Oral Presentations

Session 1 Nuclear EOS part 1

O1-1 19th 10:30-11:20

Equations of state of compact star matter with clusters and phase transitions

Stefan Typel

In the first part of this contribution, a new set of EoS tables is described that are based on an extended generalized relativistic density functional with nucleons, nuclei and leptons as degrees of freedom. Particular attention is paid to the formation and dissolution of nuclear clusters and the occurrence of phase transitions at subsaturation densities. In the second part, the latest developments of the CompOSE (Compstar online supernovae equations of state) project - an online database of EoS tables and associated software - are presented.

O1-2 19th 11:20-11:40 Hajime Togashi

Supernova equation of state with realistic nuclear interactions and hyperon mixing in hot dense matter

Hajime Togashi

We have constructed a new table of the nuclear equation of state (EOS) for numerical simulations of core-collapse supernovae. The EOS of uniform matter is calculated with the cluster variational method based on the Argonne v18 two-nucleon and Urbana IX three-nucleon potentials. For the inhomogeneous nuclear phase, we adopt the Thomas-Fermi approximation to obtain the EOS of non-uniform matter in a self-consistent manner. The obtained thermodynamic quantities for various temperatures, proton fractions, and densities are reasonable, as compared with the Shen EOS. It is also found that, in simplified numerical simulations of core-collapse supernovae, the stellar core created after the bounce with the present EOS is more compact than that with the Shen EOS. This result implies that the variational EOS is softer than the Shen EOS.

In this presentation, we will report on the properties of our EOS in detail, and its applications to neutron stars and spherically symmetric simulations of core-collapse supernovae. Furthermore, as an extension of the present EOS, we will discuss the effects of Lambda hyperon mixing in dense nuclear matter at zero and finite temperatures.

O1-3 19th 11:40-12:00

Self consistent calculation of nuclear composition in supernova matter

Shun Furusawa

We investigate the in-medium effects on the nuclear matter that consists of mixture of nucleons and all nuclei in the dense and hot stellar environment. In the new approach, the equilibrium densities and abundances of individual nuclei are self-consistently optimized to minimize the free energy. We find that heavy nuclei in the ensemble are either compressed or decompressed at high densities depending on the isospin asymmetry of the system and that more neutron-rich nuclei become unstable and disappear one after another at lower temperatures.

Session 2 NS merger, GW & EOS

O2-1 19th 13:30-14:20

GW170817 : Observations and Theoretical modelling

Yuichiro Sekiguchi

GW170817, observed by Advanced LIGO/Virgo detectors, is the first gravitational-wave (GW) event (candidate) from the merger of a binary neutron star (NS). Surprisingly, information of NS structure, and hence equation of state is extracted using GW. This is also the first multi-messenger event in which both GW and a wide variety of electromagnetic (EM) signals are detected, such as a weak GRB discovered in close time-coincidence with the GW detection, the delayed rise of X-ray and radio orphan afterglows, and optical and near-infrared emissions consistent with the so-called kilonova. In this talk, after reviewing the above main observational features, I will attempt to interpret and theoretically model this event based on recent numerical-relativity simulations, paying particular attention to the kilonova observation.

O2-2 19th 14:30-15:20

Binary-compact-stars gravitational waves and equation of state

Luca Baiotti

I will present a review of methods for inferring knowledge of the equation of state of compact stars through the analysis of gravitational waves emitted by mergers of compact-star binaries. I will also talk about current results obtained through the analysis of GW170817.

O2-3 19th 15:20-15:40

Constraint on the EOS of protoneutron stars with asteroseismology

Hajime Sotani

The gravitational-wave (GW) asteroseismology is a powerful technique for extracting interior information of compact objects. In this work, we focus on spacetime modes, the so-called w modes, of GWs emitted from a proto-neutron star (PNS) in the postbounce phase of core-collapse supernovae. Using results from recent three-dimensional supernova models, we study how to infer the properties of the PNS based on a quasi-normal mode analysis in the context of the GW asteroseismology. We find that the w1-mode frequency multiplied by the PNS radius is expressed as a linear function with respect to the ratio of the PNS mass to the PNS radius. This relation is insensitive to the nuclear equation of state (EOS) employed in this work. Combining with another universal relation of the f-mode oscillations, we point out that the time dependent mass-radius relation of the PNS can be obtained by observing both the f- and w1-mode GWs simultaneously. Our results suggest that the simultaneous detection of the two modes could provide a new probe into finite-temperature nuclear EOS that predominantly determines the PNS evolution.

Session 3 Nucleosynthesis

O3-1 19th 16:25-17:15

r-Process nucleosynthesis in compact object mergers and GW170817

Jonas Lippuner

Compact object mergers involving at least one neutron star have become the prime candidates for the site of r-process nucleosynthesis, which is responsible for producing about half of all the elements above the iron peak. I will provide an overview of r-process nucleosynthesis especially in the context of neutron star mergers. I will discuss the range of possible nucleosynthetic outflows in different merger scenarios, as well as the expected associated kilonova signatures. I will also review GW170817, the first binary neutron star merger observed with LIGO/VIRGO, and what we learned about r-process nucleosynthesis from the kilonova that was observed in detail after the merger event.

O3-2 19th 17:15-17:35

Nucleosynthesis of trans-iron elements in magneto-rotational core-collapse supernovae

Nobuya Nishimura

Magnetically driven supernovae of massive stars are expected as viable sites of heavy-nuclei including r-process nuclei as well as the central engine of gamma-ray bursts and magnetar formation supernovae. In this talk, I show recent results of r-process nucleosynthesis based on magneto-hydrodynamical models taking into account the enhancement processes of magnetic fields due to magneto-rotational instability around the proto-neutron star. We found that the weak r-process occurs in models with the weaker magnetic-driven jet influenced by neutrino-heating, while the cases with strong magnetic-jets produce heavy nuclei. I also discuss the role of magnetically driven supernovae in the chemical enrichment history in galaxies as an alternative source of heavy elements.

O3-3 19th 17:35-17:55

Nucleosynthesis in Ultra-Stripped Supernovae

Takashi Yoshida

Ultra-stripped supernova (SN) is evolved from a secondary progenitor most of which H and He envelope has been lost in a close binary system with a neutron star. If the secondary star is less massive, it evolves to a small CO star with a thin He envelope. The SN explosion will be weak similar to an electron-capture SN and it will be observed as a subluminous fast-decaying SN. We investigate the nucleosynthesis during the two-dimensional neutrino-driven SN explosions of ultra-stripped Type Ic SNe evolved from 1.45 and 1.5 solar-mass CO stars. These SNe release 0.1 solar-mass ejecta containing 0.006-0.01 solar-mass of 56Ni. Less than 0.01 solar-mass of light trans-iron elements Ga-Zr are produced in moderately neutron-rich ejecta. We discuss the effect of the uncertainty of electron fraction in the neutrino-irradiated ejecta to the nucleosynthesis of the trans-iron elements.

Session 4 SN Mechanism

O4-1 20th 9:50-10:40

Numerical studies of core-collapse supernovae: progress toward the first-principles calculations

Kohsuke Sumiyoshi

We report recent results of numerical simulations of core-collapse supernovae by the multi-D neutrino radiation-hydrodynamics. In order to pin down the key ingredient of explosion mechanism, one has to work out 2D/3D hydrodynamics & neutrino transport with careful treatment of nuclear data. We have developed the numerical solver of the 6D Boltzmann equation and are running large-scale Boltzmann-Hydro simulations on K-computer to study 2D core-collapse supernovae from massive stars. We demonstrate salient features of multi-dimensional neutrino transfer as well as the influence of nuclear physics such as equation of state and discuss remaining issues to understand supernova explosions.

O4-2 20th 10:50-11:40

Modeling of Core-Collapse Supernovae: Challenges and Current Status

Oliver Just

Barely any astrophysical question has been studied as long and intense using large-scale numerical simulations as the explosion mechanism of core-collapse supernovae. In this talk I will give a brief overview about the physics issues and numerical obstacles that are encountered when modeling core-collapse supernovae and I will summarize the results of our recent study comparing two state-of-the-art simulation codes.

O4-3 20th 11:40-12:00

Neutron Star Kick Induced by Aspherical Core-collapse Supernova Explosions

Ko Nakamura

Core-collapse supernovae (CCSNe) are the final stage of massive stars and the site of neutron star (NS) formation. Asphericity in CCSN explosions drives a natal kick velocity of NS. In this presentation, we present a correlation between NS kick and explosion geometry based on our long-term CCSN simulations. We perform ab initio 2-dimensional CCSN simulations for progenitor stars with mass from 11 to 27 solar masses covering a wide range of compactness. We found that all of the examined models finally produce expanding shocks along symmetry axis. In terms of the compactness of the progenitor models, we found an increasing trend of the degree of the asphericity, which will be reflected to kick velocity. This can be interpreted as follows: a high compactness progenitor suffers from high mass accretion and develops SASI, leading to a large asphericity of shock geometry and high kick velocity. Our previous study suggests that high compactness progenitors leave massive NSs. This naturally leads to a reasonable correlation between NS mass and kick velocity, which is moderately supported by observational data.

Session 5 Nuclear EOS part2

O5-1 20th 13:30-14:20

Equation of state for supernovae and neutron stars

Hong Shen

We study the equation of state of dense matter for supernova simulation and neutron star structure. We employ the relativistic mean-field model for nuclear interactions and use the Thomas-Fermi approximation to describe the nonuniform nuclear matter. The phase transition from nonuniform matter to uniform matter is determined in a consistent manner, which is found to be dependent on the temperature and isospin asymmetry.

O5-2 20th 14:30-15:20

The properties of neutron star in the relativistic central variational method

Jinniu Hu

The properties of neutron stars are investigated within the relativistic central variational method by using a realistic nucleon-nucleon (NN) interaction. The strong repulsion of realistic NN interactions at short distances is treated by a Jastrow central correlation function, whose form is completely determined through minimization of the total energy of the nuclear many-body system. The relativistic Hartree-Fock wave functions are chosen as the trial wave function. In this framework, the equation of state of the neutron star matter in equilibrium is obtained self-consistently. We further determine the properties of neutron stars via the TOV equation using Bonn A, B, and C potentials. The maximum masses of neutron stars with these realistic potentials are around 2.18 times solar mass and their corresponding radii are around 11 km. These results are in accordance with the calculations of the relativistic Brueckner-Hartree-Fock theory with the same potentials. Furthermore, we also find that the splitting of proton-neutron effective masses will be reversed at high density in the neutron star matter, which are caused by the contribution of short-range correlation on kinetic energy.

O5-3 20th 15:20-15:40

Rho meson effect in hadron-quark phase transition

Wu Xuhao

The quark-hadron coexistence is investigated by using relativistic mean-field (RMF) theory for hadronic matter and Nambu-Jona-Lasinio (NJL) model for quark matter. The isovector-vector meson () plays an important role to control the symmetry energy. Since the symmetry energy in nuclear matter has been studied intensively and is known to affect the neutron star properties such as radii, it should be important in the quark-hadron coexistence. As a result, the hadron-quark mixed phase shrinks.

Session 6 PNS

O6-1 20th 16:25-17:15

Neutrinos and Nucleosynthesis from Newly Born Neutron Stars

Luke Roberts

After a successful, neutrino driven CCSN, a protoneutron star is often left behind as a remnant. This hot, extended young neutron star cools and contracts over a period of tens of seconds emitting a copious number of neutrinos. The spectrum and time dependence of this neutrino emission encodes information about the properties of dense matter, sets the initial conditions for neutrino oscillations, and can alter nucleosynthesis in the supernova. I will present models of protoneutron star cooling and discuss prospects for detection of these neutrinos from a nearby supernova. I will then talk about how microphysics, including neutrino opacities and the nuclear equation of state, impacts protoneutron star cooling and nucleosynthesis.

O6-2 20th 17:15-17:35

Neutrinos from Proto-neutron Star Cooling and Nuclear Equation of State: Effects of Coherent Elastic Scattering

Ken'ichiro Nakazato

A proto-neutron star (PNS) is a newly formed compact object in a core collapse supernova. In this Letter, the neutrino emission from the cooling process of a PNS is investigated using two types of nuclear equation of state (EOS). It is found that the neutrino signal is mainly determined by the high-density EOS. The neutrino luminosity and mean energy are higher and the cooling time scale is longer for the softer EOS. Meanwhile, the neutrino mean energy and the cooling time scale are also affected by the low-density EOS because of the difference in the population of heavy nuclei. Heavy nuclei have a large scattering cross section with neutrinos owing to the coherent effects and act as thermal insulation near the surface of a PNS. The neutrino mean energy is higher and the cooling time scale is longer for an EOS with a large symmetry energy at low densities, namely a small density derivative coefficient of the symmetry energy, L.

O6-3 20th 17:35-17:55

Corotation resonance of low T/W dynamical instabilities in differentially rotating stars

Motoyuki Saijo

We investigate the nature of low T/W dynamical instabilities in differentially rotating stars by means of both linear perturbation and three-dimensional hydrodynamical simulation. We find the unstable normal modes of differentially rotating stars by solving the eigenvalue problem along the equatorial plane of the star. We also find that the existing pulsation modes become unstable due to the existence of the corotation radius inside the star. The feature of the unstable mode eigenfrequency and its eigenfunction in the linear analysis roughly agrees with that in three-dimensional hydrodynamical simulations in Newtonian gravity. Therefore, our normal mode analysis in the equatorial motion proves valid to find the unstable equilibrium stars efficiently. Moreover, the nature of the eigenfunction that oscillates between corotation and the surface radius for unstable stars requires reinterpretation of the pulsation modes in differentially rotating stars. Amplification mechanism, gravitational waves from these instabilities and possibility to determine the stiffness of equation of state will also be discussed.

Session 7 Nuclear Weak Rates

O7-1 21st 9:50-10:40

Constraining the Nuclear EOS by Nuclear Response Experiments

Atsushi Tamii

I will report on the recent progresses on constraining the nuclear EOS by measuring nuclear responses to external fields at Research Center for Nuclear Physics, Osaka University. I plan to pick up topicses of the electric dipole responses for the electric polarizability and the symmetry energy, isoscalar monopole responses for the nuclear incompressibility, and the spin-M1 responses for the spin-magnetic susceptibility.

O7-2 21st 10:50-11:40

Constraining weak interaction rates for astrophysics by using nuclear charge-exchange reactions

Remco Zegers

Charge-exchange reactions play an important role in constraining weak interactions of importance for nuclear astrophysics. By utilizing a well-established proportionality between cross sections measured at forward scattering angles and transition strength, Gamow-Teller matrix elements can be extracted from charge-exchange experiments for transitions that cannot deduced from beta or electron-capture decay experiment, but that are important for understanding stellar evolution. The measured strengths from charge-exchange experiments are used to constrain and improve theoretical models use for calculating weak rates on many nuclei, including unstable ones. A newly developed weak-rate library based on these theoretical models is then used in astrophysical simulations of stellar evolution. The presentation will focus on the experimental program, the creation of the weak-rate library, and the application of the library for the purpose of weak-rate sensitivity studies in core-collapse supernovae.

O7-3 21st 11:40-12:00

Overview of Gamow-Teller Transitions in Nuclei

Yoshitaka Fujita

Gamow-Teller (GT) transitions caused by the "$\sigma\tau$" operator and Fermi transitions caused by τ operator are the allowed transitions in weak processes such as beta decay or neutrino-induced inverse-beta-decay reactions at the time of supernova explosion. Among them, Fermi transitions are only between isobaric analog states (IASs) and thus simple and well understood. On the other hand, GT transitions in nuclei are unique in the sense that they are different in each combination of initial and final nuclei. Not that they strongly reflect the different structures of relevant nuclei.

GT response of nuclei can be most directly studied by beta-decays. However, they can access only the low excitation-energy region due to the limitation of finite decay Q-values. At RCNP, Osaka, we overcome this difficulty by using high-resolution (3He,t) charge-exchange (CE) reactions at the intermediate beam energy of 140 MeV/nucleon. In the (3He,t) measurements at 0-degrees, interaction V($\sigma\tau$) is dominant and thus, we can obtain the overview of GT excitations up to more than 15 MeV.

Largely different GT responses are discussed for various nuclei and from them we try to extract the overview of GT strength distributions for nuclei with a large mass range. In addition, the isospin symmetry is introduced to make connections between beta-decay studies and measurements by CE reactions.

Session 8 SN Neutrino

O8-1 21st 13:30-14:20

Microphysics effects in core-collapse supernovae and neutron star mergers

David Radice

The outcome of core-collapse supernova explosion and neutron star mergers are sensitive to the nuclear equation of state and to neutrino-matter interactions. In this talk, I will review recent efforts Princeton group. I will present results from our study on the sensitivity of core-collapse supernovae to changes in the equation of state and the neutrino-matter interactions, and I will discuss the neutrino and gravitational-wave signatures predicted by our latest models. I will also present recent results on the neutron star equation of state enabled by the recent discovery by LIGO-Virgo. Finally, I will discuss the impact of neutrinos and of the equation of state on the electromagnetic counterparts from binary neutron star mergers.

O8-2 21st 14:30-15:20

Neutrino Astrophysics

Maria Cristina Volpe

Neutrino physics and astrophysics have brought milestones in our understanding of neutrino properties and of stellar evolution. Neutrinos are also tightly linked to key open questions in astrophysics, including unravelling the mechanisms of the death of massive stars and the site(s) where the heavy elements are made. Flavor oscillations in vacuum and in the Sun are well understood phenomena. However, neutrino flavor evolution in dense environments, such as core-collapse supernovae and accretion disks around compact objects (binary neutron star merger remnant or black holes) is revealing many surprises. In particular neutrino self-interactions render the study of flavor evolution in media a complex many-body problem, having formal connections to condensed matter and to atomic nuclei and revealing novel collective conversion phenomena. In this talk I will highlight major advances in the field and the importance of future observations of neutrinos, both from core-collapse supernova explosions and of the diffuse supernova neutrino background.

O8-3 21st 15:20-15:40

Supernova neutrino oscillations in three-flavor multiangle simulations and their effects on nucleosynthesis

Hirokazu Sasaki

Large numbers of neutrinos are produced in several cosmological and astrophysical sites such as the early universe, core-collapse supernovae and neutron-star mergers. In core-collapse supernovae, energetic neutrinos are emitted from a proto-neutron star after core-bounce and carry away 99 % of the gravitational binding energy. Non-linear neutrino flavor transitions called collective neutrino oscillations are induced by coherent scatterings of self-interacting neutrinos outside the proto-neutron star. Collective neutrino oscillations transform the spectra of all neutrino species. Such modified neutrino spectra could enhance reaction rates of electron neutrino absorptions on free nucleons, which is expected to affect explosion dynamics and explosive nucleosynthesis. In this presentation, we mention how collective neutrino oscillations take place inside neutrino-driven winds. These results are obtained by sophisticated three-flavor multiangle simulations which consider the angular dependences of emitted neutrinos. The multiangle effects delay the onset of flavor transitions and smear the flavor amplitudes. In addition, effects of flavor transitions on the neutrino-p process nucleosynthesis are also discussed. This result would be helpful to more realistic studies to reveal the origin of solar-system isotopic abundances of p-nuclei.