Oral Presentations

Session 1 Birth of Star

O1-1 26th 10:10-11:00

Massive Star Formation

Kei E. I. Tanaka

Massive stars play important roles throughout the cosmic history. They are the dominant source of UV radiation, turbulent energy, and heavy elements. Massive close binaries are the progenitors of merging black holes, which have been detected by their gravitational wave emission. Therefore, it is essential to understand the formation process of massive stars. Compared to low-mass star formation whose standard scenario has been established in the 1980s, research on massive star formation has been dramatically developing in the recent years. In this review talk, I will introduce recent understandings of massive star formation, mainly based on our theoretical and observational studies (but I will try not to be too biased).

O1-2 26th 11:15-11:40

Zoom In to the Heart of Massive Star Formation

Yichen Zhang

It is still unclear how massive stars form, especially how massive protostars accrete and how such accretion regulated by various feedbacks. Recent high-resolution observations start to reveal these processes with great details. My first topic is about feedback process in massive star formation. Toward G45.47+0.05, our recent observation revealed a wide-angle bipolar ionized outflow. The outflow is found to be photoevaporative driven by the ionizing radiation from a 30–50$M_\odot$ forming star. The mass loss rate of this photoevaporation outflow is estimated to be $\sim (2–4) \times 10^{-5} M_\odot$ per year. However, despite of such strong photoionization feedback, there are also hints of a jet embedded in the ionized outflow, suggesting the accretion is still going on and the star can grow further. This study shows that the ionization feedback may not be the limiting process for the mass of formed massive stars. My second topic is about massive binary formation. Although almost all massive stars have bound stellar companions, essentially all information about massive binaries is derived from observations of already formed stars. Little is known about how they are like during formation stages. In IRAS 07299-1651, our observation revealed a forming massive binary with an apparent separation of 180 au. Both protostars are associated with HRL emissions, and have a line-of-sight velocity difference of ~ 10 km/s, which can be explained by binary orbital motions and used to constrain binary properties, which is the first time for a forming massive binary. This system is most likely to be formed via fragmentation of a rotationally supported disk with a few hundred au scale. There are large-scale infalling and rotating gas streams from $\sim 10,000$ au down to $\sim 1,000$ au from the center, and rotating circumstellar disk of 10 au radius around the primary. Are such rotationally supported disks common in formation of massive stars? Although searching for rotationally supported disks in massive star formation is still challenging, I will show a few examples of detecting such disks formed within an ordered infalling-rotating envelope, via chemical signatures in addition to kinematic signatures—a new approach which may help efficiently identify such disks. In general, these results indicate ordered behaviors in the innermost region of massive star formation.

O1-3 26th 11:40-12:05

ALMA observations of high-mass star-forming filamentary cradles in the Large Magellanic Cloud

Kazuki Tokuda

The Large Magellanic Cloud (LMC) is an ideal laboratory to study high-mass star formation in molecular clouds thanks to its uncontaminated face-on view at the closest distance among the external galaxies. ALMA offers a fantastic opportunity to resolve the star formation mechanism at a $\sim 10^4$ au (0.06 pc) scale. We present spatially resolved molecular filaments at two high-mass star-forming regions, N159E/W, in the LMC. Our ALMA observations revealed remarkable hub filament systems with a typical width of 0.1 pc, where a young HII region (the Papillon Nebula) and an embedded high-mass protostar along with several protostellar outflows have been newly discovered/resolved. All these young objects have an age of 10^4–10^5 yrs, whereas they are scattered over a distance spanning ~ 50 pc. We propose that the two system was formed coherently over a 50 pc scale in both N159W/E under the external triggering driven by the large-scale supersonically colliding flow. The proposed collision, driven by the tidal interaction between the LMC and SMC, explains the formation of the hub multi-filament system as shown by recent MHD simulations, which predict the synchronized triggered formation of the most massive star at the hub and additional star formation along the dense filaments.

Session 2 Evolution of Single Star

O2-1 26th 13:30-14:20

Shocking consequences of waves on the deaths of massive stars

Jim Fuller

In the late phase evolution of massive stars approaching core-collapse, vigorous convection driven by intense nuclear burning determines the pre-supernova state of the star. The burning shapes the core's density profile and seeds asymmetries that are amplified during the impending explosion. Convection also excites gravity waves that carry energy toward the star's surface, driving outbursts and enhanced mass loss in the final years of massive star evolution. The ejected mass contributes to a dense circumstellar medium that shapes the appearance of many types of interacting supernovae (e.g., type IIn, Ibn, FBOTs, etc.). Waves trapped in the core of the star change its angular momentum content and may control the spin rates of newborn pulsars. Finally, I will show how waves excited by convection in the cores of proto-neutron stars can contribute significantly to the explosions of core-collapse supernovae.

O2-2 26th 14:30-14:55

Rotational equilibria on the 2D Lagrange coordinates

Kotaro Fujisawa

One of the fascinating challenges in stellar astrophysics is understanding the structures of rotating stars and their evolution. Massive stars in particular, such as B and O stars, tend to have rapid rotation. The shape of the rapidly rotating star is oblate due to the centrifugal force, and spherical models cannot well describe them. We develop a new formulation and numerical method to obtain axisymmetric rapidly rotating stars on the 2D Lagrange coordinates. This numerical method might be useful for investigating 2D stellar evolution models with rapid rotations.

O2-3 26th 14:55-15:20

Multi-dimensional simulations of oxygen-shell burning just before the core collapse of massive stars

Takashi Yoshida

We perform 3D hydrodynamics simulations of the evolution for $\sim 100\,\mathrm{s}$ before the core collapse of massive stars. We investigate characteristics of turbulent motion activated by oxygen-shell burning in an oxygen-silicon rich layer. A $25 M_\odot$ model has a Si/O layer with a scale of several times 10^8 cm. The turbulent Mach number in the Si/O layer in this star reaches ~ 0.1. The spectrum analysis of turbulent velocity shows that a low mode with $l \sim 2$–3 is dominated, i.e., large-scale convection is dominated in this layer. We will also present the results of the 3D simulations of other massive star models.

Session 3 Evolution of Binary Star

O3-1 26th 16:10-17:00

From two stars to two merging compact objects

Pablo Marchant

The detection of gravitational waves from merging compact objects provides a new window into the stellar evolution, synthesizing the entire life of two stars into one high energy event. Identifying the actual astrophysical origin of these sources remains a challenging prospect, with binary evolution being a prominent candidate for their formation. In this talk I will summarize some of the main processes in binaries that are believed to play a role, and how they are predicted to leave distinct imprints on the observed populations of merging compact objects. I will also describe how different evolutionary phases can be constrained through electromagnetic observations, including the study of nearby stellar populations, transient events and X-ray sources.

O3-2 26th 17:10-17:35

Remnants of first stars for gravitational wave sources

Tomoya Kinugawa

We showed that the typical mass of binary black holes (BH-BHs) whose origin is the first star is $\sim 30 M_{\odot}$ and mergers of Pop III BH-BH can have sufficiently long merger times to occur in the nearby universe before GW150914 (Kinugawa et al. 2014). The detection rate of the coalescing Pop III BH-BHs is ~ 200 events/yr. This result predicted the gravitational wave events of massive BH-BHs like GW150914 and LIGO paper said 'recently predicted BBH total masses agree astonishingly well with GW150914 and can have sufficiently long merger times to occur in the nearby universe (Kinugawa et al. 2014)' (Abbot et al. ApJL 818,22 (2016)). Thus, there is a good chance to check indirectly the existence of Pop III massive stars by gravitational waves. In this talk, I will summarise the Pop III binary evolutions and the features of Pop III BH-BHs and the detectability of Pop III BH-BHs by the gravitational detectors including future plans

O3-3 26th 17:35-18:00

Co-evolution of massive stars and neutron stars in wind-fed high mass X-ray Binaries

Shigeyuki Karino

Neutron stars in wind-fed high-mass X-ray binaries (HMXBs) have a wide spin distribution from several seconds to 10 kilo-seconds, and also have various spin up/down rates. To investigate the origin of these various neutron star spins, we calculated the spin evolution of neutron stars in HMXBs. As a result, it was suggested that the difference of the parameters of stellar wind from the massive donor could generate such a spin diversity. On the other hand, stellar winds from massive stars are greatly affected by X-ray irradiation from neutron stars. Here, we would like to discuss the co-evolution scenarios of massive stars and neutron stars in wind-fed HMXBs.

Session 4 Supernova

O4-1 27th 9:45-10:35

3D Simulations of Core-Collapse Supernovae Populations

David Vartanyan

Massive stars end their lives in a vibrant explosion as core-collapse supernovae (CCSNe). CCSNe dynamically shape the universe and source much of its heavy-metal composition. Despite its significance, the CCSNe explosion mechanism has only been dubiously understood. The resolution of this problem requires the synergy of cutting-edge theory with high-performance computation. For over half a century—since early supernova simulations by Stirling Colgate in 1966—the astrophysical community has struggled to reproduce stellar explosions with theoretical models. I present one of the first state-of-the-art 3D simulations of core-collapse supernovae populations. This unprecedented study spans over a dozen stellar progenitors, the majority of which explode. Due to improved understanding of stellar microphysics and stellar evolution, multi-dimensional CCSNe simulations are now capable of reproducing stellar explosions for a gamut of stellar models, ameliorating this 50-year astrophysical conundrum. Furthermore, the majority of the models explode robustly, with explosion energies approaching the canonical value of 10^{51} ergs. The study of such a diverse suite of stellar models allows an understanding of the global dynamics of CCSNe and their observational signatures in gravitational waves and neutrinos. These signatures can be used in tandem to probe the physics of the otherwise-opaque CCSNe cores as well as the large-scale turbulent evolution of CCSNe. Such a broad array of stellar progenitors also enables a priori predictions of the explosion likelihood for a given stellar progenitor. A comprehensive study of CCSNe—from stellar death to explosion outcome to observational signatures—remains an open pursuit but is now buttressed by successful multi-dimensional models that highlight our improved understanding of this multi-faceted problem.

O4-2 27th 10:50-11:15

Recent Progress of the Core-collapse Supernova Simulations under axisymmetry with the Boltzmann-radiation-hydrodynamics code

Akira Harada

We have developed the Boltzmann-radiation-hydrodynamics code to investigate the neutrino heating mechanism of the core-collapse supernovae. The code simultaneously solves the Boltzmann equation for the neutrino transport, the hydrodynamic equations, and the Poisson equation for the Newtonian gravitational potential. We have performed several simulations under axisymmetry using this code. Various nuclear equations of state, progenitor models, and rotational velocities are employed. In this talk, I will show the results of these simulations to summarize what is found

by solving the Boltzmann-radiation-hydrodynamics.

O4-3 27th 11:15-11:40

Nucleosynthesis Constraints on the Energy Growth Timescale of a Core-collapse Supernova Explosion

Ryo Sawada

Details of the explosion mechanism of core-collapse supernovae (CCSNe) are not yet fully understood. There are an increasing number of numerical examples by ab initio core-collapse simulations leading to an explosion. Most, if not all, of the ab initio core-collapse simulations represent a "slow" explosion in which the observed explosion energy ($\sim 10^{51}$ erg) is reached in a timescale of ~ 1 s. It is, however, unclear whether such a slow explosion is consistent with observations. In this work, by performing nuclear reaction network calculations for a range of the explosion timescale $t_{\rm grow}$, from the rapid to slow models, we aim at providing nucleosynthetic diagnostics on the explosion timescale. We employ one-dimensional hydrodynamic and nucleosynthesis simulations above the proto-neutron star core, by parameterizing the nature of the explosion mechanism by $t_{\rm grow}$. The results are then compared to various observational constraints: the masses of ^{56}Ni derived for typical CCSNe, the masses of ^{57}Ni and ^{44}Ti observed for SN 1987A, and the abundance patterns observed in extremely metal-poor stars. We find that these observational constraints are consistent with the "rapid" explosion ($t_{\rm grow} < 250$ ms), and especially the best match is found for a nearly instantaneous explosion ($t_{\rm grow} \sim 50$ ms). Our finding places a strong constraint on the explosion mechanism; the slow mechanism ($t_{\rm grow} > 1000$ ms) would not satisfy these constraints, and the ab initio simulations will need to realize a rapid explosion.

Session 5 ν-physics

O5-1 27th 13:20-14:10

General Relativistic Neutrino Transport and Quantum Kinetics

Sherwood Richers

The theory of the core-collapse supernova (CCSN) explosion mechanism relies on an accurate treatment of neutrino transport inside the exploding star. There is a wealth of physical processes that become important at different times and locations, large neutrino optical depths, and nontrivial geometries that make understanding neutrino-driven explosions particularly interesting and challenging. Many state of the art simulations of CCSNe employ a moment-based transport scheme that employs an approximate closure relation. I will describe a method to provide a closure via a time-independent Monte Carlo transport calculation at every timestep and will present test one-dimensional simulations of CCSNe using this method. Finally, I will comment on the state of the field of neutrino flavor transformations in CCSNe and the numerical challenges simulating these effects presents.

O5-2 27th 14:25-14:50

Collective neutrino-flavor conversion in the pre-shock region of core-collapse supernova

Taiki Morinaga

We make a strong case that the fast neutrino-flavor conversion, one of the collective flavor oscillation modes, commonly occurs in core-collapse supernovae (CCSNe). It is confirmed in the numerical data obtained in realistic simulations of CCSNe but the argument is much more generic and applicable universally: the coherent neutrino-nucleus scattering makes the electron lepton number (ELN) change signs at some inward direction and trigger the flavor conversion in the outward direction in the pre-shock region. Although the ELN crossing is tiny and that is why it has eluded recognition so far, it is still large enough to induce the flavor conversion. Our findings may have an important observational consequences for CCSNe neutrinos.

O5-3 27th 14:50-15:15

The impacts of nuclear-reaction rate uncertainties on νp-process nucleosynthesis in core-collapse supernovae

Nobuya Nishimura

It has been suggested that a νp process can occur when hot, dense, and proton-rich matter around the proto-neutron-star surface is expanding within a strong flux of anti-neutrinos. In such an environment, proton-rich nuclides can be produced in sequences of proton captures and (n,p) reactions, where the free neutrons are created in situ by the neutrino capture by protons. In this work, the uncertainties on the final isotopic abundances stemming from uncertainties in the nuclear reaction rates were investigated in a large-scale Monte Carlo approach, simultaneously varying ten thousand reactions. Based on a large range of hydrodynamical model conditions, we found the key nuclear reactions dominating the uncertainty for a given nuclide abundance. It is also found that the solar ratio of the abundances of ^{92}Mo and ^{94}Mo could be reproduced within uncertainties.

Session 6 Dynamics of Compact Objects

O6-1 27th 16:05-16:55

Dynamics of Compact Objects

Naoki Seto

I will discuss celestial mechanical effects for multiple systems including compact objects. Paying special attention to relativistic corrections, I will explain interesting phenomena such as the Kozai oscillation and capture into a peculiar resonant state.

O6-2 27th 17:10-17:35

General Relativistic Effects on Hill Stability of three-body systems

Haruka Suzuki

Nowadays, the dynamical interaction among several compact objects around a massive black hole attract researchers' interest because it may cause the gravitational emission that is detectable with future gravitational-wave detectors. The stability of complicated evolution of orbits in such many-body systems has been discussed in Newtonian mechanics. In our study, we extend the analysis of Hill stability by using General Relativity and investigate the relativistic effect on the Hill stability of the system with a supermassive or intermediate mass black hole.

O6-3 27th 17:35-18:00

A strategy to search for an inner binary black hole from the motion of the tertiary star

Toshinori Hayashi

After LIGO detects gravitational waves from binary black hole (BBH) mergers, the origin and evolution of such binaries are being widely discussed. Since current proposed formation scenarios of BBHs usually require a long-term orbital evolution before coalescence, there should be abundant progenitor BBHs with longer orbital period in the universe. However, such BBHs are not yet detected in part because they normally do not have detectable emission of electromagnetic or gravitational waves.

Currently, many projects are ongoing to search for stars orbiting invisible companions such as black holes. A fraction of the candidates can be a triple consisting of a star and inner unseen BBH.

We therefore propose a possible methodology to search for an inner BBH through short-period radial velocity (RV) variations of a star induced by gravitational perturbation of BBH with follow-up RV monitoring.

Actually, LB-1 system, a binary consisting of a B-type star and massive unseen companion at a few kpc away, is recently discovered with RV observation. The discovery implies a large fraction of multiples including unseen objects even in our Galaxy.

In this presentation, we will first explain basic observational strategy and expected signatures of inner BBHs. We will next show the expected RV variations calculated with N-body numerical simulations especially for our fiducial cases inspired by LB-1 system, considering a variety of orbital configurations. We will then discuss the observational feasibility and future prospects of the methodology.

Session 7 Supernova

O7-1 28th 9:45-10:35

Gravitational-wave and neutrino signatures from multi-D core-collapse supernova models

Kei Kotake

Based on three-dimensional core-collapse supernova simulations, we present results about GW and neutrino emission from both non-rotating, rapidly rotating and strongly magnetized massive stars. For non-rotating progenitors, we report how the SASI activity is imprinted in the neutrino and GW signatures. For the magnetohydrodynamically-driven model, we present preliminary results including the LESA phenomena, the kink instability, and the neutrino signatures. Finally we briefly mention prespectives toward multi-messenger analysis from a CCSN event.

O7-2 28th 10:50-11:15

iPTF14hls as a variable hyper-wind from a very massive star

Takashi Moriya

The origin of iPTF14hls, which had Type IIP supernova-like spectra but kept bright for almost two years with little spectral evolution, has been actively debated. We propose that iPTF14hls was not a sudden outburst like supernovae but rather a long-term outflow similar to stellar winds. The properties of iPTF14hls, which are at odds with a supernova scenario, become natural when interpreted as a stellar wind with variable mass-loss rate. Based on the wind hypothesis, we estimate the mass-loss rates of iPTF14hls in the bright phase. We find that the instantaneous mass-loss rate of iPTF14hls during the 2-year bright phase was more than a few $M_{\odot}$ /yr ("hyper-wind") and it reached as much as $10 M_{\odot}$ /yr. The total mass lost over two years was about $10 M_{\odot}$. Interestingly, we find that the light curve of iPTF14hls has a very similar shape to that of eta Carinae during the Great Eruption, which also experienced a similar but less extreme brightening accompanied by extraordinary mass loss, shedding more than $10 M_{\odot}$ in 10 years. The progenitor of iPTF14hls is less than $150 M_{\odot}$ if it still exists, which is similar to eta Carinae. The two phenomena may be related to a continuum-driven extreme wind from very massive stars.

O7-3 28th 11:15-11:40

Shape of nebular emission line of core-collapse supernova exploded by neutrino heating mechanism

Yukari Ohtani

The emission lines shown in the nebular phase of a supernova are known as the probe of the morphology of the ejected matter, which reflects the explosion mechanism. In the previous studies, the evolution of fluid dynamics has been traced with artificially injected energy. In this study, we calculate the shapes of the emission lines of striped core-collapse supernovae to investigate the relations of the distribution of ejecta. The hydrodynamics are calculated by using the 3DnSEP code (developed by Takiwaki et al.), and the initial conditions are the profiles of Nakamura et al. (2015) model in which the neutrino-radiation hydrodynamics are solved self-consistently. In the self-consistent calculation, the ejecta expands unipolarity, and the resultant oxygen line has a single-peaked shape while in some observations oxygen lines have double-peaked shapes.

Session 8 Nuclear Physics

O8-1 28th 13:20-14:10

Variational methods for nuclear matter and their applications to neutron stars

Masatoshi Takano

We have been studying two variational methods for infinite nuclear matter. One is the cluster variational method, with which we constructed a nuclear EOS table for core collapse supernovae. Starting from the AV18 two-body potential and the UIX three-body potential, we calculated free energies per nucleon of hot asymmetric nuclear matter; for the nonuniform phase, we adopted the Thomas-Fermi approximation. We are currently applying the nuclear EOS to the calculation of the neutrino emissivity from the modified Urca process. The other is the variational method with explicit energy functionals. This variational method is more sophisticated taking into account contributions from many-body correlations; the energy per neutron of neutron matter with the AV6' two-body potential and the UIX three-body potential calculated using this variational method is in good agreement with that obtained by the quantum Monte Carlo method. Moreover, masses and radii of neutron stars with the obtained nuclear EOS are reasonable as compared with recent observational data. In this talk, I will present the status of these variational studies.

O8-2 28th 14:25-14:50

Neutron Star Mass and Radius Measurements with the NICER X-ray Observatory

Teruaki Enoto

The Neutron Star Interior Composition ExploreR (NICER) was launched in 2017 and started X-ray observations of various types of neutron stars from the International Space Station (ISS). One of the primary objectives of NICER is to measure neutron star mass and radius to determine the equation of states of the high density matter inside neutron stars. Here we review the NICER project and some of early results.

O8-3 28th 14:50-15:15

Quark-Hadron phase transition by Color Molecular Dynamics and Lattice QCD simulations

Nobutoshi Yasutake

Quark-hadron phase transition is studied by Color-Molecular-Dynamics (CMD) simulations. The interactions between quarks are based on SU(3) dynamics, and derived by the comparison with the Lattice QCD (LQCD) simulations. We found that our results are consistent with LQCD in a few baryons system, e.g. the bound states of dibaryons, predicted by LQCD, appear as the result of the interactions. We also show the results of CMD simulations of many quark systems, which can predict the order of the quark-hadron phase transition. Hence, the equation of state with CMD might play a critical role in this gravitational wave era.

Session 9 Cooling of Protoneutron Star

O9-1 28th 15:30-16:20

Transport theory of neutron star matter

Peter Shternin

I review the transport properties of the dense matter in the neutron star interiors. The transport properties are important microphysical ingredients for the modeling of various evolutionary processes in the compact objects. I consider various phases found in the star from the outer layers in the crust to the densest possible phases in the core. The talk is largely based on the recent review (A. Schmitt and P.S. Shternin, 2108, Chapter 9 in Physics and Astrophysics of Neutron Stars, Springer Astrophys. Space Sci. Libr. 457, p. 455).

O9-2 28th 16:35-17:00

Dependence of Neutron Star Cooling on the Symmetry Energy

Akira Dohi

One of the important problems on thermal evolution of isolated neutron stars is whether the rapid cooling process, e.g., Direct Urca process, occurs or not, which is determined by the equation of state (EOS). EOS and the neutron star cooling are deeply related via symmetry energy of nuclear matter, but the detail in high density regions has been unknown. In this presentation, we will talk about the relevancy between the EOS stiffness and the Direct Urca process from cooling calculation results.

O9-3 28th 17:00-17:25

Muon creation in proto-neutron stars and its implications for neutrino signal in cooling phase

Ken'ichi Sugiura

Muon existence was usually neglected in core-collapse supernovae (CCSNe) or its central objects, proto-neutron stars (PNS) in numerical simulations, since muon have much higher rest mass than SN matter temperature. However due to high degeneracy of electrons in the PNS, chemical potential of electron can be exceed muon mass and thus muon is created. It is known that the appearance of muon softens the equation of state and give supportive effects on the SN, so detailed modeling of SN explosion and neutron star formation is indispensable. We calculated the relevant neutrino reactions with muons in which the detailed kinematics of reaction particles were fully included. I will present the absorptivity end emissivity of these reactions in the realistic situations and discuss possible impacts on PNS cooling and its neutrino signals.