly interacting matter under extreme conditions is one of the most important topics in the exploration of Quantum Chromodynamics (QCD).

In this talk, we present new measurements by the High Acceptance DiElectron Spectrometer (HADES) at GSI Helmholtzzentrum für Schwerionenforschung, relating to flow phenomena at high nuclear densities. HADES provides a large acceptance, combined with a high mass-resolution, and therefore allows to study dielectron, hadron and light nuclei production in heavy-ion collisions with unprecedented precision. HADES has accumulated data at highest statistics in Au+Au and Ag+Ag collisions at SIS18 energies.

We discuss recent results on light nuclei production and their collective phenomena. Moreover, flow coefficients v_n up to the 6^{th} order are investigated for the first time in this energy regime. Their combined information allows to construct for the first time a full 3D-picture of the angular particle emission in momentum space. The multi-differential analysis in different centrality classes over a large region of phase space will be shown and various scaling properties will be discussed.

The data provide essential constraints for theoretical transport models utilised in the determination of the properties of dense baryonic matter, such as its viscosity and equation-of-state (EOS).

This work is supported by the Helmholtz Forschungsakademie HFHF

Microscopic calculations of neutron-rich, dense nuclear matter / 44

How meson crossing terms reconcile the recent observational data.

Korrespondenzautor: sebastian.kubis@pk.edu.pl

The last decade observational data show that massive neutron star have masses above 2.1 Msun what indicate rather stiff EOS, whereas the lightweight star observed by NICER and HESS appears to be very compact what suggest rather soft EOS. Such opposite properties (stiff at higher densities and soft at lower) are available in RMF nuclear model equipped with new kind of crossing terms, describing coupling between isovector and isoscalar mesons.

Poster flash talks / 39

Robust universal relations in neutron star asteroseismology

Autoren Deepak Kumar[1]; TUHIN MALIK[2]; Hiranmaya Mishra[3]; Constança Providência[4]

[1] *Indian Institute of Science Education and Research Bhopal*

[2] *CFisUC, Department of Physics, University of Coimbra, 3004-516 Coimbra, Portugal*

[3] *School of Physical Sciences, National Institute of Science Education and Research, Jatni, 752050 India*

[4] *Universidade de Coimbra*

Korrespondenzautor: dpqraja02@gmail.com

The non-radial oscillations of the neutron stars (NSs) have been suggested as an useful tool to probe the composition of neutron star matter (NSM). With this scope in mind, we consider a large number of equations of states (EOSs) that are consistent with nuclear matter properties and pure neutron matter EOS based on a chiral effective field theory (chEFT) calculation for the low densities and perturbative QCD EOS at very high densities. This ensemble of EOSs is also consistent with astronomical observations, gravitational waves in GW170817, mass and radius measurements from Neutron star Interior Composition ExploreR (NICER). We analyze the robustness of known universal relations (URs) among the quadrupolar f mode frequencies, masses and radii with such a large number of EOSs and we find a new UR that results from a strong correlation between the f mode frequencies and the radii of NSs. Such a correlation is very useful in accurately determining the radius from a measurement of f mode frequencies in the near future. We also show that the quadrupolar f mode frequencies of NS of masses 2.0 $M_\odot$ and above lie in the range $\sim$ 2-3 kHz in this ensemble of physically realistic EOSs. A NS of mass 2$M_\odot$ with a low f mode frequency may indicate the existence of non-nucleonic degrees of freedom.

Constraints from heavy-ion collisions at relativistic energies / 59

Directed and elliptic flow observations in Sn+Sn collisions with radioactive beams at 270 MeV/u

Autor Mizuki Kurata-Nishimura[1]

Co-Autoren: Tadaaki Isobe [1]; Tetsuya MURAKAMI [2]; Akira Ono [3]; Natsumi Ikeno [4]; Chun Yuen Tsang [5]; William Lynch [6]; Betty Tsang [6]; SπRIT collaboration

[1] *RIKEN*

[2] *Department of Physics, Kyoto University*

[3] *Tohoku University*

[4] *Tottori University*

[5] *Kent State University*

[6] *Michigan State University*

Korrespondenzautor: mizuki@riken.jp

Rapidity dependence of directed flow (v_1) and elliptic flow (v_2) were analyzed for various particles, including proton, deuteron, triton, $^{3}\mathrm{He}$, and $^{4}\mathrm{He}$ observed in collisions involving $^{132}\mathrm{Sn} + {}^{124}\mathrm{Sn}$ and $^{108}\mathrm{Sn} + {}^{112}\mathrm{Sn}$ collisions at 270 $\mathrm{MeV/u}$.
The flow was larger for heavier charged particles, i.e.,
the slope of v_1 (v_{11}) and the negative v_2 at the mid-rapidity (v_{20}) were enhanced for the heavier charged particles.
To understand the experimental data, we compared them with AMD calculations which explicitly consider the cluster correlation.
Two types of momentum-dependent mean field potential were utilized.
AMD calculations explain the increasing flow trend for the heavier particles, but a close comparison shows that the mass dependence is stronger in experimental data.

The sensitivity to the density dependence of the symmetry energy and the system dependence is also examined.

Nuclear structure, short-range correlations and direct reactions / 50

Constraining the nuclear equation of state using Coulomb excitation of neutron-rich tin isotopes

Autor Ivana Lihtar[1]

Co-Autoren: Andrea Horvat [2]; Dominic Michel Rossi [3]; Eleonora Kudaibergenova [4]; Hans Törnqvist [5]; Igor Gašparić [2]; Jose Luis Rodriguez Sanchez [6]; Martina Feijoo [7]; Thomas Aumann [3]; Valerii Panin [3]

[1] *Institut Ruder Boškovic(IRB)*

[2] *Ruđer Bošković Institute*

[3] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[4] *IKP, TU Darmstadt*

[5] *Chalmers University of Technology*

[6] *University of Coruña*

[7] *Universidad de Santiago de Compostela(USC)*

Korrespondenzautor: i.lihtar@gsi.de

An experiment measuring the Coulomb-excitation cross section, σC [1] in neutron-rich tin nuclei (124 Sn–134 Sn) at relativistic energies was performed at GSI, Darmstadt with the aim to constrain the slope of the symmetry energy, L. This particular cross section correlates with dipole polarizability, α D , a well-established observable for constraining L [2], which enables achieving the same goal but in a simpler and more accurate manner with the used experimental setup [3].
Large acceptance spectrometer R3B-GLAD was used to conduct the experiment as a part of the FAIR Phase-0 campaign [4]. Neutron-rich tin isotopes were produced in fragmentation and fission reactions at energies close to 1 GeV/u, while a lead target was used to provide a strong field to induce Coulomb excitations. At these energies, de-excitation occurs through the emission of gammas and neutrons which were detected using the CALIFA gamma calorimeter [5] and NeuLAND neutron detector [6].
In the scope of this contribution, ongoing analysis with some preliminary results will be presented.

[1] T.Aumann, C.A.Bertulani, Prog. Part. Nucl. Phys. 112 (2020) 103753
[2] S.Bassauer et al., Phys. Lett. B 810 (2020) 135804
[3] A.Horvat, Doctoral thesis, Technische Universität Darmstadt (2019)
[4] R3B Collaboration, https://www.r3b-nustar.de/.
[5] H. Alvarez Pol et al., Nucl. Instrum. Meths. Phys. Res. A 767, 453 (2014)
[6] K.Boretzky et al., Nucl. Instrum. Methods Phys. Res. A 1014 (2021) 165701

Combined analysis of nuclear and astrophysics information, Bayesian approach, and machine learning / 25

Toward a quantitative evaluation of the nuclear equation of state

Autor Olivier Lopez[1]

[1] *LPC Caen, France*

Korrespondenzautor: lopezo@lpccaen.in2p3.fr

This contribution concerns the characterization of the nuclear equation of state (EOS) evaluated from ground state properties of nuclei, i.e. from nuclear masses, charge radii and neutron thickness. By using a Thomas-Fermi framework combined with a specific Seyler-Blanchard nucleon-nucleon interaction containing both non-local and density terms, I will show that quantitative information about the EOS empirical parameters can be deduced. Specifically, the density dependence of the isovector part of the EOS (symmetry energy) is here estimated and discussed. The results are also successfully compared to a non-parametric regression (gaussian process) trained on experimental evaluations. Hence, these results provide a brand new set of quantitative constraints for the nuclear EOS by taking into account both experimental and theoretical inputs.

Constraints from heavy-ion collisions at relativistic energies / 8

Equation-of-state studies with HADES (perspectives)

Autor Manuel Lorenz[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Korrespondenzautor: m.lorenz@gsi.de

We review the current status of studies related to the equation of state as extracted from HADES data and will discuss future perspectives in heavy-ion runs at lower energies.

International long-range plan round-table / 86

Heavy-ion collisions

Korrespondenzautoren: m.lorenz@gsi.de, lopezo@lpccaen.in2p3.fr, w.trautmann@gsi.de, p.senger@gsi.de

Overview / 82

Constraining the Equation of State of Nuclear Matter (Overview)

Autor William Lynch[1]

[1] *Michigan State University*

Korrespondenzautor: lynch@nscl.msu.edu

Experimental measurements of nuclear systems with different neutron and proton numbers have enabled significant progress in constraining the EoS of nuclear matter. Careful experimental and theoretical analyses can now provide experimentally grounded constraints on the nuclear symmetry energy over a range of densities and isospin asymmetries. Over such densities, existing constraints on the symmetric matter exist. When these are combined with newer symmetry energy constraints, values for the nuclear matter Equation of State (EoS) can be obtained over a range of densities and asymmetries. One may expect that such experimentally based constraints on the symmetry energy become more stringent when more focused investigations of the nuclear symmetry energy are performed at advanced rare isotope facilities. At least three such measurements are currently being prepared and more can be expected. Nuclear constraints have been combined with Neutron Star (NS) radii deduced from NICER/XMM-Newton NS observations of PSRJ0030+0451 and PSRJ0740+6620

and with NS deformabilities obtained by the LIGO-VIRGO collaboration from the GW170817 NS merger event. Such combinations allow overall constraints on the total EoS of nuclear matter at densities of up to 3 times saturation density as well as predictions regarding the probability of Dirac Urca cooling processes in a massive NS.

Microscopic calculations of neutron-rich, dense nuclear matter / 43

What are true ab initio calculations of neutron-rich matter?

Autor Ruprecht Machleidt[1]

[1] *University of Idaho*

Korrespondenzautor: machleid@uidaho.edu

Microscopic nuclear theory is based on the tenet that atomic nuclei and nucleonic matter can be accurately described as collections of point-like nucleons interacting via two- and many-body forces obeying nonrelativistic quantum mechanics—and the concept of the ab initio approach is to calculate nuclear systems accordingly. The forces are fixed in free-space scattering and must be accurate. I will critically review the history of this approach from the early beginnings until today. The main focus of this contribution will then be on current microscopic predictions of neutron-rich matter and the symmetry energy—as relevant to this symposium. A critical analysis reveals that many calculations presented as ab initio do not pass muster. Moreover, most contemporary calculations apply nuclear forces of a rather low order of chiral effective field theory. The ultimate goal are high-precision ab initio predictions which, as it turns out, may be possible only at the fifths order of the chiral expansion. Calculations of this kind, which must also include all many-body forces at that order, are very challenging, and the current status of ab initio calculations is far from meeting that goal.

Theory of supernovae and neutron stars / 11

Nuclear symmetry energy and neutron stars

Autor Jérôme Margueron[1]

Co-Autor: Jean-François Coupechoux [2]

[1] *CNRS-IN2P3, IP2I Lyon*

[2] *IP2I Lyon*

Korrespondenzautor: j.margueron@ip2i.in2p3.fr

The understanding of neutron star properties from fundamental physics is still far from being completed. One of the reasons is that the theory for strong force, QCD, does not apply simply to neutron star matter at a few times the nuclear saturation density. At low density, chiral effective field theory is fixing a limit which can be incorporated in the description of the crust of neutron stars. Above saturation density, the question of phase transition(s) and the onset of new degrees of freedom are extremely important since it impacts the properties of the core of neutron stars. Astrophysical observations (gravitational wave, x-rays, radio) and nuclear physics experiments can be employed to constrain the equation of state for neutron stars, including the symmetry energy. Prospects for future detections will also be discussed.

Transport model simulations of heavy-ion reactions / 76

Towards constraints on the Equation of State with SMASH

Autor Justin Mohs[1]

Co-Autor: Hannah Elfner [2]

[1] *Goethe University Frankfurt*

[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

Korrespondenzautor: mohs@fias.uni-frankfurt.de

In this work, we aim to put constraints on the equation of state of nuclear matter by comparing transport calculations with SMASH to the recent high-precision data from the HADES experiment.

In order to achieve reliable constraints, we first investigate different methods of taking light nuclei formation into account, as a large fraction of nucleons is bound to nuclei. We find that flow coefficients of protons are sensitive to light nuclei formation at small transverse momenta, but at large p_T, one can extract information about the nuclear potential in a more controlled way.

We further improve the model by including a momentum-dependent term in the nuclear potential and show that this improves the description of experimental data for several observables, such as the flow coefficients of protons and particle spectra for different species.

A first estimate for the equation of state is presented, but more importantly, this work lays a basis for quantitative constraints using Bayesian methods in the future.

Transport model simulations of heavy-ion reactions / 53

Searching for isospin drift sites in heavy dissipative nuclear systems

Autor Paolo Napolitani[1]

[1] *IJCLab*

Korrespondenzautor: paolo.napolitani@ijclab.in2p3.fr

Heavy nuclear systems formed in dissipative collisions at Fermi energy develop a variety of possible sites where density gradients and instabilities combine in different possible ways.
Depending on physical conditions, these sites may host different distinct isospin processes, either related to isospin transport or to phase transitions.
As we will show on the basis of a suited set of microscopic simulations, these processes result in different types of fragment emissions, in terms of chronology, size and density conditions.
Still, they may appear simultaneously in the same nucleus-nucleus collision event and, more generally, they may mix up when initial conditions are similar.
Supposedly, if more attention could be payed to the competition of different isospin processes occurring in similar physical conditions, even more reliable isospin observables could be extracted from the experiments.

Astrophysical, multi-messenger observations / 29

Probing neutron stars with resonant shattering flares and gravitational waves

Autor Duncan Neill[1]

Co-Autoren: David Tsang [1]; William Newton [2]

[1] *University of Bath*

[2] *Texas A&M University-Commerce*

Korrespondenzautor: dn431@bath.ac.uk

Asteroseismic modes within neutron stars (NSs) provide can provide novel insight into NS structure and the physics of dense matter, as they are sensitive to a variety of different stellar properties. The multimessenger detection of a resonant shattering flare and gravitational waves from a binary NS merger could allow us to measure the frequency of the crust-core interface mode. This mode is sensitive to the shear speed within the NS crust, which in turn depends on the nuclear symmetry energy. I will discuss the possibility of detecting such multimessenger events, and examine what such detections could be used to infer about the symmetry energy.

Combined analysis of nuclear and astrophysics information, Bayesian approach, and machine learning / 52

Inferring the symmetry energy by combining nuclear and astrophysical data using a consistent model of nuclear matter

Autor William Newton[1]

[1] *Texas A&M University-Commerce*

Korrespondenzautor: william.newton@tamuc.edu

We have entered the era of multi-messenger nuclear astrophysics; bringing a host of astrophysical observations and nuclear experimental data to collectively measure the properties of neutron star matter and the nuclear force in neutron-rich systems. In order to combine disparate data sets with meaningful uncertainty quantification, over the past decade the statistical inference techniques employing ensembles of models of each observable have been increasingly employed. In order to minimize systematic model uncertainty, where possible the same underlying model should be used to construct neutron star and nuclear models. We present an example of such an approach, using an Energy-Density Functional to model bulk properties of neutron stars such as the maximum mass, radii, tidal deformabilities and moments of inertia, crust properties of neutron stars, and nuclear properties including nuclear masses, neutron skins and dipole polarizabilities. We demonstrate how different observables constrain the symmetry energy in different density ranges, and discuss some of the remaining model uncertainties.

Theory of supernovae and neutron stars / 79

Neutron stars: probing ultra dense (and hot) matter (online)

Autor Micaela Oertel[1]

[1] *LUTH-CNRS/Observatoire de Paris*

Korrespondenzautor: micaela.oertel@obspm.fr

Observed for the first time in 1967 as pulsars, neutron stars represent the most extreme bodies known in our universe. Relict of the gravitational collapse and subsequent supernova explosion of a massive star at the end of his life, they gather a mass of up to twice that of our sun in a sphere with a radius of about 10 km. Their phenomenology is very rich and complex. Modelling requires many different fields of physics such as general relativity, nuclear physics and solid state physics. During this talk, after an

introduction, I will discuss some examples of how the confrontation of observational data with neutron star models allows to probe properties of ultra-dense and hot matter. Future prospects to improve our understanding and in particular to pin down the potential existence of a phase transition in dense matter with constraints from gravitational wave detections will be discussed, too.

Transport model simulations of heavy-ion reactions / 45

When and where are clusters formed in expanding systems? (online)

Autor Akira Ono[1]

[1] *Tohoku University*

Korrespondenzautor: ono@nucl.phys.tohoku.ac.jp

In central heavy-ion collisions at several hundred MeV/nucleon, a compressed nuclear system is formed up to about twice the saturation density and then rapidly expands, to produce a lot of light clusters. Recently, cluster observables from the SpiRIT experiment have been compared with the AMD calculation in some published papers and a paper in preparation. Some cluster observables showed sensitivity to the density dependence of symmetry energy. However, it still has to be clarified how the clusters ultimately emitted into free space can convey information about the compressed nuclear matter.

In this short contribution, I will present my recent investigation on the space-time point of two-nucleon collisions in the time evolution of central heavy-ion collisions. In the version of AMD with cluster correlations, a two-nucleon collision may form cluster(s) in the final state as N1 + N2 + B1 + B2 $\rightarrow$ C1 + C2. The analysis shows that clusters, especially A=3 clusters, are most frequently formed in the central part of the system around the time of the maximum compression. Many clusters survive until they are spatially separated, due to the simple expansion of the system. This implies a promising potential to obtain valuable information on the high-density phase from cluster observables. The influence of the Mott effect will also be discussed.

Nuclear structure, short-range correlations and direct reactions / 7

What If the Nuclear Symmetry Energy is Larger than Expected?

Autor Nico Orce[1]

[1] *University of the Western Cape*

Korrespondenzautor: jnorce@uwc.ac.za

Here we provide experimental evidence for an increasing nuclear symmetry energy for nuclei at temperatures typically found in neutron mergers and collapsars, which may lead to the close in of the nuclear chart (or neutron dripline) at the limits of stability, and constrain the paths of various r-process nucleosynthesis mechanisms; hence, supporting the universal pattern of abundances for heavy elements with $56 < Z < 90$ found in our sun, extremely metal poor stars and meteorites. We believe that this is a ground breaking discovery arising from the classical study of giant dipole resonances built on the excited states of nuclei. More work is crucially needed, but our conclusion is supported by theory and astronomical findings.

Nuclear structure, short-range correlations and direct reactions / 65

Implications of CREX and PREX for energy density functionals

Autor Nils Paar[1]

[1] *University of Zagreb*

Korrespondenzautor: npaar@phy.hr

New insights into the nuclear symmetry energy and related formation of neutron skin in nuclei have been gained through recent precise parity-violating electron scattering experiments on ^{48}Ca (CREX) and ^{208}Pb (PREX-II). To understand the implications of these experiments for the nuclear energy density functionals (EDF), consistent investigation is required to address the nuclear matter symmetry energy and isovector properties of finite nuclei, including neutron skin thickness and dipole polarizability. Recently, the weak-charge form factors obtained from the CREX and PREX-II experiments have been employed directly to constrain the relativistic density-dependent point coupling EDFs [1]. Interestingly, the EDF established with the CREX data yields significantly smaller values for the symmetry energy parameters, neutron skin thickness, and dipole polarizability both for ^{48}Ca and ^{208}Pb, in comparison to the EDF obtained using the PREX-II data, as well as previously established EDFs [1]. Despite the valuable insights provided by CREX and PREX-II experiments, it is essential to assess why they do not offer consistent constraints for the isovector sector of the EDFs. Further theoretical and experimental investigations are necessary to improve our understanding of this aspect.

[1] E. Yuksel, N. Paar, "Implications of parity-violating electron scattering experiments on Ca-48 (CREX) and Pb-208 (PREX-II) for nuclear energy density functionals", Phys. Lett. B 836, 137622 (2023).

Combined analysis of nuclear and astrophysics information, Bayesian approach, and machine learning / 6

Constraining Neutron-Star Matter with Microscopic and Macroscopic Collisions

Autoren Peter T. H. Pang[1]; Sabrina Huth[2]; Ingo Tews[3]; Tim Dietrich[4]; Arnaud Le Fevre[5]; Achim Schwenk[6]; Wolfgang Trautman[5]; Kshitij Agarwal[7]; Mattia Bulla[8]; Michael Coughlin[9]; Chris Van Den Broeck[1]

[1] *Nikhef / GRASP Utrecht University*

[2] *Department of Physics, Technische Universität Darmstadt / ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH*

[3] *Theoretical Division, Los Alamos National Laboratory*

[4] *Institut für Physik und Astronomie, Universität Potsdam / Max Planck Institute for Gravitational Physics*

[5] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

[6] *Department of Physics, Technische Universität Darmstadt / ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH / Max-PlanckInstitut für Kernphysik*

[7] *Physikalisches Institut, Eberhard Karls Universität Tübingen*

[8] *Department of Physics and Earth Science, University of Ferrara*

[9] *School of Physics and Astronomy, University of Minnesota*

Korrespondenzautor: thopang@nikhef.nl

Interpreting high-energy, astrophysical phenomena, such as supernova explosions or neutron-star collisions, requires a robust understanding of matter at supranuclear densities. However, our knowledge about dense matter explored in the cores of neutron stars remains limited. Fortunately, dense matter is not only probed in astrophysical observations, but also in terrestrial heavy-ion collision experiments. In this work, we use Bayesian inference to combine data from astrophysical multi-messenger observations of neutron stars and from heavy-ion collisions of gold nuclei at relativistic energies with microscopic nuclear theory calculations to improve our understanding of dense matter. We find that the inclusion of heavy-ion collision data indicates an increase in the pressure in dense matter relative to previous analyses, shifting neutron-star radii towards larger values, consistent with recent NICER observations. Our findings show that constraints from heavy-ion collision experiments show a remarkable consistency with multi-messenger observations and provide complementary information on the nuclear matter at intermediate densities. This work combines nuclear theory, nuclear experiment, and astrophysical observations, and shows how joint analyses can shed light on the properties of neutron-rich supranuclear matter over the density range probed in neutron stars.

Poster flash talks / 42

Precise Measurement of Total Interaction Cross Sections of 12C+12C with R3B

Autor Lukas Ponnath[1]

[1] *Technische Universität München(TUM-PE18)*

Korrespondenzautor: lukas.ponnath@tum.de

The R3B (Reactions with Relativistic Radioactive ion Beams) experiment as a major instrument of the NUSTAR collaboration for the research facility FAIR in Darmstadt, enables kinematically complete measurements of reactions with high-energy radioactive beams. Part of the broad physics program of R3B is to gain a deep insight into the nuclear structure and dynamics of exotic nuclei far off stability.
A promising approach to constrain the slope parameter of the symmetry energy at saturation density is by measuring the neutron-skin thickness of neutron-rich nuclei via total reaction or total neutron-removal cross sections reactions. A direct comparison of integrated cross sections with predictions based on a realistic reaction model allows to determine the matter radius.
For a precise determination of the neutron-skin thickness, it is essential to quantify the uncertainty and challenge the reaction model under stable conditions.
The measurement of the total interaction cross sections of 12C+12C collisions at relativistic energies represents the perfect case for a direct comparison with theory.
The S444 commissioning experiment for R3B, performed in the FAIR Phase-0 campaign in 2019, was the first operation of many new R3B detectors in a common setup. During this successful commissioning, we have precisely measured the energy dependence of total interaction cross sections of a 12C beam on a 12C target, which is poorly known for energies above 400 MeV/nucleon. In my talk, I will present the results of the analysis and discuss the technique and evaluated error budget for the different steps, also applicable for exotic nuclei in the future.
(Results presented here are based on the experiment s444/s473, which was performed at the beamline infrastructure Cave-C at the GSI Helmholtzzentrum fuer Schwerionenforschung, Darmstadt (Germany) in the context of FAIR Phase-0.
The project was supported by BMBF 05P21WOFN1 and 05P19WOFN1)

Combined analysis of nuclear and astrophysics information, Bayesian approach, and machine learning / 10

Bayesian inference of the dense matter equation of state built within mean field models

Autoren Adriana R. Raduta[1]; Mikhail Beznogov[2]

[1] *IFIN-HH, Bucharest*

[2] *IFIN-HH*

Korrespondenzautor: adriana.raduta@gmail.com

In the last years Bayesian techniques are employed more and more frequently to build equations of state of dense neutron rich matter by imposing various sets of constraints on functional relations derived within models with different degrees of sophistication and physical underpinning. In this talk I shall confront the results obtained when the same constraints are imposed to models of equation of state generated within the non-relativistic mean field model with Skyrme interactions and the covariant density functional theory with density dependent couplings.

Microscopic calculations of neutron-rich, dense nuclear matter / 38

Self-energy of pion and its impact on equation of state

Autor Ninoy Rahman[1]

Co-Autor: Gabriel Martínez-Pinedo [1]

[1] *GSI*

Korrespondenzautor: n.rahman@gsi.de

We study the pionic self-energy and its impact on the energy-momentum dispersion relation of pion in neutron-rich conditions such as interior of a neutron star. In such neutron-rich state, the negatively charged pions can be produced copiously. Furthermore, these negatively charged pions can form a Bose-Einstein condensate with zero momentum above nuclear saturation densities. In this paper, we evaluate the self-energy of the negatively charged pion using the phase shift data from the pion-nucleon scattering as well the pion-pion scattering experiments. The self-energy is determined at material conditions present in a neutron star during binary merger. We notice that the pion-nucleon scattering can lead to both positive (attractive) and negative (repulsive) pionic self-energy. This pion-nucleon interaction can lead to a few percent change in the pion energy from its free value at supranuclear densities. On the other hand, the repulsive pion-pion interaction results in purely positive self-energy. While evaluating the self-energy related to the purely pionic interaction, we consider both the condensed pions with zero momentum, and the thermal pions with finite momenta. At zero temperature, the self-energy due to the pion-pion interaction is dominated by the condensate part. Whereas, the thermal part can prevail over the condensate part at finite temperatures. Similar to the pion-nucleon case, the self-energy due to the pion-pion interaction also results in a few percent change in the pion energy compared to that of the free pion. Overall, we see that the pionic self-energy is dominated by the pion-pion interaction at lower pion momenta and by the pion-nucleon interaction at greater momenta. Moreover, the pion momentum, where the pion-nucleon interaction becomes dominant over the pion-pion interaction, depends on the
matter condition. Furthermore, we studied the impact of the interacting pions on the high-density nuclear equation of state, and on the neutron star structure under the β-equilibrium condition. For this study, we modified the non-pionic SFHo equation of state is modified to include pions. The introduction of pions softens the equation of state and reduces the maximum neutron star mass compared to that of the equation of state without pions. Moreover, the pion production leads to the shrinking of the NS radius for a given central baryonic number density. Furthermore, we notice rather similar mass-radius, and mass-density relations of the neutron star between the EOS with interacting pions and the EOS with free/non-interacting pions.

Astrophysical, multi-messenger observations / 71

Nuclear equation-of-state in neutron star mergers

Autor Carolyn Raithel[1]

[1] *Institute for Advanced Study / Princeton University*

Korrespondenzautor: craithel@ias.edu

Binary neutron star (BNS) mergers provide a unique probe of the dense-matter equation of state (EOS) across a wide range of parameter space, from the cold, equilibrium conditions of the inspiral to the shock-heated and dynamical environment of the post-merger remnant. In this talk, I will discuss what we can (and cannot) learn about the EOS from current and upcoming observations of binary neutron star inspirals. I will then present recent BNS merger simulations to discuss the new EOS constraints we may be able to extract from a future measurement of gravitational waves from the hot and massive remnant that forms following the merger.

Astrophysical, multi-messenger observations / 35

Extreme matter with gravitational wave observations

Autor Jocelyn Read[1]

[1] *CSU Fullerton*

Korrespondenzautor: jread@fullerton.edu

Gravitational-wave observatories have established a new field of transient astronomy. The most recent LIGO-Virgo-Kagra catalog, GWTC-3, identifies 90 merging binaries, which range from a double neutron star with a total mass of 2.7 at 40 Mpc (GW170817) to a double black hole with a total mass of 150 at 5.3 Gpc (GW190521). These observations have many potential implications for dense matter physics: revealing the remnants of supernovae in merging binary systems, constraining rates and astrophysical environments of heavy-element nucleosynthesis events, and illuminating the dense matter dynamics inside the mergers of neutron stars. Here, I will describe the imprint of dense matter physics and implications from existing observations, and outline prospects for the coming years including the science potential of proposed next-generation observatories like Cosmic Explorer and Einstein Telescope.

Colloquium / 63

Binary Neutron Stars: from macroscopic collisions to microphysics

Autor Luciano Rezzolla[1]

[1] *Institute for Theoretical Physics, Frankfurt*

Korrespondenzautor: rezzolla@itp.uni-frankfurt.de

I will argue that if black holes represent one the most fascinating implications of Einstein's theory of gravity, neutron stars in binary system are its richest laboratory, where gravity blends with astrophysics and particle physics. I will discuss the rapid recent progress made in modelling these systems and show how the gravitational signal can provide tight constraints on the equation of state and sound speed for matter at nuclear densities, as well as on one of the most important consequences of general relativity for compact stars: the existence of a maximum mass. Finally, I will discuss how the merger may lead to a phase transition from hadronic to quark matter. Such a process would lead to a signature in the post-merger gravitational-wave signal and open an observational window on the production of quark matter in the present Universe.

Nuclear structure, short-range correlations and direct reactions / 32

The symmetry energy from ground and excited state properties of atomic nuclei

Autor Xavier Roca Maza[1]

[1] *Universita' degli Studi di Milano and Istituto Nazionale di Fisica Nucleare*

Korrespondenzautor: xavier.roca.maza@mi.infn.it

This contribution reviews a selection of available constraints to the nuclear symmetry energy around saturation density from nuclear structure calculations on ground and collective excited state properties of atomic nuclei. Special focus will be given to the parity violating asymmetry and dipole polarizability in 48Ca and 208Pb. Phenomenologic as well as microscopic results –whenever available– will be presented and discussed.

Investigations at existing and future accelerator facilities and detectors / 66

ASY-EOS II –observable and expectations

Autoren Paolo Russotto[1]; Arnaud Le Fevre[2]; Jerzy Łukasik[3]

[1] *Instituto Nazionale di Fisica Nucleare (INFN-Catania)*

[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)*

[3] *IFJ PAN*

Korrespondenzautor: russotto@lns.infn.it

Elliptic flow as measured in heavy-ion collisions has proven to be very effective in constraining nuclear matter equation of state at supra-saturation densities. In particular neutron-to-proton and neutron-to-charged particles elliptic flow ratio in Au+Au at 400 MeV/nucleon collisions, measured at GSI in FOPI-LAND and ASY-EOS experiments, have allowed to investigate the symmetry energy behavior up to about 1.5 ρ_0. Our future plans foresee the measure of the neutron-to-proton elliptic flow ratio excitation function in Au+Au collisions at GSI from 250 to 800 MeV/nucleon. This will allow to extend the studies toward higher densities than before and to get more precise constraints. The obtainable results, in conjunction to the novel ones coming from multi-messenger astronomy, could be of great importance in the field.

Microscopic calculations of neutron-rich, dense nuclear matter / 1

The Symmetry Energy: Current Status of Ab Initio Predictions vs. Empirical Constraints

Autor Francesca Sammarruca[1]

[1] *University of Idaho*

Korrespondenzautor: fsammarr@uidaho.edu

Infinite nuclear matter is a suitable laboratory to learn about nuclear forces in many-body systems. Modern theoretical predictions of neutron-rich matter are particularly timely in view of recent and planned measurements of observables which are sensitive to the equation of state of isospin-asymmetric matter. For these reasons, over the past several years we have taken a broad look at the equation of state of neutron-rich matter and the closely related symmetry energy, which is the focal point of this article. Its density dependence is of paramount importance for a number of nuclear and astrophysical systems, ranging from neutron skins to the structure of neutron stars. We review and discuss ab initio predictions in relation to recent empirical constraints. We emphasize and demonstrate that free-space NN data pose stringent constraints on the density dependence of the neutron matter equation of state, which essentially determines the slope of the symmetry energy at saturation.

Theory of supernovae and neutron stars / 55

Impact of symmetry energy on heavy baryon formation in neutron stars

Autor Armen Sedrakian[1]

[1] *FIAS and UWR*

Korrespondenzautor: sedrakian@fias.uni-frankfurt.de

I will discuss the equation of state and composition of dense matter with heavy baryons within covariant density functional (CDF) theory. The sensitivity of the results on the structure of compact stars to variation of the slope of symmetry energy and the skewness is demonstrated. The finite temperature equation of state and its implications for multimessenger astrophysics is also discussed

Poster flash talks / 73

Nuclear pastas in neutron stars: role of the symmetry energy

Autoren Nikolai Shchechilin[1]; Nicolas Chamel[2]; John Michael Pearson[3]

[1] *Universite Libre de Bruxelles*

[2] *Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles, Belgium.*

[3] *Universite de Montreal*

Korrespondenzautor: nikolai.shchechilin@ulb.be

The deepest region of the neutron star (NS) crust may consist of a layer of so-called nuclear pastas. If they exist, these exotic nuclear structures could significantly affect the transport and mechanical properties of dense matter, leaving their imprints on such NS observables as continuous gravitational-wave emission, NS oscillations and their damping, the spin period of x-ray pulsars, and NS cooling.

Here we study the pasta phases by employing the fourth-order extended Thomas-Fermi method (ETF) with Strutinsky integral (SI) and pairing corrections consistently added on top. We consider the series of Brussels-Montreal functionals accurately fitted to nuclear masses but imposing various symmetry-energy coefficients J or constraining to reproduce a different neutron-matter equation of state. These functionals predict different behaviors for the symmetry energy at subsaturation densities corresponding to the pasta phases.

In our calculations at the pure ETF level, we observe a larger fraction of pasta phases for functionals with higher values of the symmetry energy at the relevant densities (generally corresponding to lower values for J and slope L). This is due to the threshold density $\bar{n}_{\rm sp}$ for the onset of pasta phases being decreased while the crust-core transition density $\bar{n}_{\rm cc}$ is raised. However, the inclusion of microscopic (SI plus pairing) corrections reduces substantially the abundance of pastas for

all functionals by shifting $\bar{n}_{\rm sp}$ and blurring its correlation with symmetry energy. As a result, the influence of symmetry energy on the pasta phases presence weakens.

Combined analysis of nuclear and astrophysics information, Bayesian approach, and machine learning / 70

Multi-messenger astrophysics and the nuclear symmetry energy (online)

Autor Rahul Somasundaram[None]

Korrespondenzautor: rsomasun@syr.edu

The last few years have seen tremendous progress in multi-messenger observations of neutron stars (NS) that have constrained their global properties such as their masses, radii and tidal deformabilities. These constraints could be used to obtain valuable information on the nuclear symmetry energy. However, in order to do so, we require rigorous theoretical nuclear physics inputs to interpret the data. The main focus of my talk will therefore be the interplay between these theoretical models and experimental NS observations that allow us to infer the nuclear symmetry energy. On the theory side, I will discuss the metamodel- a powerful approach that allows us to model the symmetry energy in a model-agnostic manner as well as chiral effective field theory- the dominant state-of-the-art approach that allows for ab-initio constraints on the low-density equation of state. I will show how an approach that combines the two methods provides stringent constraints on the symmetry energy at relatively low density ($n \leq n_{\rm sat}$). As an offshoot, I will discuss properties of NSs that are directly impacted by the low-density symmetry energy, such as the crust of NSs. Finally, I will show how these theoretical models can be used together with multi-messenger observations, such as gravitational wave and X-ray observations, to probe the symmetry energy at larger densities explored in the inner cores of NSs.

Constraints from heavy-ion collisions at relativistic energies / 47

The equation of state of symmetric nuclear matter from heavy-ion collisions

Autor Agnieszka Sorensen[1]

[1] *University of Washington*

Korrespondenzautor: agnieszka.sorensen@gmail.com

Constraining the equation of state (EOS) of dense symmetric nuclear matter has been the goal of numerous experimental heavy-ion efforts worldwide, including the early experiments at the AGS and SPS, the currently ongoing efforts such as the Beam Energy Scan program at RHIC and the HADES experiment at GSI, and future experiments such as the Compressed Baryonic Matter experiment at FAIR. Beyond being interesting on its own, constraints on the symmetric nuclear matter EOS can provide an important baseline for studies of the nuclear symmetry energy, whether using state-of-the-art experiments at rare isotope beam facilities or based on observations of neutron stars and neutron star mergers. In this talk, I will discuss recent theoretical developments in constraining the dense symmetric nuclear matter EOS from comparisons of heavy-ion collision simulations to experimental data. I will also highlight the necessary steps needed for a robust extraction of the EOS from the available and upcoming experimental results.

International long-range plan round-table / 88

Transport models of heavy-ion collisions

Korrespondenzautoren: dan.cozma@theory.nipne.ro, agnieszka.sorensen@gmail.com

Theory of supernovae and neutron stars / 30

Neutrino emission in (proto-)neutron star matter

Autor Lami Suleiman[1]

Co-Autoren: Micaela Oertel [2]; Marco Mancini [2]

[1] *Nicholas and Lee Begovich Center for Gravitational Wave Physics and Astronomy, California State University Fullerton*

[2] *Laboratoire Univers et Theories, Observatoire de Paris*

Korrespondenzautor: lami.suleiman@hotmail.fr

Neutrinos play a crucial role in neutron star physics, from their birth in a core-collapse supernovae where neutrinos dictate the dynamics of the explosion, to the merger by determining the matter composition in the ejecta for heavy element nucleosynthesis. They are also key actors of cooling in (proto-)neutron stars and of the thermal relaxation of accreting neutron stars. Identifying different efficient neutrino emission processes in neutron star matter, and providing an accurate calculation of neutrino emissivity is important to understand the astrophysical features of neutron stars, and to investigate highly dense matter.

After a quick overview of the various neutrino emission processes that can occur in neutron star matter, we propose to focus on Urca reactions. The so called direct Urca (dUrca) and modified Urca (mUrca) reactions operate via the charged current of the weak interaction. It is well known that dUrca reactions (very efficient neutrino emission process) observe a threshold that depend on the cinematic conditions and on the equation of state of dense matter. The mUrca reaction, which involves an additional baryon exchanging momentum via strong interaction, can lift the kinematic restrictions, but is less efficient. Although both processes were extensively studied in cold neutron star matter, and investigated in finite temperature dilute matter, calculations for the mUrca neutrino emission always implied limiting approximations.

We present new results for the mUrca neutrino emission in thermodynamic conditions which are relevant for supernovae, proto-neutron stars and mergers of neutron stars. We alleviated several of the usual approximations taken and compared our results to already established derivations. We find that there exists regimes of temperature and density in which the mUrca emission can be of the same order as the dUrca emission even when the latter is active. We show that those regimes can be anticipated from the thermodynamic quantities determined by the equation of state using a simple analytical derivation. These regimes are potentially relevant to determine beta-equilibrium conditions in binary neutron star merger or the late cooling of a proton neutron star.

Combined analysis of nuclear and astrophysics information, Bayesian approach, and machine learning / 37

The Nuclear Equation of State from Experiments and Astronomical Observations

Autoren Chun Yuen Tsang[1]; Betty Tsang[2]; William Lynch[2]; Rohit Kumar[3]; Charles Horowitz[4]

[1] *Kent State University*

[2] *Michigan State University*

[3] *FRIB*

[4] *Indiana University*

Korrespondenzautoren: tsang@nscl.msu.edu, ctsang@bnl.gov

With recent advances in astronomical observations, major progress has been made in determining the pressure of neutron star matter at high density. This pressure is constrained by the neutron star deformability, determined from gravitational waves emitted in a neutron-star merger, and measurements of radii for two neutron stars with measured masses, using a new X-ray observatory on the International Space Station. Previous studies have relied on nuclear theory calculations to constrain the equation of state at low density. Here we use a combination of 15 constraints composed of three astronomical observations and twelve nuclear experimental constraints that extend over a wide range of densities. A Bayesian inference framework is then used to obtain a comprehensive nuclear equation of state. This data-centric result provides benchmarks for theoretical calculations and modeling of nuclear matter and neutron stars. Furthermore, it provides insights on the composition of neutron stars and their cooling via neutrino radiation.

Astrophysical, multi-messenger observations / 28

Using Multimessenger Observations of Neutron Star Mergers to Probe Symmetry Energy

Autoren David Tsang[1]; Duncan Neill[1]; William Newton[2]

[1] *University of Bath*

[2] *Texas A&M University-Commerce*

Korrespondenzautor: d.tsang@bath.ac.uk

Neutron stars are the universe's best natural laboratories to study dense nuclear, matter. At high densities, low temperatures, and high isospin asymmtery inaccessible in terrestrial collider experiments, neutron stars host the most extreme matter in the universe. Different regions of neutron stars will probe different physics, with some observables dominated by the poorly understood physics at supranuclear densities, while others can be used to constrain properties of nucleonic matter, such as the nuclear Symmetry Energy. I will discuss our latest work on Resonant Shattering Flares, multimessenger signatures which can be used as a powerful constraint on the Symmetry Energy. Studying different astrophysical observables of neutron stars can provide probes at different densities, and hence of different physics.

International long-range plan round-table / 85

Nuclear structure, short-range correlations

Korrespondenzautor: stypel@ikp.tu-darmstadt.de

International long-range plan round-table / 87

Future facilities and experiments

Korrespondenzautoren: zbigniew.chajecki@wmich.edu, p.senger@gsi.de, giuseppe.verde@ct.infn.it

Nuclear structure, short-range correlations and direct reactions / 23

Nuclear symmetry energy from isobar collisions at RHIC

Autor Fuqiang Wang[1]

[1] *Purdue University*

Korrespondenzautor: fqwang@purdue.edu

Isobar $^{96}_{44}$Ru+$^{96}_{44}$Ru and $^{96}_{40}$Zr+$^{96}_{40}$Zr collisions at nucleon-nucleon center-of-mass energy of 200 GeV at the Relativistic Heavy Ion Collider (RHIC) were initially proposed as a decisive experiment on the chiral magnetic effect, presuming identical QCD background [1]. They turned out to be rather different, by, for instance, as large as 5% in multiplicity [2]. Such a difference roots in the differing nuclear structures of the $^{96}_{44}$Ru and $^{96}_{40}$Zr nuclei, the latter having a significantly thicker neutron skin. This is predicted by energy density functional calculations [3] and can be utilized to probe the nuclear symmetry energy [4]. In this talk, I will present the density slope parameter of the symmetry energy extracted from the isobar data at RHIC. I will detail the systematics due to model dependencies, which are distinct from those in low-energy scattering experiments, highlighting the importance of such a measurement at RHIC. I will end with a set of outlooks bridging the subfields of nuclear structure and high-energy nuclear collisions.
[1] Sergei A. Voloshin, Phys.Rev.Lett. 105 (2010) 172301
[2] STAR Collaboration, Phys.Rev.C 105 (2022) 1, 014901
[3] Hao-jie Xu et al. Phys.Rev.Lett. 121 (2018) 022301
[4] Hanlin Li et al., Phys.Rev.Lett. 125, 222301 (2020)

Transport model simulations of heavy-ion reactions / 9

Kinetic approach of light-nuclei production in intermediate-energy heavy-ion collisions

Autor Rui Wang[None]

Co-Autoren: Che Ming Ko ; Zhen Zhang ; Lie-Wen Chen ; Kai-Jia Sun ; Yu-Gang Ma

Korrespondenzautor: ray_sjtu@hotmail.com

We develop a kinetic approach to the production of light nuclei up to mass number A = 4 in intermediate-energy heavy-ion collisions by including them as dynamic degrees of freedom. The conversions between nucleons and light nuclei during the collisions are incorporated dynamically via the breakup of light nuclei by a nucleon and their inverse reactions. We also include the Mott effect on light nuclei, i.e., a light nucleus would no longer be bound if the phase-space density of its surrounding nucleons is too large. With this kinetic approach, we obtain a reasonable description of the measured yields of light nuclei in central Au+Au collisions at energies of 0.25 - 1.0A GeV by the FOPI collaboration. Our study also indicates that the observed enhancement of the α-particle yield at low incident energies can be attributed to a weaker Mott effect on the α-particle, which makes it more difficult to dissolve in nuclear medium, as a result of its much larger binding energy.

Microscopic calculations of neutron-rich, dense nuclear matter / 4

Nuclear matter and neutron stars from the relativistic Brueckner-Hartree-Fock theory in the full Dirac space

Autoren Sibo Wang[1]; Hui Tong[2]; Xiaoying Qu[3]; Chencan Wang[4]; Qiang Zhao[5]; Peter Ring[6]; Jie Meng[7]

[1] *Chongqing University*

[2] *Helmholtz-Institut für Strahlen- und Kernphysik and Bethe Center for Theoretical Physics, Bonn University, Germany*

[3] *School of Mechatronics Engineering, Guizhou Minzu University, China*

[4] *School of Physics and astronomy, Sun Yat-Sen University, China*

[5] *Center for Exotic Nuclear Studies, Institute for Basic Science, Daejeon, Korea*

[6] *TU Munich, Germany*

[7] *School of Physics, Peking University, China*

Korrespondenzautor: sbwang@cqu.edu.cn

It is still a challenging task to derive the symmetry energy and equation of state for neutron stars from the underlying realistic nucleon-nucleon interaction. The relativistic Brueckner-Hartree-Fock (RBHF) theory provides a relativistic ab-initio approach, which is able to reproduce saturation properties of symmetric nuclear matter without three-body forces. However, most of the past work have considered only the positive-energy states, with different additional approximations on the neglected negative-energy states. Recently, the self-consistent solution of the RBHF equations in the full Dirac space was achieved for the first time. The symmetry energy and its slope parameter at the saturation density are 33.1 MeV and 65.2 MeV, in good agreement with empirical and experimental values. Further applications predict the radius of the neutron star with 1.4 times solar mass 12 km and the maximum mass of a neutron star less than 2.4 times solar mass. These applications reveal clearly the importance of the full Dirac space. We anticipate that our work can be suitably gauged against other theoretical approaches which are based on phenomenological and non-relativistic ab-initio methods, thus leading to a concerted effort to pin down the properties of nuclear matter and neutron star matter.

Constraints from heavy-ion collisions at Fermi energies / 3

Nuclear equation-of-state studies with the compact spectrometer for heavy-ion experiment (CSHINE)

Autor Yijie Wang[1]

Co-Autoren: Mengting Wan ; Li Ou ; Zhigang Xiao

[1] *Tsinghua University*

Korrespondenzautor: yj-wang15@tsinghua.org.cn

The isospin-dependent equation of state of nuclear matter, i.e. symmetry energy $E_{sym}(\rho)$ plays an important role in the study of nuclear physics and Astrophysics. In terrestrial lab, heavy ion collision provides a unique way to constrain $E_{sym}(\rho)$. So a compact spectrometer for heavy ion experiment（CSHINE）is built and coincident events are measured.
Via HBT intensity interferometry method, the proton emission timescale $\tau_p \approx$ 100 fm/c is extracted, and the dynamic emission order of $\tau_p\ \ \tau_d\ \ \tau_t$ is evidenced in $30MeV/u^{40}Ar +^{197} Au$, indicating that the neutron rich particles are emitted earlier. Transport model simulations demonstrate that the emission order of light charged particles depends sensitively on the stiffness of the nuclear symmetry energy [PLB, 825, 136856 (2022)].
The anticorrelation of the neutron-to-proton ratio N/Z of the two emitted clusters in $25MeV/u^{86}Kr+^{208} Pb$ is observed, revealing a vivid ping-pong picture on how the isospin degree of freedom evolves to equilibration through cluster emission. The novel observation provides a new window to inspect the coupling of isospin dynamics and cluster formation, and confirms the general importance of symmetry energy in systems from ground to highly excited states [PRC, 107, L041601 (2023)].

Transport model simulations of heavy-ion reactions / 75

Transport Model Evaluation Project (TMEP): Status and Future Directions

Autor Hermann Wolter[1]

[1] *University of Munich*

Korrespondenzautor: hermann.wolter@lmu.de

Transport models are indispensable in order to obtain information on the nuclear equation-of-state and in-medium properties of nucleons from heavy-ion collisions generally, and, in particular, in the hadronic intermediate-energy regime to constrain such quantities as the density dependence of the symmetry energy, since they are able to take into account the non-equilibrium features of such processes. Because of the complexity of the underlying equations, they are commonly solved by simulations, which involve choices of strategies, which are not always determined by theory. In the past this has led to conflicting results derived from the same experimental data. It is thus important to assess und possibly reduce the uncertainty of transport model studies, which is the idea behind the TMEP.
In the past years we have performed a number of comparative studies of transport simulations with controlled input of physical models both for full heavy-ion collisions and in boxes with periodic boundary conditions approximating nuclear matter conditions. The present result of these studies is on one hand, that considerable differences are seen between the results of different codes, and, on the other hand, that these differences can be traced back to particular strategies of the codes. In some cases we can recommend optimal strategies, others touch basic questions of non-equilibrium physics, such as the amount and treatment of fluctuations.
This contribution will also discuss suggestions for future directions of these studies. As the present comparisons have mostly involved rather simple physical models, one needs to obtain information on the influence of important ingredients for realistic descriptions of HICs, as e.g. momentum-dependent interactions, clustering, and short-range correlations. Secondly, one should study the sensitivity of transport model studies to the physical model, which should be greater than the uncertainty of the predictions. And finally, in order to quantify the uncertainty, it is important that a viable simulation describes not only some rare probes, but also a range of observables which correspond to the degrees of freedom, that dominate the reaction dynamics.

Investigations at existing and future accelerator facilities and detectors / **69**

Studies of nuclear equation of state with the HIRFL-CSR external target experiment (CEE)

Autor Zhigang Xiao[1]

[1] *Department of Physics, Tsinghua University*

Korrespondenzautor: xiaozg@tsinghua.edu.cn

The HIRFL-CSR external-target experiment (CEE) will be the first large-scale nuclear physics experiment working at GeV/u energy regime in China, providing new opportunities to the studies of nuclear equation of state. The construction of the whole spectrometers is in good progress, most of the design parameters of the detector are fixed. Based on these parameters, we have conducted the fast simulations of the detector performance and the responses to various physical observables, using GEANT 4 to track the charged particles produced by UrQMD transport model as the event generator. The design, construction status and performance expectations of CEE, as well as the feasibility of the studies of nuclear EOS are introduced in this talk.

Nuclear structure, short-range correlations and direct reactions / **2**

Probing neutron skin with free spectator nucleons in ultracentral relativistic heavy-ion collisions

Autor Jun Xu[1]

Co-Autoren: Lu-Meng Liu ; Jiangyong Jia ; Chun-Jian Zhang

[1] *Tongji University*

Korrespondenzautor: junxu@tongji.edu.cn

The neutron-skin thickness is one of the most robust probes of the slope parameter of the nuclear symmetry energy, which is responsible for the main uncertainty of the nuclear matter equation of state. Relativistic heavy-ion collisions may serve as a complementary measurement of the neutron-skin thickness, in addition to various methods in nuclear structure studies. In these collisions, we propose that the free spectator nucleons, which can be measured by zero-degree calorimeters, are clean probes of the neutron-skin thickness of the colliding nuclei. Based on the initial density distributions of typical nuclei calculated from the Skyrme-Hartree-Fock-Bogolyubov model, the information of spectator matter can be obtained from the Glauber model, and the free spectator nucleons are produced from a multi-fragmentation process from the spectator matter. In ultracentral collisions, these free spectator nucleons are most robust probes of the neutron skin, free from the uncertainty of the deexcitation process. In deformed nuclei, the neutron-skin thickness may have a polar angular distribution, which is sensitive to the nuclear spin-orbit interaction as well as the neutron and proton numbers of the nucleus. We have further explored the possibility of probing the polar angular distribution of the neutron skin in colliding nuclei, by measuring the numbers of free spectator neutrons and protons in different collision configurations.

Nuclear structure, short-range correlations and direct reactions / 74

Recent progress of nuclear matter EOS and cluster studies via direct nuclear reactions (online)

Autor Juzo Zenihiro[1]

[1] *Kyoto University*

Korrespondenzautor: juzo@scphys.kyoto-u.ac.jp

Nuclear many-body system is a self-organizing active matter, which has seemingly contradictory aspects of uniform single-particle matter and non-uniform cluster-forming matter. Recently, we have launched two complementary experimental programs "ESPRI/ONOKORO" to study uniform/non-uniform properties in nuclei and nuclear matter. In the projects, direct reaction methods with hadronic probes at intermediate energy have been developed to extract fundamental quantities in nuclei like isovector nucleon density distributions and cluster formation probabilities. In this talk, the recent progress of the projects and the future plans will be presented.

Theory of supernovae and neutron stars / 13

Impact of Symmetry Energy on Sound Speed and Spinodal Decomposition in Dense Neutron-Rich Matter

Autoren Nai-Bo Zhang[1]; Bao-An Li[None]

[1] *Southeast University*

Korrespondenzautor: naibozhang90@foxmail.com

Using a meta model for nuclear Equation of State (EOS) with its parameters constrained by astrophysical observations and terrestrial nuclear experiments, we examine effects of nuclear EOS especially its symmetry energy \esym term on the speed of sound squared $C_s^2(\rho)$ and the critical density ρ_t where $C_s^2(\rho_t)$ vanishes (indicating the onset of spinodal decomposition) in both dense neutron-rich

nucleonic matter relevant for relativistic heavy-ion collisions and the cold $n+p+e+\mu$ matter in neutron stars at β-equilibrium. Unlike in nucleonic matter with fixed values of the isospin asymmetry δ, in neutron stars with a density dependent isospin profile $\delta(\rho)$ determined consistently by the β equilibrium and charge neutrality conditions, the $C_s^2(\rho)$ almost always show a peak and then vanishes at ρ_t. The latter strongly depends on the high-density behavior of \esym if the skewness parameter J_0 characterizing the stiffness of high-density symmetric nuclear matter (SNM) EOS is not too far above its currently known most probable value of about -190 MeV inferred from recent Bayesian analyses of neutron star observables. Moreover, in the case of having a super-soft \esym that is decreasing with increasing density above about twice the saturation density of nuclear matter, the ρ_t is significantly lower than the density where the \esym vanishes (indicating the onset of isospin-separation instability and pure neutron matter formation) in neutron star cores.

Transport model simulations of heavy-ion reactions / 18

Refinements of the transport models and the constraints on symmetry energy

Autor Yingxun Zhang[1]

[1] *China Institute of Atomic Energy*

Korrespondenzautor: zhyx@ciae.ac.cn

In my talk, I will present the efforts on the refinement of the transport models after the TMEP projection. The improvements include the refined nonlinear term in the nucleonic mean field, momentum-dependent interactions, and NN→NΔ cross sections. Based on the updated models, the influence of symmetry energy and effective mass splitting on the neutron to proton yield ratios, triton to Helium-3 ratios are discussed. Further, the nucleonic flow and pion ratios are also discussed for learning the symmetry energy at suprasaturation density.

Poster flash talks / 33

KRAB detector for the ASY-EOS II experiment

Autor Jerzy Łukasik[1]

Co-Autoren: Andrzej Wieloch ; Bogdan Sowicki ; Janusz Brzychczyk ; Konrad Krawczyk ; Konrad Łojek ; Krzysztof Szczepaniec ; Paweł Lasko ; Piotr Pawłowski

[1] *IFJ PAN*

Korrespondenzautor: jerzy.lukasik@ifj.edu.pl

First results of the tests of the newly constructed KRAB detector will be presented. The tests have been performed with the Bi source, cosmic rays and with the proton beams from the CCB cyclotron in Krakow. The detector was designed to provide fast, multiplicity based trigger for the future ASY-EOS II experiment as well as the information on the azimuthal distributions of the reaction products and on the centrality of the collision. The experiment is aimed to provide new constraints on the stiffness of the nuclear Equation of State based on the analysis of the neutron and proton flows.

KRAB consists of 736 plastic scintillating fiber segments distributed in 5 rings and read out by silicon photomultipliers. It was successfully commissioned in May 2022. The detector is equipped with the helium sleeve enclosing the remotely controlled target wheel, FPGA based trigger box and CITIROC based front end

electronics. The sleeve is supposed to reduce the background caused by the delta-electrons. The wheel has 4 target slots.

The detector is fully operational, 100% of channels work. Generation of the trigger takes about 50 ns. To complete the tests and provide optimal settings for the electronic channels a heavy ion beam test is needed and is foreseen to be performed at GSI, Germany or at HIMAC, Japan in the near future.