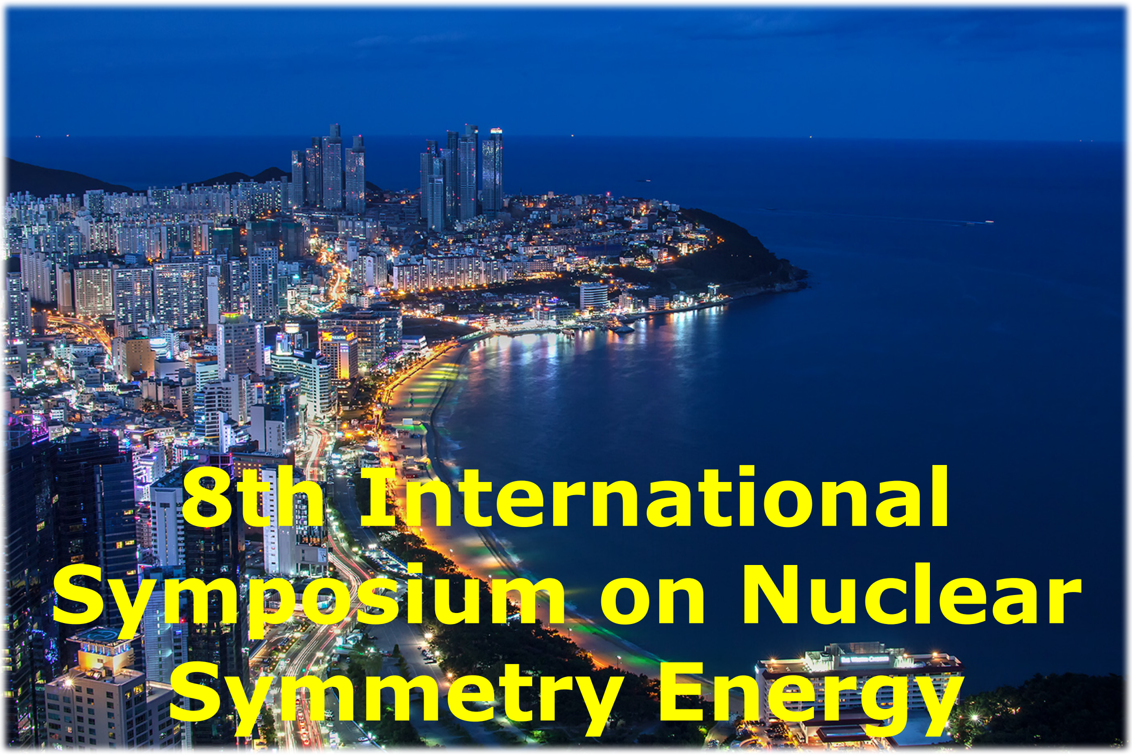

8th International Symposium on Nuclear Symmetry Energy (NuSYM2018)

10 ~ 13 September 2018
Hanwha resort (Haeundae Tivoli)
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Hosted by

고려대학교 기초과학연구원 THE INSTITUTE OF BASIC SCIENCE

PUSAN NATIONAL UNIVERSITY

ASIA PACIFIC CENTER FOR THEORETICAL PHYSICS (APCTP)

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Program

Monday, September 10

09:00-09:15 Welcoming address

- Session 1: Overview
  (Chair: Byungsik Hong)
  1. 09:15-09:45 Mannque Rho (CEA Saclay), Uncanny workings of the nuclear tensor force from exotic nuclei to neutron stars
  2. 09:45-10:15 Bill Lynch (NSCL/MSU), Present and expected constraints on the nuclear symmetry energy.

10:15-10:40 Break

- Session 2: Microscopic approaches I
  (Chair: Abdou Chbihi)
  1. 10:40-11:00 Jeremy W. Holt (Texas A&M University), Universal correlations in the nuclear symmetry energy, slope parameter, and curvature
  2. 11:00-11:20 Niels-Uwe Friedrich Bastian (University of Wroclaw), A unified quark-hadron equation of state and the effect of symmetry energy in quark-matter
  3. 11:20-11:40 Yeunhwan Lim (Texas A&M University), Nuclear symmetry energy from finite nuclei to neutron stars
  4. 11:40-12:00 Kris Hagel (Texas A&M University), The symmetry energy of low density nuclear matter

12:00-13:30 Lunch

- Session 3: Microscopic approaches II
  (Chair: Chang Ho Hyun)
  1. 13:30-13:50 Ulugbek Yakhshiev (Inha University), Symmetry energy in the chiral soliton model
  2. 13:50-14:10 Tsuyoshi Miyatsu (Tokyo University of Science), The role of Fock terms on nuclear symmetry energy in a relativistic framework
  3. 14:10-14:30 Kie Sang Jeong (APCTP), Isospin asymmetry in perspective of QCD symmetry breaking
  4. 14:30-14:50 Stefano Gandolfi (LANL), Quantum Monte Carlo calculations of pure neutron systems and the symmetry energy

14:50-15:20 Break

- Session 4: Neutron stars
  (Chair: Edward Brown)
  1. 15:20-15:40 Slavko Bogdanov (Columbia University), The Neutron Star Interior Composition Explorer
  2. 15:40-16:00 David Alvarez (BLTP JINR), The symmetry energy in neutron stars: constraints from GW170817 and direct Urca cooling.
  3. 16:00-16:20 Betty Tsang (NSCL/MSU), Comparison of symmetry energy constraint from neutron star merger and heavy ion collisions
  4. 16:20-16:40 Hyun Kyu Lee (Hanyang University), Nuclear symmetry energy in compact star matter II
  5. 16:40-17:00 Young-Min Kim (UNIST), Gravitational waves and tidal deformability of neutron stars
  6. 17:00-17:15 Soonchul Choi (Soongsil University), Relations between symmetry energy and tidal deformability
  7. 17:15-17:35 Morgane Fortin (N. Copernicus Astronomical Center), Neutron star properties, nuclear parameters, (hyper)nuclei, and gravitational waves

18:00-21:00 Reception

Tuesday, September 11

- Session 5: Equation of state
  (Chair: Peter Senger)
  1. 09:00-09:20 Paolo Napolitani (IPN Orsay), How DO volume and surface instabilities rival in heavy-ion collisions?
  2. 09:20-09:40 Abdou Chbihi (GANIL), Isospin effects on the nuclear equation of state
  3. 09:40-10:00 Zbigniew Chajecki (Western Michigan University), Probing the equation of state of asymmetric nuclear matter with heavy ion collisions
  4. 10:00-10:20 Jong-won Lee (Korea University), An application of 500 Msps FADC DAQ system to the NSCL LANA Detector
  5. 10:20-10:35 Myungguk Kim (Pusan National University), Application of parity doublet model in HIC

10:35-11:00 Break

- Session 6: Astrophysical objects
  (Chair: Zhigang Xiao)

1. 11:00-11:20 Andre da Silva Schneider (Stockholm University), Equation of state effects on core-collapse supernovae
2. 11:20-11:40 Kenichiro Nakazato (Kyushu University), Astrophysical implications of the nuclear symmetry energy
3. 11:40-12:00 Hajime Togashi (RIKEN), Supernova equation of state and symmetry energy at subnuclear densities
4. 12:00-12:20 Edward Brown (MSU), Measuring the specific heat and neutrino emissivity of neutron stars

12:20-14:00 Lunch

- Session 7: Heavy-ion collisions I
  (Chair: TadaAki Isobe)

1. 14:00-14:20 Gao-Chan Yong (IMP CAS), Several aspects on probing the high-density symmetry energy by HI collisions
2. 14:20-14:40 Peter Senger (GSI), Exploring the nuclear matter equation-of-state at neutron star core-densities
3. 14:40-14:55 Jung Woo Lee (Korea University), Charged particle track reconstruction for heavy ion collision experiments with SπRIT Time Projection Chamber
4. 14:55-15:15 Rensheng Wang (SooChow University & NSCL/MSU), Quality assurance for TPC data analysis of intermediate energy heavy ion collisions
5. 15:15-15:35 Mizuki Kurata-Nishimura (RIKEN), Collective flow at neutron rich Sn+Sn collisions with 270 MeV/u
6. 15:35-15:55 Arnaud Le Févre (GSI), Results of the ALADiN experiment at GSI: The asymmetry energy at sub-saturation density

15:55-16:20 Break

- Session 8: Heavy-ion collisions II
  (Chair: Jerzy Lukasik)

1. 16:20-16:40 Akira Ono (Tohoku University), Interplay between cluster correlations and collision dynamics
2. 16:40-17:00 Jun Su (Sun Yat-sen University), Dynamical properties and secondary decay effects of projectile fragmentations in ^{124}Sn,^{107}Sn + ^{120}Sn collisions at 600 MeV/nucleon
3. 17:00-17:20 Yingxun Zhang (CIAE), Constraints of symmetry energy from HICs and the in-medium NN→NΔ cross section
4. 17:20-17:40 Jun Xu (SINAP), Relevant studies on isospin splitting of nucleon effective mass

5. 17:40-18:00 Kyungil Kim (RISP/IBS), Effects of isospin asymmetry on the energy isotropy ratio of nucleons in heavy-ion collisions
6. 18:00-18:15 Masanori Kaneko (Kyoto university), Study of light cluster production in intermediate energetic heavy-RI collision at RIBF

Wednesday, September 12

- Session 9: Pions and deltas
  (Chair: Su Houng Lee)

1. 09:00-09:25 Che-Ming Ko (Texas A&M University), Pion production in HIC
2. 09:25-09:45 Natsumi Ikeno (Tottori University), Pauli blocking effects on pion production in heavy-ion collisions
3. 09:45-10:05 Genie Jhang (NSCL/MSU), Recent results on pion analysis of Sn+Sn collisions
4. 10:05-10:25 Masayasu Harada (Nagoya University), Study of phase structure of nuclear matter based on a parity doublet model

10:25-10:50 Break

- Session 10: Nuclear structure I
  (Chair: Zbigniew Chajecki)

1. 10:50-11:10 Long Zhu (Sun Yat-sen University), The mechanism of multinucleon transfer reactions for producing neutron-rich heavy nuclei
2. 11:10-11:30 Stefano Burrello (INFN Catania & Sevilla University), Understanding the isovector channel of nuclear interaction through heavy ion charge-exchange reactions
3. 11:30-11:50 Pawel Danielewicz (MSU/University of Kinshasa/African Institute for Mathematical Sciences), Stiff symmetry energy from thick isovector aura

11:50-13:00 Lunch

13:00-18:00 Excursion

18:00-21:00 Banquet

Thursday, September 13

- Session 11: Nuclear structure II
  (Chair: Giuseppe Verde)

1. 09:00-09:25 Robert Michaels (TJNL), Electroweak measurements of neutron densities in CREX and PREX at JLab, USA
2. 09:25-09:45 Bao-Hua Sun (Beihang University), Measurements of neutron-skin thickness of exotic nuclei via nuclear reaction cross section measurements
3. 09:45-10:05 Atsushi Tamii (RCNP), Electric dipole response of nuclei studied by proton scattering
4. 10:05-10:25 Panagiota Papakonstantinou (RISP/IBS), From homogeneous matter straight to nuclei: KIDS functional
5. 10:25-10:45 Chang Xu (Nanjing University), Density dependence of symmetry energy constrained by nuclear radioactivity data

10:45-11:10 Break

- Session 12: Microscopic approaches III
  (Chair: Ulugbek Yakhshiev)

1. 11:10-11:30 Marcella Grasso (IPN Orsay), From dilute matter to the equilibrium point in the energy-density-functional theory
2. 11:30-11:50 Xavier Roca-Maza (University of Milan & INFN), The nuclear symmetry energy and the breaking of the isospin symmetry: how do they reconcile with each other?
3. 11:50-12:10 Bao Yuan Sun (Lanzhou University), Correlated structure of nuclear symmetry energy from covariant nucleon self-energy
4. 12:10-12:30 Arianna Carbone (ECT*), Ab initio studies of infinite matter from a Green's function approach

12:30-14:00 Lunch

- Session 13: Heavy-ion collisions III
  (Chair: Yvonne Leifels)

1. 14:00-14:20 Giuseppe Verde (INFN Catania & IPN Orsay), In-medium structure in dilute and hot nuclear matter
2. 14:20-14:40 Jerzy Lukasik (IFJ-PAN, Krakow), Telescope energy spectra and the Ockham's razor
3. 14:40-15:00 Maria Colonna (INFN-LNS, Catania), Connecting the nuclear EoS to the interplay between low-energy reaction mechanisms
4. 15:00-15:20 Dan Cozma (IFIN-HH), Relativistic covariance corrections to transport models and symmetry energy constraints

15:20-15:50 Break

- Session 14: Facilities and future
  (Chair: Betty Tsang)
  1. 15:50-16:10 Wolfgang Trautmann (GSI), Symmetry energy at GSI/FAIR
  2. 16:10-16:30 Dominic Rossi (TU Darmstadt), Status of symmetry-energy studies at R3B
  3. 16:30-16:45 Hyunha Shim (Korea University), Performance of prototype neutron detectors for large-acceptance multipurpose spectrometer at RAON
  4. 16:45-17:05 Young Kwan Kwon (RISP/IBS), Status of RAON

- Session 15: Summary & Discussion
  (Chair: Betty Tsang)
  1. 17:05-17:35 Hermann Wolter (University of Munich), Summary
  2. 17:35-18:15 Discussion by all participants: Future emphasis

Session 1
Overview

Chair : Byungsik Hong

Session 1.1
Uncanny workings of the nuclear tensor force from exotic nuclei to neutron stars

Mannque Rho[1,*]

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The uncanny role of the nuclear tensor force in the properties of exotic nuclei as well as in the symmetry energy governing the EoS of compact stars is discussed. A topology change that takes place near twice nuclear matter density takes over the role of a smooth hadron-quark transition and impacts on the sound velocity in neutron stars and on the bound on the tiidal polarizability observed in coalescing neutron stars. I conjecture how to go from asymmetric nuclei to neutron stars in terms of what transpired at the WCU/Hanyang program.

Session 1.2
Present and expected constraints on the nuclear symmetry energy.

Bill Lynch[1,*]

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The nuclear symmetry energy is central to the understanding of matter found in neutron stars and in explosive stellar environments. This includes the correlation between neutron star radii and their masses, as well as the dynamics in neutron star mergers and core collapse supernovae in which many of the heavy elements are formed. Astrophysical observations have already provided some

constraints on the symmetry energy at supra-saturation densities. Measurements of masses, isobaric analog states, skins, giant resonances, pygmy resonances and dipole polarizabilities of nuclei, for example, have already provided laboratory constraints on the symmetry energy below saturation density. Constraints on the EoS at more extreme densities have been probed in nuclear reactions. In my talk, I will review progress that is being made in constraining the symmetry energy and discuss prospects where future progress may be expected. I will also discuss how to combine existing measurements to improve constraints on the symmetry energy.

Session 2
Microscopic Approaches I

Chair : Abdou Chbihi

Session 2.1
Universal correlations in the nuclear symmetry energy, slope parameter, and curvature

Jeremy W. Holt[1,*]

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From general Fermi liquid theory arguments, we derive correlations among the symmetry energy, its slope parameter, and curvature at nuclear matter saturation density. We show that certain properties of these correlations do not depend on details of the nuclear forces used in the calculation. We derive as well a global parametrization of the density dependence of the symmetry energy that is more reliable, especially at low densities, than the usual Taylor series expansion around saturation density. We then benchmark these predictions against explicit results from chiral effective field theory.

Session 2.2
A unified quark-hadron equation of state and the effect of symmetry energy in quark-matter.

Niels-Uwe Friedrich Bastian[1,*]

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The aim of our work is to develop a unified equation of state (EoS) for nuclear and quark matter for a wide range in temperature, baryon density and iso-spin asymmetry, which will make it applicable for heavy-ion collisions as well as for the astrophysics of neutron stars, neutron-star mergers and supernova explosions.

As a first step, we use improved EoS for the hadronic and quark matter phases and join them via Maxwell construction. To go beyond this simple Ansatz, we are developing a consistent cluster expansion for quark matter, based on the Phi- derivable formalism [1]. In hadronic phase this reproduces the generalized Beth-Uhlenbeck formalism by Roepke et.al. [2]. To this end, we work with a relativistic density functional approach for the self energies in a quasi particle picture [3], which gives us the possibility to start with a reasonable physical basis and apply improvements to fit certain constraints from lattice QCD and neutron star measurements.

Here the particular question about the symmetry energy of quark matter arises. Most quark matter models neglect the possible coupling to a iso-vector mean field (equivalent to the rho meson in hadronic sector), so their symmetry energy comes only from kinetic contributions. I would like to discuss the effect of such a field and the possible approaches for its (so far unknown) coupling parameters [4].

[1] N. U. F. Bastian, D. Blaschke, T. Fischer and G. Röpke, Universe 4, 67 (2018).
[2] G. Röpke, N.-U. Bastian, D. Blaschke, T. Klähn, S. Typel and H. H. Wolter, Nucl. Phys. A 897, 70 (2013).
[3] M. A. R. Kaltenborn, N. U. F. Bastian and D. B. Blaschke, Phys. Rev. D 96, 056024 (2017).
[4] T. Fischer, N. U. F. Bastian, M. R. Wu, S. Typel, T. Klähn and D. B. Blaschke, arXiv:1712.08788.

Session 2.3
Nuclear symmetry energy from finite nuclei to neutron stars

Yeunhwan Lim[1,*]

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The nuclear symmetry energy, the energy difference between pure neutron matter and symmetric nuclear matter, plays an essential role to understand various nuclear phenomenon. Symmetry energy parameters are constrained by various experimental results as well as astrophysical phenomenon and theoretical calculation of nuclear matter. We show how the neutron dripline varies as the symmetry energy parameter changes. The tidal deformabilities and moment of inertia of neutron stars according to the nuclear symmetry energy are also discussed.

Session 2.4
The Symmetry Energy of low density nuclear matter

Kris Hagel[1,*]

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Understanding the properties of low density nuclear matter is very important to understanding the evolution of core-collapse supernova explosion and properties of the neutrinosphere. Central collisions at intermediate energies produce nuclear matter having energies and densities similar to those of core-collapse supernovae. Products from sources of the hot early reaction stage of violent collisions of heavy ion reactions, denoted as femtonovae, are identified and analyzed in the context of a coalescence model. Various quantities from the analysis indicate that the temperature and density of the femtonovae is similar to that near the neutrinosphere. This talk will focus on the evolution of the symmetry energy of low density nuclear matter and what astrophysical implications can be drawn from that information.

Session 3
Microscopic Approaches II

Chair : Chang Ho Hyun

Session 3.1
Symmetry energy in the chiral soliton model

Ulugbek Yakhshiev[1,*]

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We will discuss the modifications of EoS and symmetry energy properties in the framework of in-medium modified chiral soliton model.

Session 3.2
The role of Fock terms on nuclear symmetry energy in a relativistic framework

Tsuyoshi Miyatsu[1,*]

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Using the relativistic Hartree-Fock approximation, we investigate the effect of Fock terms on the high-dense behavior of the nuclear symmetry energy and its slope parameter by taking into account the Lorentz-covariant decomposition of the nucleon self-energy. It is found that the Fock contribution suppresses the nuclear symmetry energy at high densities, compared with that calculated by the relativistic Hartree model. We also discuss how the Fock contribution affects the equation of states for dense nuclear matter.

Session 3.3
Isospin asymmetry in perspective of QCD symmetry breaking

Kie Sang Jeong[1,*]

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Isospin asymmetry is universal feature in various type of nuclear matter. Assuming quasi-nucleon states in the matter, one can define the equation of state (EOS) and conjecture the various properties of the matter. However, due to the lack of experimental information on the higher or lower density circumstance from the normal nuclear matter density, it has been hard to derive the EOS from the verified dynamics in hadron phase. If one can start from the first principle, quantum chromodynamics (QCD), different assumptions in different models would be classified as related one by analyzing the QCD effective structures in nucleon and quasi-nucleon. In this talk, I will present QCD interpolating currents for the baryon structure and the consequence of chiral symmetry breaking to the nucleon and quasi-nucleon state. Also, the asymmetric nature can be accounted by considering the other symmetry breaking natures such as axial anomaly. The strangeness puzzle and Delta isobar problem will be discussed in the same logic. Also the quark matter symmetry energy and updated results for the isospin asymmetry in perspective of QCD symmetry will be provided.

Session 3.4
Quantum Monte-Carlo calculations of pure neutron systems and the symmetry energy

Stefano Gandolfi[1,*]

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Recent advances in experiments of the symmetry energy of nuclear matter and in neutron star observations yield important new insights on the equation of state of neutron matter at nuclear densities. In this regime the EOS of neutron matter plays a critical role in determining the mass-radius relationship for neutron stars. We show how microscopic calculations of neutron matter, based on realistic two- and three-nucleon forces, make clear predictions for the relation between the isospin-asymmetry energy of nuclear matter and its density dependence, and the maximum mass and radius for a neutron star. We will also present results of neutrons confined in external potentials. We preformed ab-initio and mean-field calculations for these artificial systems, and we will show that their properties are correlated to the symmetry energy and its slope.

Session 4
Neutron Stars

Chair : Edward Brown

Session 4.1
The Neutron Star Interior Composition Explorer

Slavko Bogdanov[1,*]

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The state of cold matter at densities exceeding the nuclear saturation density is one of the principal unknowns in modern physics. Neutron stars are the only known setting in the Universe where matter in this regime can stably exist. For a give mass, the radius of the neutron star is determined by the pressure-density relation of the matter in its interior. X-ray photons emitted from the surface of a neutron star carry valuable information about the mass and radius of the star. Therefore, detail modeling of the surface X-ray radiation from neutron stars can, in principle, provide stringent constraints on the dense matter equation of state. The Neutron Star Interior Composition Explorer (NICER) is a NASA observatory deployed in June 2017 as an attached payload on the International Space Station. One of the principal science goals of NICER is to obtain constraints on the neutron star mass-radius relation via sensitive X-ray timing observations. In this talk, I will describe the NICER mission, the measurement technique it employs to deduce the dense matter equation of state, and present preliminary results.

Session 4.2
The symmetry energy in neutron stars: constraints from GW170817 and direct URCA Cooling.

David Alvarez[1,*]

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In this contribution I will review the state of the art measurements for the symmetry energy from both astrophysical and terrestrial laboratories. In particular the recent detection of gravitational radiation from the GW170817 event shed light on the properties of the neutron star equation of state, thus comprising both the study of the symmetry energy and stellar radius. Furthermore, I shall address the question on the possibility of a universal symmetry energy contribution to the neutron star equation of state under restricted Direct Urca cooling. When these two aspects are combined, powerful predictions for the neutron star equation of state are obtained.

Session 4.3
Comparison of symmetry energy constraint from neutron star merger and heavy ion collisions.

Betty Tsang[1,*]

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Session 4.4
Nuclear symmetry energy in compact star matter II

Hyun Kyu Lee[1,*]

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We discuss the effect of nuclear symmetry energy for the equation of state of compact star matter in relation to the tidal deformation due to the strong gravity of a companion star.

Session 4.5
Gravitational waves and tidal deformability of neutron stars

Young-Min Kim[1,*]

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Gravitational waves (GW170817) produced in a binary neutron star inspiral have been observed followed by gamma-ray burst (GRB 170817A) and afterglows from X-ray to radio. By combining the distance obtained by gravitational waves and red shift obtained by electromagnetic waves, even Hubble constant has been estimated. This indicates the start of new era of multimessenger astronomy. In addition to the masses of inspiralling neutron stars, the tidal deformability which depends on the inner structure of neutron stars has been estimated from gravitational waves. This confirms that even strong interactions can be tested by gravitational waves. In this talk, we discuss the effect of tidal deformability of neutron stars to the gravitational waves produced in the inspiral process and discuss the implications of detected tidal deformability to the neutron star equations of state. (This presentation is based on the review article published in New Physics: Sae Mulli.)

Session 4.6
Relations between symmetry energy and tidal deformability

Soonchul Choi[1,*]

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* gilgoon0211@naver.com

In 2017, the gravitational wave from binary neutron star merger is detected by the LIGO-Virgo Collaboration [Phys. Rev. Lett. 119, 161101 (2017)]. It gives the tidal deformability of the neutron star. The valuable information of equation of state (EoS) for the neutron star can be obtained from the tidal deformability. The equation of state for neutron star is related to the nuclear symmetry energy. Namely, There is a close relationship between the symmetry energy and properties of the neutron star.
On the other hand, [Phys. Rev. Lett. 120, 172702 (2018)] gives the relation between neutron skin thickness and neutron star radius. This reference provides an upper limit of the neutron skin thickness of 208Pb comes from the tidal deformability. The slope parameter of nuclear symmetry energy determines the neutron skin thickness [Phys. Rev. C 96, 024311 (2017)].
In this talk, we present the connection between neutron skin thickness and tidal deformability via the nuclear symmetry energy. We calculated the symmetry energy by using the two-type equation

of state. One is a density functional theory (DFT) which can be obtained by Skyrme-effective interaction. Another one is relativistic mean-field theory (RMF). Through these two-approach, we can obtain the neutron skin thickness and tidal deformability at the same time. We discuss how to the symmetry energy affect the neutron skin thickness and tidal deformability.

Session 4.7
Neutron star properties, nuclear parameters, (hyper)nuclei, and gravitational waves

Morgane Fortin[1,*]

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Neutron stars are formed in supernovae during the collapse that marks the end of the life of stars with a mass of about 10 solar masses. Although they have observed in all wavelengths for 50 years and gravitational waves were recently detected from a binary neutron star system, their structure and the properties of the matter inside them are still poorly known. I will present how multi-messenger observations of neutron stars and laboratory experiments may enable us to better understand and constrain the properties of neutron star matter.

Session 5
Equation of state

Chair : Peter Senger

Session 5.1
How volume and surface instabilities rival in heavy-ion collisions

Paolo Napolitani[1,*]

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Along the equation-of-state landscape, extreme values of density and incompressibility may result in unstable conditions and lead to clusterisation: an example is the spinodal instability. At variance with ideal conditions achievable in nuclear matter, heavy-ion collisions further introduce cohesive effects related to the surface, which also lead to fragment formation under high deformations: an example is fission and neck fragmentation. The scenario of heavy-ion collisions is therefore a battlefield where volume and surface instabilities compete. This intricate mechanism can be studied through the use of one-body approaches, well suited to describe zero-sound conditions and collective effects, supplemented by higher-order correlations to introduce fluctuations. Fluctuations are then able to develop spontaneously and enhance the leading instability, either of volume or surface type, depending on incompressibility, density, temperature and symmetry energy. A survey of practical cases, moving from nuclear-matter-like isotropic situations to extremely deformed conditions in heavy-ion collisions is proposed.

Session 5.2
Isospin effects on the nuclear equation of state

Abdou Chbihi[1,*]

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In this contribution we investigate the nuclear dynamics and the nuclear equation of state (NEOS) by a detailed study of heavy-ion collisions at intermediate energies. Indeed, we explore the isospin transport phenomena occurring during the collision between the projectile and target having different isospin contents. In particular, two observables are investigated the isospin diffusion and isospin migration. The former is related to the nucleon exchange process between the projectile and target; the latest is related to the neutron migration towards the low density region in the neck formed at mid-rapidity. Both observables provide an important information on the density dependence of the symmetry energy term of the NEOS.
We will report on the experiments ^{40,48}Ca+^{40,48}Ca at E/A=35 MeV performed at GANIL, where we coupled the VAMOS spectrometer with the 4 INDRA detector. The use of the high acceptance spectrometer is to measure the isotopic and velocity distributions of the projectile like fragment (PLF) with high resolution, and INDRA is used, to estimate the impact parameter and excitation energy by measuring all charged products emitted in coincidence with PLF. From these experiments we obtain a set of data that for the first time measure different isospin sensitive observables in the same reaction. In particular a direct detection of the PLF residue in coincidence with an extraction of information about the N/Z of mid-rapidity. The set of data is open to comparison to all transport models engaged to link data to the symmetry energy.

Session 5.3
Probing the equation of state of asymmetric nuclear matter with heavy ion collisions

Zbigniew Chajecki [1,*]

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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. The density and momentum dependence of the EOS of asymmetric nuclear matter, especially the symmetry energy term, is widely unconstrained. Collisions of neutron-deficient and neutron-rich heavy ions studied in the laboratory already provide initial constraints on the EoS of neutron-rich matter at sub-saturation densities. Finding appropriate constraints, especially at higher densities, requires new experimental measurements as well as advances in theoretical understanding of nuclear collisions and neutron stars. We present the results from the recent experiment performed at the National Superconducting Cyclotron Laboratory focused on studying the EOS through the observables involving charged particles and neutrons (e.g. neutron to proton spectral ratios, isoscaling). We show the comparison of experimental results to transport model calculations with the main focus on their sensitivity to both the density and momentum dependence of the nuclear symmetry potential and their importance to understanding the EOS of neutron star mergers.

Session 5.4
An application of 500 Msps FADC DAQ system to the NSCL LANA detector

Jong-won Lee[1,*]

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Korean LAMPS experiment group developed a 500 Msps FADC DAQ system for neutron detectors. The Large Area Neutron Array (LANA) was used to detect neutrons in NSCL experiments e14030 and e15190. Some of the LANA data was taken simultaneously with both the MSU-conventional electronics and Korean electronics. In this talk, I will discuss the characteristics of the FADC DAQ systems and the measured performance of the FADC as well as comparisons with conventional electronics.

Session 5.5
Application of parity doublet model in HIC

Myungguk Kim[1,*]

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The heavy-ion collision simulation using transport theory can describe various physical information expected in HIC experiments. We newly developed new transport code called "DaeJeon Boltzmann-Uehling-Uhlenbeck" (DJBUU). The parity doublet model is defined by adding chiral partner of the nucleon to linear sigma model in dense nuclear matter. However, the parity model is only considered in dense matter calculation. In this talk, I will present the application of DJBUU work frame to parity double model. Furthermore, we are expecting for testing new mean field potential model of dense matter in HIC simulation.

Session 6
Astrophysical objects
Chair : Zhigang Xiao

Session 6.1
Equation of state effects on core-collapse supernovae

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We use the open-source SROEOS code to construct several finite-temperature equations of state (EOSs) of dense matter. These EOSs are used to investigate how uncertainties in the properties of nuclear matter affect the core-collapse of a massive star and the resulting proto-neutron star. Nucleon effective masses, which play a minor role in the properties of cold beta-equilibrated neutron stars, play a major role on the observables of a core-collapse supernovae.

Session 6.2
Astrophysical implications of the nuclear symmetry energy

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The nuclear symmetry energy is an important ingredient to characterize the property of nuclear matter. In this talk, I will introduce the astrophysical implication of the symmetry energy. In sub-saturation densities, a phase of inhomogeneous nuclear matter appears. The property of this phase is known to be determined by the symmetry energy at the saturation density, Esym, and its slope parameter, L. Recently, we found [1] that the inhomogeneous nuclear matter affects the neutrino emission from a proto-neutron star, which is a nascent compact object and born after the supernova explosion. In contrast, to determine the mass-radius relation of

neutron stars, symmetry energy above the saturation density is important. I will emphasize this point in this talk.

[1] K. Nakazato et al., Phys. Rev. C 97, 035804 (2017).

Session 6.3
Supernova equation of state and symmetry energy at subnuclear densities

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Recently, we have constructed a new nuclear equation of state (EOS) for numerical simulations of core-collapse supernovae by using the cluster variational method for uniform matter and using the Thomas-Fermi calculation for non-uniform matter. In comparison with the Shen EOS, masses of heavy nuclides with our EOS are slightly larger in neutron-rich nuclear matter because of the smaller value of the density derivative coefficient of the symmetry energy in our EOS. In this study, we investigate the influence of the symmetry energy on the EOS of inhomogeneous nuclear matter at finite temperature in more detail. For this purpose, we systematically construct the non-uniform EOSs at finite temperature with the Thomas-Fermi calculation based on the macroscopic uniform EOS models. In this presentation, we will present the properties of a family of the non-uniform EOSs and discuss the effects of the saturation parameters included in uniform EOSs on the supernova matter in the low-density inhomogeneous region.

Session 6.4
Measuring the specific heat and neutrino emissivity of neutron stars

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Observational constraints on the mass-radius relation for neutron stars have improved considerably in the last decade. While this relation provides insight into the pressure-density relation of dense matter, it does not directly convey information about the composition of the interior. Observations of isolated cooling neutron stars provide constraints on the specific heat and neutrino emissivity of dense matter, but are limited by a small sample population and large systematic uncertainties in the age of the neutron star. In this talk, I report on work showing how observations of transiently accreting neutron stars can be used to place a robust lower bound on the specific heat of the neutron star core. For several neutron star binaries, this lower bound is a factor of a few below the core heat capacity expected if neutrons and protons in the core are paired; moreover, this lower limit rules out a core dominated by a quark color-flavor-locked (CFL) phase. Secondly, I will argue that for one system, MXB1659-29, the inferred core neutrino emissivity substantially exceeds that of the modified Urca process and is consistent with the direct Urca process operating over about 1% of the core volume. Finally, I will highlight how future observations of this source can place an upper limit on the core specific heat.

Session 7
Heavy-ion collisions I

Chair : TadaAki Isobe

Session 7.1
Several aspects on probing the high-density symmetry energy by HI collisions

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The nuclear symmetry energy around or below saturation density has been roughly pinned down, while the symmetry energy at high densities is still very uncertain. To probe the high-density symmetry energy by HI collisions at rare-isotope accelerator facilities worldwide, great efforts have been made by many people from many aspects. In this talk, I will review our recent several studies on probing the high-density symmetry energy by HI collisions, i.e., the model dependence of the frequently used symmetry-energy-sensitive observables, the qualitative probe of the high-density symmetry energy, the possibly more sensitive probe eta production, the cross-check constraints by many observables, the determination of the density region of the symmetry energy probed by charged pion ratio and nucleon flow, the short-range correlations and the high-density symmetry energy.

Session 7.2
Exploring the nuclear matter equation-of-state at neutron star core-densities

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One of the important scientific goals of the Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion

Research (FAIR) is to investigate the equation-of-state of nuclear of nuclear matter up to 6 times saturation density as it is reached in collisions of heavy nuclei at high bombarding energies. The experiment is designed to measure observables which are sensitive to the nuclear incompressibility such as the collective flow of identified particles, and the production of multi-strange hyperons at beam energies close or below the production threshold in nucleon-nucleon collisions. The possibility to study the symmetry energy at high nuclear densities will be discussed.

Session 7.3
Charged particle track reconstruction for heavy ion collision experiments with SπRIT Time Projection Chamber

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To constrain the symmetry energy term in the Equation of State (EOS) of nuclear matter at super-saturation densities, the SπRIT (SAMURAI Pion-Reconstruction and Ion-Tracker) Time Projection Chamber (TPC) was constructed at the National Superconducting Cyclotron Laboratory (NSCL) at the Michigan State University and Texas A&M University in the U.S.A. The experiment was successfully completed at RIBF (Rare Isotope Beam Factory), RIKEN in Japan in 2016. The experiment utilized the four tin isotope beams (^{132} Sn, ^{124} Sn, ^{112}Sn, and ^{108}Sn) and the two stable tin isotope targets (^{124}Sn and ^{112}Sn). These heavy ion collisions produce high-density tracks of pion, proton, deuteron, triton and helium isotopes. To analyze such high-density events, we developed SπRITROOT the analysis software capable of simulation, event reconstruction, and analysis. in this talk, I will discuss how pattern recognition is done, momentum/vertex is reconstructed, and how the particle species are identified.
This work was supported by the U.S. Department of Energy under Grant Nos. DE-SC0014530, DE-NA0002923, US National Science Foundation Grant No. PHY-1565546 and the Japanese MEXT KAKENHI (Grant-in-Aid for Scientific Research on Innovative Areas) grant No. 24105004.

Session 7.4
Quality assurance of TPC data analysis for heavy ion collisions

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Increasingly, time projection chambers (TPC) are employed to detect charged particles in nuclear physics experiments. TPC operates on a simple concept that charged particles ionize the detector gas and their drift under the influence of magnetic and electric field towards the anode region. The positions of these particles tracks can be recorded electronically as a function of time, thus creating a 3D image of the tracks. However, analysis of TPC data including reconstruction of particle tracks and especially the determination of their efficiencies in heavy ion reactions, are very complicated. In this talk, I will discuss the techniques used to obtain good mass and charge resolution for pions through Z=3 despite the large difference in the stopping power of pions and light heavy ions. I will also describe a procedure using Monte Carlo simulation events to ensure the quality of the analysis and to quantify the detection and analysis efficiencies using SpiRIT TPC as an example.
This work is supported by the U.S. Department of Energy under Grant Nos. DE-SC0014530, DE-NA0002923, US National Science Foundation Grant No. PHY-1565546 and the Japanese MEXT KAKENHI (Grant-in-Aid for Scientific Research on Innovative Areas) grant No. 24105004.

Session 7.5
Collective flow at neutron rich Sn + Sn collisions with 270 MeV/u

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Investigation of nuclear Equation of State (EoS) is one of the most attractive topics not only for nuclear physics but also astrophysics since the neutron star merger was discovered with the gravitational wave. Nuclear EoS indicates large uncertainly in theory, because of lack of information above the normal nuclear density. Neutron rich heavy ion collisions are suitable to investigate isospin symmetry dependence of nuclear EoS at supra-saturation. A neutron-proton differential collective flow would be sensitive for the isospin symmetry potential because it could minimize influence of the isoscalar potential [Ref: PRL85,4221]. The first experiment was performed at RIKEN-RIBF-SAMURAI in 2016 using SAMURAI Pion-Reconstruction and Ion-Tracker-Time-Projection Chamber (SπRIT-TPC). The nuclear collisions with ^{132}Sn and ^{108}Sn beams at 270 MeV/u on ^{124}Sn and ^{112}Sn targets were utilized for the systematic study. In this talk, the recent results of collective flow obtained by SπRIT-TPC experiment will be shown and discussed.

Session 7.6
Results of the ALADiN experiment at GSI: The asymmetry energy at sub-saturation density

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The charge and the mass of products of the projectile fragmentation at relativistic energies have been measured with the ALADiN forward spectrometer at SIS, covering a broad range of collision centralities and fragment sizes. The S254 experiment was dedicated to the projectile N/Z dependence of fragment partitions, in relation with thermodynamical properties and the nuclear asymmetry energy. Au, stable and radioactive Sn and La beams with an incident energy of 600A MeV have been used in order to explore a wide range of isotopic compositions. Confronting the measured isotope yields with the new clustering algorithm FRIGA applied on IQMD transport model predictions, we have deduced a value $\gamma = 0.7 \pm 0.1$ for the power-law coefficient describing the density dependence of the potential part in the parametrization of the asymmetry energy. This result represents a new and more stringent constraint for the regime of sub-saturation density and confirms with a similar accuracy the moderately soft density dependence deduced from the recent AsyEOS data at supra-saturation densities. The densities probed here are shown to range between 0.3 and 0.8 times the normal density.

Session 8
Heavy-ion collisions II

Chair : Jerzy Lukasik

Session 8.1
Interplay between cluster correlations and collision dynamics

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The large yields of light clusters produced in heavy-ion collisions at various conditions can be explained by the antisymmetrized molecular dynamics (AMD) calculations when cluster correlations are assumed to be strong. In this talk, I would like to discuss the influence of cluster correlations on heavy-ion collision dynamics in the results of AMD. For example, we observe stronger stopping with cluster correlations than without them if the same two-nucleon matrix elements are assumed. A question to be addressed is whether the correlations should exist only at low densities. The one-body motions of neutrons and protons, which are believed to be sensitive to the symmetry energy, are also affected by the strength of cluster correlations.

Session 8.2
Dynamical properties and secondary decay effects of projectile fragmentations in ^{124}Sn,^{107}Sn + ^{120}Sn collisions at 600 MeV/nucleon

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- Background: The projectile fragmentation is a well-established technique to produce rare isotope beams, but its underlying physical processes are not fully known.

- Purpose: We devote ourselves to studying the dynamical properties and secondary decay effects of projectile fragmentations in ^{124}Sn, ^{107}Sn + ^{120}Sn collisions at 600 MeV/nucleon.
- Method: The formation of the projectile spectator and the fragmentation process are studied with the isospin-dependent quantum molecular dynamics (IQMD) model. The minimum spanning tree algorithm and the ratio of parallel to transverse quantities are applied to distinguish the equilibrated projectile spectator during the dynamics evolution. The influence of secondary decay on fragmentation observables is investigated by comparing the calculations with and without the statistical code GEMINI. The validity of the theoretical approach is tested by comparing the calculated product yields with the experimental results of the ALADIN Collaboration for the studied reactions.
- Results: The general correlation of an increasing excitation energy with a decreasing mass of the spectator system is found for collisions with impact parameter of b = 5-10 fm. The nucleon evaporation of the pre-fragments reduces the multiplicity of intermediate-mass fragments, but does not change their dependence on the isospin of the projectile. The sequential decay also leads to narrower isotope distributions. Switching to GEMINI at a higher excitation energy results in slightly narrower isotope distributions. With the GEMINI code, in which the nuclear masses with shell and pairing corrections are adopted, the calculations can rather generally reproduce the data of the isotope distributions and mean neutron-to-proton ratios of the light fragments.
- Conclusion: By permitting only evaporation in GEMINI, the IQMD+GEMINI model is able to reproduce the main features of projectile fragmentation in the studied Sn+Sn reactions.

Session 8.3
Constraints of symmetry energy from HICs and the in-medium NN→NΔ cross section

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In my talk, I will present the efforts on the way of reliable constraints of symmetry energy from heavy ion collisions. Reliable constraints on the symmetry energy from HICs depends on the progress of experiment and theory. In theoretical side, we improve the description of nucleon-nucleon collisions and got a progress on the reliable of transport models, through the collaboration project with the different code authors. Secondly, the influence of impact parameter smearing, which has been ignored in many studies of isospin physics, are also investigated for understand the uncertainties from it. Finally, I will show our recent efforts on constraints of symmetry energy and Skyrme Energy density functional in 5-dimension parameter surface. For the constraints on symmetry energy at high density, an information of isospin dependent medium correction factor $R=\sigma(NN\to N\Delta)^*/\sigma(NN\to N\Delta)^{free}$ is needed. I will also show our theoretical results on in-medium NN→NΔ cross section in isospin asymmetric nuclear matter, which will be useful for deep understanding the reaction mechanism.

Session 8.4
Relevant studies on isospin splitting of nucleon effective mass

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Based on an effective isospin- and momentum-dependent nuclear interaction, we have studied some relevant topics on the isospin splitting of nucleon effective mass in neutron-rich nuclear matter. In the studies on the thermodynamic properties of nuclear matter, we found that the neutron-proton effective mass splitting affects the momentum distributions of neutrons and protons, the temperature dependence of the nuclear symmetry energy, as well as the isospin fractionation in nuclear liquid-gas phase transition. In the studies on the transport properties of nuclear matter, we found that the neutron-proton effective mass splitting affects the specific shear viscosity of the neutron-rich nuclear medium, while its minimum point near nuclear liquid-gas phase transition is not affected. It was further found that the isovector giant resonance of neutron-rich nuclei is a useful probe for extracting valuable information of both the nuclear symmetry energy and the neutron-proton effective mass splitting. Recent studies about effects of isovector nuclear

interactions on the isospin relaxation time in intermediate-energy heavy-ion collisions will also be discussed.

Session 8.5
Effects of isospin asymmetry on the energy isotropy ratio of nucleons in heavy-ion collisions

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We study the energy isotropy ratio, R_E, of emitted particles from heavy-ion collisions with the quantum molecular dynamics (QMD) model. Since the symmetry energy in the asymmetry nuclear matter has ambiguity and the in-medium NN cross-sections are still controversial, it requires the investigation of good observables for these. The ratio of longitudinal and transverse energies of nucleons depends on the nucleon-nucleon (NN) potential and the in-medium NN cross-sections in the QMD model, so that it would be a candidate. We investigate the neutron-proton differences of R_E in a variety of isospin asymmetry with different symmetry potential slopes, and discuss the validity as a probe of the symmetry energy. Also, we study the dependence of R_E on the in-medium NN cross-sections.

Session 8.6
Study of light cluster production in intermediate energetic heavy-RI collision at RIBF

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The physics motivation of the SπRIT (SAMURAI Pion- reconstruction and Ion Tracker) collaboration is to place a constraint on the symmetry energy term in the nuclear equation of state at around twice saturation densities. Charged pion ratio or its spectrum ratio in intermediate energetic heavy-ion collisions (HIC) is predicted as a good probe to extract symmetry energy in dense matter, however, there is still large model dependence. Not only nucleon dynamics but also cluster production and cluster-cluster correlation in HIC are reported to influence production of Δ resonance state, and subsequent pion dynamics. In order to discuss pion with less uncertainty, it is necessary to understand properties on nucleon and cluster well. We performed the experiment at the RIKEN-RIBF with Sn-Sn isotopic collisions at 270 MeV/nucleon in spring 2016. Four kinds of collision systems with different isospin asymmetry were used for systematic measurement. Charged particles at forward and mid-rapidity regions were measured by the SpiRIT-Time-Projection-Chamber in combination with the SAMURAI dipole magnet. In various kinds of isotopes produced in HIC, light charged particles could be a possible benchmark to understand cluster property. In this talk, yields of light charged particles and their kinematics will be discussed.

This work is supported by the Japanese MEXT KAKENHI grant No. 24105004, and the U.S. DOE under Grant Nos. DE-SC0004835, DE-SC0014530, DE-NA0002923, the US NSF Grant No. PHY- 1565546, and the Polish NSC Grant Nos. UMO- 2013/09/B/ST2/04064 and UMO-2013/10/M/ST2/00624.

Session 9
Pions and deltas

Chair : Su Houng Lee

Session 9.1
Pion production in HIC

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An overview of pion production in HIC will be presented, particularly on the treatment of pions in transport models and the effect of symmetry energy.

Session 9.2
Pauli blocking effects on pion production in heavy-ion collisions

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In order to investigate the nuclear symmetry energy at high density, we have studied the pion production in the central collisions of neutron-rich nuclei in the energy region around 270-300 MeV/nucleon, using the transport model that combines antisymmetrized molecular dynamics (AMD) and a hadronic cascade model (JAM). We found that Pauli blocking plays some important role on the pion observables. For example, in the Delta production process near the threshold, a Delta resonance is produced together with a nucleon which typically has a small momentum in the final state. Therefore, the Pauli blocking for the nucleon can affect the multiplicities and the isospin ratios of Delta resonances and consequently of pions. In this presentation, I will discuss and compare different treatments of Pauli blocking in our approach in

detail. I will also show the impacts of Pauli blocking as well as of the high-density symmetry energy on the pion productions.

Session 9.3
Recent results on pion analysis of Sn + Sn collisions

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Theoretical calculations expect that pions from the collisions reflect the properties of high density asymmetric matter. However, the models have large discrepancies resulting in the nuclear symmetry energy near the twice saturation density yet to be well constrained. It is important to understand the nuclear symmetry energy not only for the properties of isospin asymmetric nuclear matter, but also for the properties of neutron stars. Heavy-ion collisions with neutron-rich rare isotope provide a terrestrial method to probe the high density and isospin asymmetric nuclear matter. At RIKEN in 2016, we performed the series of experiments with the SπRIT Time Projection Chamber having ^{132}Sn and ^{108}Sn beams impinged on ^{124}Sn and ^{112}Sn producing neutron-rich and neutron-deficient nuclear matter, respectively. In this talk, we present the latest results on pion analysis of the data.

Session 9.4
Study of phase structure of nuclear matter based on a parity doublet model

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I will summarize our recent studies on the phase structure of nuclear matter based on a parity doublet structure. In the former half, I will show our recent study on the phase structure of dense hadronic matter including Delta(1232) as well as N(939) based on the work done in Ref. 1. Our results show that, in symmetric matter, Delta

enters into matter in the density region of about one to four times normal nuclear matter density.
In the latter half, I will show our study on the dual chiral density wave (DCDW) in nuclear matter based on the work done in Ref. 2, where we find, in addition to the ordinary DCDW phase where the space average of the chiral condensate vanishes, a new DCDW phase with a nonvanishing space average.

[1] Y. Takeda, Y. Kim and M. Harada, Phys. Rev. C 97, no. 6, 065202 (2018).
[2] Y. Takeda, H. Abuki and M. Harada, Phys. Rev. D 97, no. 9, 094032 (2018).

Session 10
Nuclear structure I

Chair : Zbigniew Chajecki

Session 10.1
The mechanism of multinucleon transfer reactions for producing neutron-rich heavy nuclei

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Multinucleon transfer process is one promising approach for producing heavy neutron-rich nuclei. The shell, incident energy, and isospin effects on production cross sections were investigated. The shell effect plays one important role on nucleon flow. Because of shell effects, the inverse charge equilibration process was noticed. Based on the beam intensities, the radioactive beam induced transfer reactions were investigated. For producing neutron-rich nuclei around N=126, radioactive beam induced reactions show great advantages. We also found production yields of actinide neutron-rich nuclei strongly depend on the incident energy, while for producing heavy neutron-rich nuclei around N=126 the incident energy effects are weak.

Session 10.2
Understanding the isovector channel of nuclear interaction through heavy ion charge-exchange reactions

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Understanding the behavior of the isovector channel of the nuclear interaction is an outstanding question of modern nuclear physics. Reactions involving heavy-ions reveal in particular an important

probe to study the collective nuclear response, then being helpful to shed light on the fundamental properties of the interaction itself. Moreover, there is a nowadays a renewed experimental and theoretical interest in studying single and double charge exchange reactions with heavy ions. Theoretical aspects of these reactions are then discussed, looking at the attempt to provide an accurate description of the spin-isospin resonances as well as focusing on the possibility of extracting nuclear beta-decay matrix elements. In this context, also the role of competing mechanisms, such as multi-nucleon transfer processes feeding the same outgoing channels, is investigated, with the aim to achieve a complete description of the process and a reliable comparison with recent experimental data.

Session 10.3
Stiff symmetry energy from thick isovector aura

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On account of symmetry energy dropping with density, nuclear isovector density extends farther out than the isoscalar density, leading to an isovector aura surrounding a nucleus. The faster the drop of the symmetry energy and energy of neutron matter with density, the thicker the aura. The width and sharpness of the aura can be assessed by simultaneously analyzing elastic scattering and quasielastic charge-exchange data off the same target, with the two, respectively, testing primarily isoscalar and isovector densities. In the past [P. Danielewicz et al., Nucl. Phys. 958, 147 (2017)] we analyzed unpolarized nucleon elastic and quasielastic cross sections on ^{48}Ca, ^{90}Zr, ^{120}Ca and ^{208}Pb. We now augment the analyzed set with two more targets, ^{92}Zr and ^{94}Zr, and expand the data to include vector analyzing powers. The results consistently point to large widths, ~1 fm, of the isovector aura, now for 6 nuclei. Such an aura implies stiff symmetry energy, with a slope parameter L>70MeV, and stiff energy of neutron matter. The neutron skins may be viewed as nucleus-dependent reflections of the aura.

Session 11
Nuclear structure II

Chair : Guiseppe Verde

Session 11.1
Electroweak measurements of neutron densities in CREX and PREX at JLab, USA

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Measurement of the parity-violating electron scattering asymmetry from ^{208}Pb has demonstrated a new opportunity at Jefferson Lab to measure the weak charge distribution and hence pin down the neutron radius and the density-dependence of the symmetry energy in nuclei in a relatively clean and model-independent way. This is because the Z boson of the weak interaction couples primarily to neutrons. We will describe the PREX and CREX experiments on ^{208}Pb and ^{48}Ca respectively. PREX-I ran in 2010, and CREX and a second run of PREX are currently in preparation to run in 2019. These are both doubly-magic nuclei whose first excited state can be discriminated by the high resolution spectrometers at JLab. The heavier lead nucleus, with a neutron excess, provides an interpretation of the neutron skin thickness in terms of properties of bulk neutron matter. For the lighter ^{48}Ca nucleus, which is also rich in neutrons, microscopic nuclear theory calculations are feasible and are sensitive to poorly constrained 3-neutron forces.

Session 11.2
Measurements of neutron-skin thickness of exotic nuclei via nuclear reaction cross section measurements

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Matter and charge radii in finite nuclei are two fundamental quantities to characterize the ground state properties of atomic nuclei. Their difference gives the neutron skin thickness, an important quantity for constraining the nuclear equation of state in astrophysics for neutron-proton asymmetric nuclear matter. The reaction cross section (σ_R) has been playing a decisive role in determining the nuclear matter radius since the very beginning of RIB physics. Recently, the measurement of the charge-changing cross section (σ_{CC}) was developed as a potential means to extract the proton radius. These investigations present the advantage that both cross sections and thus neutron-skin thickness of exotic nuclei can be measured consistently by the same setup. In this contribution, I will review the principle of neutron-skin thickness measurements of exotic nuclei via nuclear reaction measurements, and then show a few experimental programs worldwide. Finally, I will introduce the recent experimental progress based on RIBLL2 at HIRFL-CSR in China, and also the plans.

Session 11.3
Electric dipole response of nuclei studied by proton scattering

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The responses of nuclei against external electromagnetic fields are of fundamental importance for studying the bulk properties of the nuclear matter. Among various external fields, the electric dipole (E1) field induces isovector responses that are sensitive to the symmetry energy of the nuclear equation of state. We have measured the E1 response of nuclei employing high-resolution proton inelastic scattering at very forward angles, covering the pygmy dipole resonances (PDRs) and the giant dipole resonances (GDRs). The missing mass spectroscopy method enabled us to probe the total strength independently of the decay channels. Multipole decomposition and spin-transfer analyses allowed the extraction of the full *E1* strength distribution including contributions from unresolved small strengths.
The method was applied to ^{208}Pb [1], ^{120}Sn [2], ^{48}Ca [3] and other representative stable nuclei. The full E1 strength distributions were extracted for the excitation energies from 5 to ~20 MeV. The static electric-dipole-polarizabilities were precisely determined by applying the inversely-energy-weighted sum-rule of the *E1* strength distribution.

Constraints on the symmetry energy parameters was determined with a help of the mean-field model calculations [4]. The method has also been expanded for the studies of PDRs [5], gamma-strength functions, and nuclear level-densities [6]. Coincidence measurements of the gamma decays are progressing.
I will report on the status of the recent studies on the electric dipole response of nuclei from the proton inelastic scattering and on the projects in near future.

1. A. Tamii *et al*., "*Complete Electric Dipole Response and the Neutron Skin in ^{208}Pb*", Phys. Rev. Lett. **107**, 062502 (2011).
2. T. Hashimoto *et al.*, "*Dipole polarizability of ^{120}Sn and nuclear energy density functionals*", Phys. Rev. C **92**, 031305(R) (2015).
3. J. Birkhan *et al*., "*Electric Dipole Polarizability of ^{48}Ca and Implications for the Neutron Skin* ", Phys. Rev. Lett **118**, 252501 (2017).
4. X. Roca-Maza et al., "*Neutron skin thickness from the measured electric dipole polarizability in ^{68}Ni, ^{120}Sn, and ^{208}Pb*", Phys. Rev. C **92**, 064304 (2015).
5. See *e.g.*, I. Poltoratska *et al*., "*Pygmy dipole resonance in ^{208}Pb*", Phys. Rev. C **85**, 041304 (2012).
6. D. Martin et al., "*Test of the Brink-Axel Hypothesis for the Pygmy Dipole Resonance*", Phys. Rev. Lett. **119**, 182503 (2017) and the references therein.

Session 11.4
From homogeneous matter straight to nuclei: KIDS functional

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Recent astronomical observations, nuclear-reaction experiments, and microscopic calculations have placed new constraints on the nuclear equation of state (EoS), particularly the symmetry energy, and revealed that most nuclear structure models fail to satisfy those constraints upon extrapolation to infinite matter. A reverse procedure for imposing EoS constraints on nuclear structure calculations has been elusive. I will present precisely such a newly developed method dubbed KIDS (Korea: IBS-Daegu-SKKU) for generating an energy density functional (EDF) for nuclei from a given immutable EoS. The method takes advantage of a natural Ansatz for homogeneous nuclear matter, the Kohn-Sham framework, and the Skyrme formalism and is suited for studying the effect of the symmetry energy parameters directly on nuclear structure as well as stellar objects. I will show 1) that the application of the method to a realistic nuclear EoS (Akmal-Pandharipande-Ravenhall) leads to a successful description of nuclei and 2) indications that the high-order parameters K_{sym} and Q_{sym} of the symmetry energy influence the neutron-star mass-radius relation.

Session 11.5
Density dependence of symmetry energy constrained by nuclear radioactivity data

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It is well known that most of nuclei in the chart of nuclides are unstable to various decay modes. The isospin-related effect becomes more and more important for the radioactivity of unstable nuclei far from the beta stability line. With the accumulation of nuclear radioactivity data in the past years, it is of interest and now possible to extract isospin-related information from these measured data. In this talk, I would like to introduce our recent work of using three kinds of nuclear radioactivity, namely the proton radioactivity, the cluster radioactivity and the double beta decay energy, to constrain the density dependence of symmetry energy.

Session 12
Microscopic Approaches III

Chair : Ulugbek Yakhshiev

Session 12.1
From dilute matter to the equilibrium point in the energy-density-functional theory

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Various properties of nuclear matter are intimately related to nuclear phenomena. Such links strongly guide us in constraining effective interactions within the energy-density-functional (EDF) theory, especially close to the equilibrium density of symmetric matter, which roughly corresponds to central densities of medium-mass and heavy nuclei. Reproducing simultaneously the equation of state (EOS) of symmetric and pure neutron matter is an important step for producing interactions tailored to treat both stable and neutron-rich unstable nuclei or even, in the most extreme cases, the isospin-asymmetric systems located in the crust of neutron stars.
In phenomenological EDFs, attention is usually not paid to correctly describe the very-low-density regime and only density scales of interest in nuclear phenomena are explored: Due to the large value of the scattering length in nuclear systems, standard density-functional theories based on effective interactions usually fail to reproduce the nuclear Fermi-liquid behavior both at very low densities and close to equilibrium. Guided on one side by the success of the Skyrme density functional and inspired, on the other side, by second-order calculations for the EOS of nuclear matter and by resummation techniques used in effective field theories for systems with large scattering lengths, a new energy- density functional was proposed. This functional, adjusted on microscopic calculations, reproduces the nuclear EOSs of neutron and symmetric matter at various densities. Furthermore, it provides reasonable saturation properties as well as appropriate density dependence for the symmetry energy. Along this line of research, other functionals have been recently proposed, such

as a Lee-Yang inspired functional with a density-dependent scattering length. In all cases, the obtained EOSs will be compared with other EDF and microscopic calculations.
Finally, applications of these new functionals to neutron drops will be discussed.

Session 12.2
The nuclear symmetry energy and the breaking of the isospin symmetry: how do they reconcile with each other?

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In this contribution, we will analyze and propose a solution to the apparent inconsistency between our current knowledge of the Equation of State of asymmetric nuclear matter, the energy of the Isobaric Analog State (IAS) in a heavy nucleus, and the isospin symmetry breaking forces in the nuclear medium. This is achieved by performing state-of-the-art Hartree-Fock plus Random Phase Approximation calculations of the IAS that include all isospin symmetry breaking contributions. To this aim, we propose a new effective interaction that is successful in reproducing the IAS excitation energy without compromising other properties of finite nuclei.

Session 12.3
Correlated structure of nuclear symmetry energy from covariant nucleon self-energy

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Nuclear symmetry energy plays an essential role in understanding the isospin dependent aspects in nuclear physics and the critical issues in astrophysics. Based on the covariant density functional (CDF), the relativistic Hartree-Fock (RHF) theory has been developed and been utilized to study the symmetry energy and neutron star related physics, and the importance of the Fork diagram on the isospin properties of the in-medium nuclear force is illustrated. It is found that in the CDF theory the kinetic part of the symmetry energy is reduced, the fourth-order symmetry energy is suppressed, and the Landau mass are enhanced due to the inclusion of the Fock terms. These results can be related to the nonlocal structure of the nucleon in-medium self-energy demonstrated by the Hugenholtz-Van Hove theorem, and also the effects of nuclear tensor force which is embedded naturally in the Fock diagrams of various meson-nucleon couplings. The influence on the neutron star physics such as the core-crust transition density and DUrca neutrino emissivity is discussed as well.

Session 12.4
Ab initio studies of infinite matter from a Green's function approach

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Understanding the properties of infinite nuclear matter has important implications on many branches of nuclear science: from the bulk properties of exotic nuclei to the equation of state of neutron star matter. After we have extended the self-consistent Green’s function (SCGF) theory to account for three-nucleon forces, it is now possible to make reliable predictions of nucleonic matter at both zero and finite temperatures and with full chiral interactions, a task that was not possible until some years ago. The talk will present the SCGF approach as a very convenient way to investigate microscopic and thermodynamical properties of nucleonic matter. I will show how the infinite matter symmetry energy is predicted employing saturating potentials, built to reproduce properties of light and medium-mass nuclei. Furthermore, we will see how the prediction of the liquid-gas phase transition critical temperature in symmetric matter appears to be in reasonable agreement with experimental outcomes. I will then conclude presenting first-principle tests of thermal approximations used in equations of state to study stellar environments, which questions the validity of such astrophysical simulations.

Session 13
Heavy-ion collisions III

Chair : Yvonne Leifels

Session 13.1
In-medium structure in dilute and hot nuclear matter

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Heavy-ion collisions allow one to explore the EoS of nuclear matter and its effects on structure properties of unbound and exotic nuclear systems. These aspects can be accessed by means of multi-particle correlation measurements and invariant-mass spectroscopy with high resolution detector arrays capable of also characterizing correctly collision events (impact parameter, reaction plane, momentum shape, etc.). These techniques will be shown to explore a number of unbound states in light nuclei produced in collisions between different nuclear systems, Ar+Ni, Xe+Sn, Xe+Au as well as the alpha-conjugate systems ^{20}Ne+^{12}C and ^{32}S+^{12}C. These reactions are studied with multi-detector arrays such as INDRA, LASSA and FAZIA. In particular, structure and dynamics aspects of multi-alpha correlations in ^{8}Be and ^{12}C decays will be shown with te aim of exploring in-medium structure in dilute and hot nuclear systems. Interplay's between structure properties and reaction dynamics are discussed.

Session 13.2
Telescope energy spectra and the Ockham's razor

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A method to identify and calibrate the KRATTA telescope punch through hits will be presented. The method allows to increase the

dynamical range of a telescope by about 100 MeV/nucleon above the punch through limit for Z=1 particles with precise isotopic identification. Using regularized decomposition, it allows also to estimate, with some moderate precision, the particle mass and energy in the whole energy range measured for the Au+Au collisions at 400 MeV/nucleon. Some preliminary results and their impact on the ASY-EOS energy spectra will be demonstrated.

Session 13.3
Connecting the nuclear EoS to the interplay between low-energy reaction mechanisms

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Within the Time Dependent Hartree Fock approach, we investigate the impact of several ingredients of the nuclear effective interaction, such as incompressibility, symmetry energy, effective mass, derivative of the Lane potential and surface terms on the exit channel (fusion vs quasifission) observed in the reaction 238U+40Ca, close to the Coulomb barrier. Our results show that all the ingredients listed above contribute to the competition between fusion and quasifission processes, however the leading role in determining the outcome of the reaction is played by incompressibility, symmetry energy and the isoscalar coefficient of the surface term. This study unravels the complexity of the fusion and quasifission reaction dynamics and helps to understand the microscopic processes responsible for the final outcome of low energy heavy ion collisions in terms of relevant features of the nuclear effective interaction and associated Equation of State.

Session 13.4
Relativistic covariance corrections to transport models and symmetry energy constraints

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Constraints for the density dependence of the symmetry energy have been previously extracted from the experimental data for pion multiplicity ratios and elliptic flow of nucleons and fragments by employing a transport model that treats dynamics within a non-relativistic framework. It is however known that for certain observables (e.g. transverse flow) relativistic covariance corrections are non-negligible. The transport model of choice is upgraded to obey (approximate) relativistic covariance by employing the formalism of constrained invariant Hamiltonian dynamics. The impact of these corrections on the extracted constraint for the density dependence of the symmetry energy is studied, with a focus on elliptic flow observables in Au+Au collisions at 400 MeV/nucleon impact energy. Predictions for higher impact energies, of interest for future ASYEOS experimental measurements, are also discussed.

Session 14
Facilities and future

Chair : Betty Tsang

Session 14.1
Symmetry energy at GSI/FAIR

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Session 14.2
Status of symmetry-energy studies at R3B

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Studies on the Pygmy Dipole Resonance and electric dipole polarizability have been successfully carried out with exotic nuclei in the past at the R3B setup at GSI. The current status of ongoing investigations with unstable nuclei intended to provide additional constraints on the symmetry energy will be presented, as well as R3B experiments planned to be carried out in the FAIR phase-0 program.

Session 14.3
Performance of prototype neutron detectors for large-acceptance multipurpose spectrometer at RAON

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The large-acceptance multipurpose spectrometer (LAMPS) system will be installed at the RAON facility in Korea. The primary purpose of LAMPS is to understand basic properties of nuclei and nuclear matter with very asymmetric neutron and proton compositions. The first stage of LAMPS consists of the time-projection chamber (TPC) with solenoid magnet and the forward neutron detector array. In particular, the neutron detector array is to measure high energy neutron in the forward region. The shape of a single module of the neutron detector is the rectangular rod with the dimensions of 10cm*10cm*200cm. We have built the prototype neutron detectors and tested the performance by using the neutron beams at 65 and 392 MeV provided by RCNP, Japan. The signals were readout by the custom-made flash ADC (FADC) with the sampling rate of 500 MHz. The quasi-monoenergetic neutron beams were generated by impinging protons on the Li target. With this test, the basic characteristics of the neutron detector were extracted. In this presentation, we present the test results of the energy, time, and position resolutions and neutron detection efficiency. We will also present the two-pulse discrimination method to analyze the two-neutron events.

Session 14.4
Status of RAON

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Session 15
Summary & Discussion

Chair : Betty Tsang

Session 15.1
Summary

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Session 15.2
Discussion: Future emphasis