Poster Presentations

P1

General Relativistic Boltzmann Solver for Core-collapse of Massive Stars

Ryuichiro Akaho

Massive stars are known to end their lives with gravitational collapse, and form compact objects like neutron stars (NSs) or black holes (BHs). Because of the lack of first-principle simulation, quantitative understanding of these events have not been achieved yet. Neutrinos are known to play significant roles, and past simulations indicate that different neutrino treatments lead to qualitatively and quantitatively different results. To accurately calculate the transfer of neutrino coupled with matter, it is necessary to directly solve Boltzmann equation, which is the equation for the distribution function in 6-D phase space. However, it is very computationally demanding to solve Boltzmann equation directly, hence many groups employ approximate schemes. In addition, general relativistic (GR) effects are neglected in many groups. As far as in realistic core-collapse simulations, no study employed full GR Boltzmann solver.
In this talk, I would like to present code validation tests for GR Boltzmann solver, which is the extension of Boltzmann-Hydro code already in use for many 3D CCSN simulations. I present two kinds of test, redshift and light deflection in Schwarzschild spacetime. The result shows good agreements with analytical solutions, or reference solutions.

P2

Occurrence of fast collective neutrino oscillations inside the neutrino sphere in core-collapse supernovae

Milad Delfan Azari

Neutrinos are believed to be a role player in the explosion mechanism of core-collapse supernovae as they carry most of the energy released by the gravitational collapse of a massive star. If their flavor is converted fast inside the neutrino sphere, the supernova explosion may be influenced.

I will report the results of the thorough survey of the electron lepton number (ELN) crossing in one of our self-consistent, realistic Boltzmann simulations in two spatial dimensions under axisymmetry for the existence of the crossings between the electron-type and anti-electron angular distributions of neutrinos, or the ELN crossing.

As a result, for the first time the positive detections, deep inside the core of the massive star in the vicinity of neutrino sphere at about $r = 16$–$21\,\mathrm{km}$ is found. It is also found that low values of the electron fraction Ye produced by convective motions together with the appearance of light elements are critically important to give rise to the ELN crossing by enhancing the chemical potential difference between proton and neutron, and hence by mitigating the Fermi-degeneracy of electron-type neutrinos. Since the region of positive detection are sustained and, in fact, expanding with time, it may have an impact on the explosion of core-collapse supernovae, observational neutrino astronomy, and nucleosynthesis of heavy nuclei.

P3

Simulations of early kilonova emission from neutron star mergers

Smaranika Banerjee

The recent detection of gravitational waves from compact object mergers has provided a new way to probe the fundamental questions, such as the formation channel of binaries, the test of gravity, and so on. Along with the gravitational wave of the neutron star merger GW170817, the astronomy community witnessed the first detection of the electromagnetic counterpart of neutron star merger, the kilonova. This is a supernova like transient but fainter in magnitude, mainly powered by the radioactive decay of the heavy elements synthesized in the site of neutron star merger ejecta. The wavelength at which it peaks depends on which elements are synthesized and consequently, the opacity in the ejecta. Previous theoretical works showed the opacity of kilonova ejecta at the late time (after 1 day) is approximately an order of magnitude higher than the gray opacity of supernova as elements higher than iron can get synthesized. The kilonova detected along with GW170817 consists of bright blue emission at the early period. So it is important to calculate the opacity to construct the early time lightcurve. One of the main barriers to calculate the opacity at an early time is, as the temperature is high, the atoms are highly ionized, and no atomic data was available. In this work, the opacity is calculated from iron to cerium for ionization up to XII for the first time. Using this opacity, the first realistic calculation of the kilonova light curve is done in timescales less than one day. The calculation with a simple one-component merger ejecta model shows a reasonable fit with the early emission data for the ejecta mass range of 0.03 solar mass or higher.

P4

Imprint of asymmetric neutrino emission of a supernova on chemical abundances in a supernova remnant

Shin-ichiro Fujimoto

Recent multi-dimensional simulations of core collapse supernovae (CCSNe) reveal asymmetric and anti-correlated neutrino emissions from a new-born, proto-neutron star. We have investigated the impact of the asymmetric neutrino emissions on the explosive nucleosynthesis in neutrino-driven CCSNe. We find that the asymmetric emissions tend to yield larger amounts of proton-rich ejecta (electron fraction,

$Y_e > 0.51$) in the hemisphere of the higher nue emissions, meanwhile neutron-rich matter ($Y_e < 0.49$) are ejected in the opposite hemisphere of the higher anti-nueb emissions. For larger asymmetric cases with $\geq 30\%$, the neutron-rich ejecta is abundantly produced, in which there are too much elements heavier than Zn compared to the solar abundances. This may place an upper limit of the asymmetric neutrino emissions in CCSNe. The characteristic features are also observed in elemental distribution; (1) abundances lighter than Ca are insensitive to the asymmetric neutrino emissions: (2) the production of Zn and Ge is larger in the neutron-rich ejecta even for smaller asymmetric cases with $\leq 10\%$. We discuss these observational consequences, which may account for the (anti-)correlations among asymmetries of heavy elements and neutron star kicks in supernova remnants (SNRs). Future SNR observations of the direct measurement for the mass and spatial distributions of alpha-elements, Fe, Zn and Ge will provide us the information on the asymmetric degree of neutrino emissions.

P5

The W4 method: a new multi-dimensional root-finding scheme for nonlinear systems of equations

Kotaro Fujisawa

We develop a new multi-dimensional root-finding scheme for nonlinear systems of equations, the W4 method. The W4 method is an iterative relaxation method like the Newton-Raphson method, but the W4 method uses acceleration and dumping terms. The W4 method avoids the non-converge oscillation during the iteration and shows better global convergence. We apply the W4 method to many astrophysical systems and obtain numerical solutions effectively.

P6

Remnant mass distribution using Hurley's single star evolution code

Kiyokazu Igarashi

We want to know the relation between supernova relic neutrino and the galactic chemical evolution with stellar population synthesis (SPS) model. To learn how to use SPS model, we calculated remnants mass for three metallicities using a Hurley's single star evolution code. Then, we combined the results with three initial mass functions to make remnant mass distributions and show them in this poster.

P7

The Core-Collapse Supernova Simulations with the Full Boltzmann Neutrino Transport in Three-Dimensional Space

Wakana Iwakami

Using a radiation-hydrodynamic code by full Boltzmann neutrino transport, we performed a simulations of core-collapse supernova for $11.2M_{\odot}$ progenitor model in thee-dimensional space until 20 ms after bounce. We solved the time-dependent 6-dimensional Boltzmann equation for three species of neutrinos and the 3-dimensional compressible Euler equations using the Furusawa and Togashi's equation of state. Focusing on the prompt convection phase around 10 ms, we investigate neutrino radiation transport with a new approach using eigenvalues and eigenvectors of Eddington tensor which is directly calculated from neutrino distribution functions (Boltzmann) or obtained by M1 closure relation (M1 method). We visualized the results into an ellipsoid whose each axis is parallel to each eigenvector with its amplitude corresponding to each eigenvalue. This approach is equivalent to the approximation of the neutrino distribution function by an ellipsoid, and enable us to evaluate the neutrino distribution function quantitatively. We found that the major axis of ellipsoid is pointed in various directions in the intermediate zone between completely optically thick and optically thin regions for Boltzmann while its direction is almost parallel to the neutrino flux in the whole region for M1 method.

P8

Linear Analysis of MHD jet in CCSNe

Kohei Michihata

According to axisymmetric simulations of magnetized CCSNe, it is predicted that the form of the explosion is jet. But recently full 3D simulation claims that the behavior of the explosion is different from this picture because of the instability of the magnetized jet. I study this instability of the MHD jet. Especially, to provide more analytical result, I try to preform the linear analysis to this MHD jet.

P9

The Final Fate of Supermassive $M \sim 5 \times 10^4 M_{\odot}$ Pop III Stars: Explosion or Collapse?

Chris Nagele

We investigate the possibility of a supernova in supermassive ($5 \times 10^4 M_{\odot}$) population three stars induced by a general relativistic instability occurring in the helium burning phase. These explosions might occur via rapid helium burning during an early contraction of the isentropic core. Such an explosion would be visible to future telescopes and would disrupt the proposed direct collapse formation channel for early universe supermassive black holes. We simulate first the stellar evolution from hydrogen burning using a 1D stellar evolution code with a post Newtonian approximation; at the point of dynamical collapse, we switch to a 1D GR hydrodynamics code with the Misner-Sharpe metric. In opposition to a previous study, we do not find an explosion in the non rotating case, although our model is close to exploding for a similar mass to the explosion in the previous study. When we include slow rotation, we find one exploding model, and we conclude that their likely exist additional exploding models, though they are probably rare.

P10

Core-collapse supernova simulations from a 3D progenitor model

Ko Nakamura

Three-dimensional (3D) hydrodynamics simulations of stellar evolution have shown that massive stars involve large-scale perturbations from convective shell burning. We choose a latest 25 solar-mass progenitor model based on 3D stellar evolution (Yoshida et al. 2019) as an initial condition and carry out multi-dimensional core-collapse supernova simulations to study the impact of the large-scale perturbations on the supernova hydrodynamics. Our results show that realistic perturbations can alter the post-bounce evolution.

P11

Cooling Timescale of Protoneutron Stars and Nuclear Matter Equation of State

Ken'ichiro Nakazato

Using a series of phenomenological equations of state, we have systematically investigated the supernova neutrino light curve of the cooling phase. As a result, the cooling timescale evaluated from the neutrino light curve is found to depend on the mass and radius of neutron stars.

P12

Research on the closure relation of radiation transport equation by neural network

Shota Nishikawa

A gravity-collapse supernova explosion is a large explosion phenomenon in which a heavy star with a mass about eight times greater than that of the Sun is known to be in the final stage of its evolution. By solving the neutrino radiation transport equation, a supernova explosion simulation can be performed. The radiation transport simulation that solves the Boltzmann equation. It spends six months even with the supercomputer "Kei". Therefore, the calculation time is often reduced by solving the approximated radiation transport equation. However, it has been pointed out that the accuracy of this approximation method is limited. Therefore, the purpose of this study is to develop a highly accurate approximation method of the radiation transport equation. Conventionally, approximation using analytic expressions has been often used, but in this study we propose an approximation method using deep learning. Then, the difference between the provided closure and NN was confirmed.

P13

The numerical construction of axisymmetric equilibria of rotating stars on Lagrangian coordinates

Misa Ogata

The stellar rotation affects the configuration and evolution: stars are flattened with the equatorial radius being larger than the polar radius. Rotation also affects the stellar internal structure and thereby changes their evolution. It is particularly important to consider the effects of rotation on core-collapse supernovae and on merger remnants of the coalescence of two stars.
To construct axisymmetric equilibria of rotating stars numerically and then calculate their evolutions, we solve the hydrostatic equilibrium equation by using Lagrangian coordinates as it is crucial for the stellar evolution calculation. Moreover, we employ a new numerical method, W4 method, which has significantly better convergence capability in the solution of nonlinear systems. We calculate the pseudo-evolution to the actual non-spherical configuration with rotation. We are able to obtain the rotating star that has a rotation speed of 90% or more of the break-up velocity. Our solution is very close to this critical case and the obtained configuration is flattened.

P14

Spectropolarimetry of Superluminous supernova

Sei Saito

Massive stars end their lives with high-energy explosion, called supernovae. Thanks to the large surveys, many unusual supernovae have been discovered in recent years. "Superluminous supernovae" are one of such examples. Superluminous supernovae are from ten to hundred times more luminous than normal supernovae. Their explosion/emission mechanisms are not yet clear: their high luminosity cannot be explained with radioactive decay of nickel, which is the major power source of normal supernovae. The shape of the explosion may considerably deviate from spherical symmetry for some proposed models, and thus, it is important to study the multi-dimensional shapes of superluminous supernova. Since all extragalactic supernovae cannot be spatially resolved, polarimetric observation is one of the most powerful tools to study their morphology.
We performed optical spectropolarimetric observations of a superluminous supernova, SN 2017egm (Type I SLSN) about 200 days after the maximum light. The

degree of interstellar polarization estimated in this study is consistent with that of polarization that is supposed to originate from the supernova in a previous study. In other words, SN 2017egm does not have a large intrinsic polarization at the early phases, indicating that the outer layer of the supernova is almost spherical. On the other hand, the degree of intrinsic SN 2017egm polarization at the late phase increases compared with that at the early phases. This indicates that the inner layer of the supernova is aspherical. Therefore, we conclude that the power source of superluminous supernovae is some kind of central energy source producing inner asphericity.

P15

Instabilty of magnetohydro-jet in supernova

Kimihiko Shimizu

In order to investigate how a jet which is considered to be generated in a magnetized supernova contributes to supernova explosion, I examined the instability of the magnetic jet and the growth rate using numerical calculations.

P16

Supernova ejecta colliding with a disk-like circum-stellar medium

Akihiro Suzuki

Circum-stellar media (CSM) are believed to play important roles in various types of supernova (SN) explosions. The collision between the SN ejecta and the CSM sometimes gives rise to very bright thermal emission, which is considered to be the main power source for specific types of SNe. Type IIn SNe are among the most important class of such interacting SNe. In the extreme case of superluminous type IIn SNe, CSMs as much as ~ 10 solar mass are suspected to be around the progenitor star. The biggest question related to interacting SNe is when and how such massive CSM are produced. Also, some type IIn SNe are known to exhibit unusual polarization and spectroscopic signatures indicating aspherical CSMs. Such aspherical geometry of CSMs may be a key to understanding the mechanism that massive stars shed their envelopes prior to the core-collapse explosion. Recently, I performed some 2D radiation-hydrodynamic simulations of SN ejecta interacting with spherical and disk-like CSMs (Suzuki, Moriya, & Takiwaki 2019). In this presentation, I report some results of our simulations and discuss observational signatures of SNe interacting with aspherical CSMs.