# MICRA2019 - Microphysics In Computational Relativistic Astrophysics

# Report of Contributions

Contribution ID: **1** Type: **Oral Contribution**

# Neutrinos in Binary Neutron Star Mergers

*Thursday, 15 August 2019 11:00 (20 minutes)*

I will present results of general relativistic hydrodynamic (GRHD) simulations of binary neutron star (BNS) mergers with a hybrid leakage-transport scheme for the neutrino treatment. I will discuss the matter dynamics and show the thermodynamic conditions of the fluid in the region where the three evolved neutrino species decouple from matter. Finally, I will give an overview of the state-of-the-art for neutrino evolution in GRHD.

## Keywords

Neutrinos

**Primary author:** ENDRIZZI, Andrea (TPI - University of Jena)

**Presenter:** ENDRIZZI, Andrea (TPI - University of Jena)

**Session Classification:** Mergers

Contribution ID: **2** Type: **Oral Contribution**

# A pulsar-runaway-pair from a nearby supernova about 1.8 Myr ago that ejected 60-Fe found on Earth

*Tuesday, 13 August 2019 14:30 (20 minutes)*

The detection of 1.5-3.2 Myr 60-Fe on Earth indicates recent nearby core-collapse supernovae. For supernovae in multiple stars, the primary stars become neutron stars, while former companions can get unbound (runaway stars). By tracing back the space motion of runaway and neutron stars to the nearest young (about 16 Myr) association of massive stars (Scorpius-Centaurus-Lupus), we found kinematic evidence that a certain runaway star and a certain radio pulsar were released by a supernova in a binary about 1.8 Myr ago at about 107 pc distance; association age and flight time determine the progenitor mass (16-18 M_sun), which can constrain supernova nucleosynthesis yields and 60-Fe uptake on Earth. Our scenario links 60-Fe found on Earth to an individual supernova in a binary.

## Keywords

Core-Collapse Supernovae

**Primary authors:** Prof. NEUHAEUSER, Ralph (AIU U Jena); Dr GIESSLER, Frank (AIU U Jena); Dr HAMBARYAN, Valeri (AIU U Jena)

**Presenter:** Prof. NEUHAEUSER, Ralph (AIU U Jena)

**Session Classification:** Core-Collapse Supernovae

Contribution ID: **3** Type: **Oral Contribution**

# Neutrinos in/from supernovae

*Monday, 12 August 2019 09:00 (30 minutes)*

The behavior of neutrinos in core-collapse supernovae is very different from their usual role as ephemeral larcenists. Neutrinos are the principle mechanism by which energy and lepton number are transported within the explosion, while core-collapse supernovae produce neutrinos in such prodigious quantities that the neutrino signal from a supernova in The Galaxy would allow us to directly observe the conditions at the center of the explosion and thus test our theories of how massive stars end their lives. In this talk I will present the current status of our understanding of neutrinos in supernovae emphasizing what has been recently learned, where the gaps in our understanding still exist, and what information we can hope to glean from a neutrino burst signal. In addition, I will discuss how new properties of neutrinos, such as interactions beyond the Standard Model or additional flavors of neutrinos, can be probed and tested in regimes of temperature and density not accessible here on Earth.

## Keywords

Neutrinos

**Primary author:** KNELLER, Jim (NC State University)

**Presenter:** KNELLER, Jim (NC State University)

**Session Classification:** Neutrinos

Contribution ID: **4** Type: **Oral Contribution**

# Probing Neutron Star Merger Properties with Metal-Poor Stars

The astrophysical production site of the heaviest elements in the universe remains a mystery. Incorporating heavy element signatures of metal-poor, <em>r</em>-process enhanced stars into theoretical studies of <em>r</em>-process-process production can offer crucial constraints on the origin of heavy elements. In this study, we apply the "Actinide-Dilution with Matching" model to a variety of stellar groups ranging from actinide-deficient to actinide-enhanced to empirically characterize <em>r</em>-process ejecta mass as a function of electron fraction ($Y_e$). We find that actinide-boost stars do not indicate the need for a unique and separate <em>r</em>-process progenitor. Rather, small variations of neutron richness within the same type of <em>r</em>-process event can account for all observed levels of actinide enhancements. The very low-$Y_e$, fission-cycling ejecta of an <em>r</em>-process event need only constitute 10-30% of the total ejecta mass to accommodate most actinide abundances of metal-poor stars. We find that our empirical $Y_e$ distributions of ejecta are similar to those inferred from studies of GW170817 mass ejecta ratios, which is consistent with neutron-star mergers being a source of the heavy elements in metal-poor, <em>r</em>-process enhanced stars. Furthermore, results from this model can constrain merger properties and distributions of neutron stars in the early universe.

## Keywords

Compact Object Mergers

**Primary author:** HOLMBECK, Erika (University of Notre Dame)

**Presenter:** HOLMBECK, Erika (University of Notre Dame)

**Session Classification:** Mergers

Contribution ID: **5** Type: **Oral Contribution**

# Optimal neutron-star mass ranges to constrain the equation of state of nuclear matter with electromagnetic and gravitational-wave observations

*Wednesday, 14 August 2019 14:30 (20 minutes)*

Exploiting a very large library of physically plausible equations of state (EOSs) containing more than $10^7$ members and yielding more than $10^9$ stellar models, we conduct a survey of the impact that a neutron-star radius measurement via electromagnetic observations can have on the EOS of nuclear matter. Such measurements are soon to be expected from the ongoing NICER mission and will complement the constraints on the EOS from gravitational-wave detections. Thanks to the large statistical range of our EOS library, we can obtain a first quantitative estimate of the commonly made assumption that the high-density part of the EOS is best constrained when measuring the radius of the most massive, albeit rare, neutron stars with masses $M > 2.1M$. At the same time, we find that radius measurements of neutron stars with masses $M \sim 1.7{-}1.85M$ can provide the strongest constraints on the low-density part of the EOS. Finally, we quantify how radius measurements by future missions can further improve our understanding of the EOS of matter at nuclear densities.

## Keywords

Nuclear Theory

**Primary authors:** WEIH, Lukas (Goethe University, Frankfurt); MOST, Elias; REZZOLLA, Luciano

**Presenter:** WEIH, Lukas (Goethe University, Frankfurt)

**Session Classification:** Equation of State

Contribution ID: **6** Type: **Oral Contribution**

# Core-collapse supernovae and equation of state effects*

*Wednesday, 14 August 2019 11:30 (20 minutes)*

Core-collapse supernovae (CCSN) are cosmic laboratories for physics at the extremes and numerical simulations are essential to help us understand the underlying mechanisms in these events. A key ingredient in simulations is the equation of state (EOS), which determines the contraction behavior of the proto-neutron star (PNS) and thus impacts neutrino energies and explosion dynamics. However, the EOS for hot and dense matter is still not fully understood and CCSN simulations rely on EOS models that differ in their underlying theory and nuclear matter properties.

We present the first systematic study on the impact of different nuclear matter properties of the EOS in CCSN simulations. This allows us to examine possible reasons for differences in commonly used EOS in simulations. We find that the contraction behavior of the PNS is mainly governed by the effective mass, which impacts the shock propagation.

*Supported by the Deutsche Forschungsgemeinschaft through SFB 1245 (Projektnummer 279384907) and the European Research Council Grant No. 677912 EUROPIUM.

## Keywords

Core-Collapse Supernovae

**Primary authors:** YASIN, Hannah; SCHÄFER, Sabrina; ARCONES, Almudena; SCHWENK, Achim

**Presenter:** YASIN, Hannah

**Session Classification:** Equation of State

Contribution ID: **7** Type: **Oral Contribution**

# Numerical relativity informed models of the electromagnetic counterpart of neutron star mergers

*Thursday, 15 August 2019 14:30 (20 minutes)*

Neutron star merger is a unique cosmic laboratory to investigate general relativity in a strong field regime and fundamental physics, including dense matter and heavy-elements-nucleosynthesis.

Our work focuses on the electromagnetic counterpart of the gravitational wave source GW170817. We study the merger dynamics and light curves employing the state of the art numerical, general relativistic simulations with microphysics.

We find that cases with long-lived remnants exhibit a quasi-steady outflow, powered by the interaction between the remnant and the surrounding disk. The outflow has distinct from well known dynamical ejecta properties and larger mass. Including it into the numerical-relativity informed kilonova models, we show that this component is imporntnat for understanding the early blue component of AT2017gfo.

## Keywords

Compact Object Mergers

**Primary author:** NEDORA, Vsevolod (Theoretisch-Physikalisches Institut)

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**Presenter:** NEDORA, Vsevolod (Theoretisch-Physikalisches Institut)

**Session Classification:** Mergers

Contribution ID: **8** Type: **Oral Contribution**

# Challenge to Black Hole Models and Supernova explosion driven by Magnetic

*Tuesday, 13 August 2019 15:30 (20 minutes)*

1) A unusually strong radial magnetic field detected near our Galactic Center (2013) is consistent with the prediction from our model of supermassive object with magnetic monopoles (MM) ( Peng and Chou 2001). The important implications of the unusually strong radial magnetic field near the GC are: a) A strong evidence of the existence of MM; b) The black hole model of the suppermassive object at the GC is unphysical (Peng et al., 2016; 2017).
2) I shall also give query on the black hole models for other quasars and active galactic nuclei.The key dilemma of the black hole model is the question on the BH mass at the center of AGNs.
The dilemma will disappear in our model of Supper-massive Stars with MM.
3) Taking the RC effect (nucleons may decay catalyzed by MM) as an energy source, we have proposed an unified model for various supernova explosion (Peng et al. 2017). In our model, the remnant of the collapsed core of supernova is still a neutron star rather than a black hole no matter how huge of the supernova mass. That means, black holes with stellar mass are impossible to be formed through supernova explosion.
4) We may explain the physical reason of the Hot Big Bang of the Universe with the similar mechanism of supernova explosion by using the RC effect as an energy source. That is , the primordial Black hole of the whole Universe is no physical

## Keywords

Core-Collapse Supernovae

**Primary author:** Prof. PENG, Qiuhe (Nanjing University)

**Presenter:** Prof. PENG, Qiuhe (Nanjing University)

**Session Classification:** Core-Collapse Supernovae

Contribution ID: **9** Type: **Oral Contribution**

# The Effects of Neutrino Oscillations on Core-Collapse Supernova Explosions

*Monday, 12 August 2019 11:30 (20 minutes)*

At the present time even the most sophisticated, multi-dimensional simulations of core-collapse supernovae do not (self-consistently) include neutrino flavor transformation. This physics is missing despite the importance of neutrinos in the core-collapse explosion paradigm. Because of this dependence, any flavor transformation that occurs in the region between the proto-neutron star and the shock could result in major effects upon the dynamics of the explosion.

We present the first hydrodynamic core-collapse supernova simulation which simultaneously includes flavor transformation of the free-streaming neutrinos in the neutrino transport. These oscillation calculations are dynamically updated and evolve self-consistently alongside the hydrodynamics. Using a $M = 15$ $\mathrm{M}_{\odot}$ progenitor, we find that while the oscillations can have an effect on the hydrodynamics, flavor transformation alone does not lead to a successful explosion of this progenitor.

## Keywords

Core-Collapse Supernovae

**Primary author:** STAPLEFORD, Charles (North Carolina State University)

**Co-authors:** FROHLICH, Carla; KNELLER, Jim (NC State University)

**Presenter:** STAPLEFORD, Charles (North Carolina State University)

**Session Classification:** Neutrinos

Contribution ID: **10** Type: **Oral Contribution**

# A unified quark-hadron equation of state

*Wednesday, 14 August 2019 14:00 (20 minutes)*

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.

[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).

## Keywords

Nuclear Theory

**Primary author:** BASTIAN, Niels-Uwe (University of Wroclaw)

**Presenter:** BASTIAN, Niels-Uwe (University of Wroclaw)

**Session Classification:** Equation of State

Contribution ID: **11** Type: **Oral Contribution**

# Influence of astrophysical and nuclear physics uncertainties on the nucleosynthesis in core-collapse supernova neutrino-driven winds

*Friday, 16 August 2019 11:00 (20 minutes)*

Neutrino-driven winds emerging after a successful core-collapse supernovae can produce the lighter heavy elements between Fe and Ag depending on the properties of the ejecta.
However, despite the fast progress in supernovae simulations in the last decades, there are still large uncertainties in the astrophysical conditions.
We rely on a steady-state neutrino-driven wind model to systematically study the influence of astrophysical uncertainties on the nucleosynthesis evolution in neutrino-driven ejecta.
Furthermore, uncertainties in the nuclear physic input to the nucleosynthesis calculation impact the abundance patterns.
In order to identify key reactions, we perform sensitivity studies based on a Monte Carlo approach for a variety of astrophysical conditions in neutron- and proton-rich ejecta.

Supported by the European Research Council Grant No. 677912 EUROPIUM and the Deutsche Forschungsgemeinschaft through SFB 1245 (Projektnummer 279384907).

**Keywords**

Nucleosynthesis

**Primary author:** JACOBI, Maximilian (TU-Darmstadt)

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**Presenter:** JACOBI, Maximilian (TU-Darmstadt)

**Session Classification:** Nucleosynthesis

Contribution ID: **12** Type: **Oral Contribution**

# Equation of State Effects in the Core Collapse of Massive Stars

*Wednesday, 14 August 2019 10:15 (30 minutes)*

Uncertainties in our knowledge of the properties of dense matter near and above nuclear saturation density are among the main sources of variations in multi-messenger signatures predicted for the core collapse of massive stars and the properties of the resulting remnants. In this talk, I discuss how variations in the equation of state of dense matter affect the core collapse of massive stars. By simulating the core collapse of many different progenitors using a wide range of equations of state we conclude that temperature effects are among the largest sort of uncertainty in the dynamics of the core collapse, the emitted neutrino signal, and the compact object formed.

## Keywords

Core-Collapse Supernovae

**Primary author:** DA SILVA SCHNEIDER, André (Stockholm University)

**Presenter:** DA SILVA SCHNEIDER, André (Stockholm University)

**Session Classification:** Equation of State

Contribution ID: **13** Type: **Oral Contribution**

# Black hole simulations with the FO-CCZ4 formulation of the Einstein equations and ADER discontinuous Galerkin schemes

*Thursday, 15 August 2019 11:30 (20 minutes)*

We present FO-CCZ4, a strongly hyperbolic first-order formulation of the Einstein equations based on the conformal and covariant Z4 system with constraint-violation damping. This formulation combines the advantages of a conformal and traceless formulation, with the suppression of constraint violations given by the damping terms, but being first order in time and space, it is particularly suited for a discontinuous Galerkin (DG) implementation. The strongly hyperbolic first-order formulation has been obtained by making careful use of first and second-order ordering constraints. A proof of strong hyperbolicity is given for a selected choice of standard gauges via an analytical computation of the entire eigenstructure of the FO-CCZ4 system. A key feature of our formulation is that the first-order CCZ4 system decouples into a set of pure ordinary differential equations and a reduced hyperbolic system of partial differential equations that contains only linearly degenerate fields. We implement FO-CCZ4 in a high-order path-conservative (ADER)-DG scheme with adaptive mesh refinement and local time-stepping, supplemented with a third-order ADER-WENO subcell finite-volume limiter in order to deal with singularities arising with black holes. We validate the correctness of the formulation through a series of standard tests in vacuum, performed in one, two and three spatial dimensions, and also present preliminary results on the evolution of binary black-hole systems. To the best of our knowledge, these are the first successful three-dimensional simulations of moving punctures carried out with high-order DG schemes using a first-order formulation of the Einstein equations. Supported by European Research Council Grant No. 677912 EUROPIUM

## Keywords

Compact Object Mergers

**Primary authors:** Prof. DUMBSER, Michael (LAM, Uni Trento); GUERCILENA, Federico Maria (Institut für Kernphysik, Technische Universität Darmstadt); Mr KÖPPEL, Sven (Uni Frankfurt); REZZOLLA, Luciano; Dr ZANOTTI, Olindo

**Presenter:** GUERCILENA, Federico Maria (Institut für Kernphysik, Technische Universität Darmstadt)

**Session Classification:** Mergers

Contribution ID: **14** Type: **Oral Contribution**

# Fully relativistic CCSN simulations of 20Msun star with magnetic field

*Tuesday, 13 August 2019 11:00 (20 minutes)*

We will report fully relativistic CCSN simulations of 20Msun progenitor star with M1 neutrino transport. To explore the role of magnetic field, particularly in the explosion dynamics and in the explosive nucleosynthesis, we calculated several models w/ and w/o rotation and magnetic field. Regarding the dynamics, we found a bipolar outflow in strongly magnetized model, while oblate like explosion is seen in non-magnetized rotating model. The ejecta in the magnetorotational explosion (MRE) model show relatively higher entropy and Ye compared to the previous studies with rather more simplified neutrino treatments. Because of the 3D effects, the MRE is not a collimated jet-like explosion and the abundance pattern reaches only up to the second peak. This is consistent with previous study. In this talk, we will also discuss their multi-messenger aspects including neutrino and GW signals.

## Keywords

Core-Collapse Supernovae

**Primary author:** KURODA, Takami (Institut für Kernphysik, Technische Universität Darmstadt)

**Co-authors:** Prof. TAKIWAKI, Tomoya (National Astronomical Observatory of Japan); Mr REICHERT, Moritz (Institut für Kernphysik, Technische Universität Darmstadt); ARCONES, Almudena; Prof. KOTAKE, Kei (Fukuoka University)

**Presenter:** KURODA, Takami (Institut für Kernphysik, Technische Universität Darmstadt)

**Session Classification:** Core-Collapse Supernovae

Contribution ID: **15** Type: **Oral Contribution**

# Neutrino emission and equation of state in core collapse supernovae

*Wednesday, 14 August 2019 11:00 (20 minutes)*

I would like to report the recent progress on microphysics and supernova neutrinos utilizing our numerical simulations based on Boltzmann equation. As recent progress of core-collapse supernova simulations is rapid toward the first principle type calculations, remaining uncertainties of the microphysics are becoming important.

We have been developing the data table of equation of state (EOS) based on the nuclear many body theories both in non-relativistic and relativistic approaches including detailed information of mixture of nuclei (Togashi, Furusawa 2017, 2019). Revision of Shen EOS table is on going with improvement of isovector interactions for neutron matter, keeping good properties of nuclei and nuclear matter with TM1 (Hu, Sumiyoshi et al., 2019). Our group is running 2D core-collapse supernovae by neutrino-radiation hydrodynamics with 6D Boltzmann solver using some of these microphysics and I would like to touch upon their effects.

I would like to also report the prediction of neutrino detection at Superkamiokande based on supernova neutrino database and a series of simulations. Long term behavior of event number of neutrino detection over 100 sec is studied by proto-neutron cooling simulations to determine the last event and burst duration. We propose the backward time plot to extract the properties of proto-neutron star (Suwa et al. 2019). 1D simulations with Boltzmann equation have been also applied to predictions of diffuse supernova neutrino background in order to assess the fraction of black hole formation from massive stars (Horiuchi et al. 2018).

## Keywords

Core-Collapse Supernovae

**Primary author:** SUMIYOSHI, Kosuke (National Institute of Technology, Numazu College)

**Presenter:** SUMIYOSHI, Kosuke (National Institute of Technology, Numazu College)

**Session Classification:** Equation of State

Contribution ID: **16** Type: **Oral Contribution**

# Multi-dimensional core-collapse supernova simulations with the Boltzmann-radiation-hydrodynamics code

*Tuesday, 13 August 2019 11:30 (20 minutes)*

In this talk, I would like to report the recent results of the multi-dimensional core-collapse simulations with the Boltzmann-radiation-hydrodynamics code, which solves the Boltzmann equations for neutrino transport directly. The neutrino transport is an important ingredient of the core-collapse supernova (CCSN) simulations since the neutrino heating plays a crucial role in the explosion mechanism. Indeed, the fact that the CCSN does not explode under the spherical symmetry is concluded by the Boltzmann-radiation-hydrodynamics simulations. Among recent multi-dimensional CCSN simulations, only our Boltzmann-radiation-hydrodynamics code solves the neutrino transport in a direct manner.

We simulate the collapse of non-rotating and rotating cores of the progenitor with $11.2\,M_\odot$ with Furusawa-Shen and Lattimer-Swesty equations of state under the axisymmetry. We pay particular attention to the neutrino distribution in phase space, which is accessible only by the Boltzmann solver. Especially, we compare the Eddington tensors calculated both from the raw data and from the M1-closure approximation. We find that the difference in the Eddington factors reaches $\sim 20\%$ in our simulation. This is due to the different dependence of the Eddington and flux factors on the angular profile of the neutrino distribution function, and hence modification to the closure relation is needed.

## Keywords

Core-Collapse Supernovae

**Primary author:** HARADA, Akira (ICRR)

**Presenter:** HARADA, Akira (ICRR)

**Session Classification:** Core-Collapse Supernovae

Contribution ID: **17** Type: **Oral Contribution**

# A multi-dimensional implementation of the Advanced Spectral neutrino Leakage scheme

*Thursday, 15 August 2019 15:30 (20 minutes)*

Merging neutron stars are both gravitational wave and electromagnetic transient sources, as confirmed by the detection of the GW170817 event. The gravitational wave emission was indeed followed by emission all across the electromagnetic spectrum, including an optical and infrared signal known as macronova. This signal is powered by the radioactive decay of freshly synthesized r-process elements.
The early blue component requires ejecta with electron fractions $Y_e > 0.25$. Such large values in a neutron rich environment like the one coming from a neutron star merger point to a re-processing of a fraction of the ejecta by weak interactions.
In this talk I will present a multi-dimensional implementation of the Advanced Spectral neutrino Leakage applicable to binary neutron star mergers. The main goal is modeling the neutrino absorption in the semi-transparent regime, which can drive winds from the merger and raise the $Y_e$. This ejection channel is thought to be behind the observed blue macronova component. Preliminary numerical tests of the scheme are presented in the form of snapshot calculations and compared against a two-moment scheme approach.

## Keywords

Compact Object Mergers

**Primary author:** Mr GIZZI, Davide (Stockholm University)

**Presenter:** Mr GIZZI, Davide (Stockholm University)

**Session Classification:** Mergers

Contribution ID: **18** Type: **Oral Contribution**

# Signatures of first order phase transitions and of spins in neutron star mergers

*Thursday, 15 August 2019 14:00 (20 minutes)*

With the detection of GW170817 we have observed the first multi messenger signal from two merging neutron stars.
This signal carried a multitude of information about the underlying equation of state (EOS) of nuclear matter, which so far is not known for densities above nuclear saturation. In particular it is not known if exotic states or even a phase transition to quark matter can occur at densities so extreme that they can't be probed by any current experiment.
In this talk we will show how the information carried in the gravitational wave signal of GW170817 can be used to constrain the EOS at densities above saturation and what we can learn about the possible existence of phase transitions. We will also comment on how we can use future gravitational wave detections in order to set limits on the existence of neutron stars having a quark matter core.
Finally, we will discuss the detectability of a hadron-quark phase transition taking place in a neutron star merger event. Starting from a fully consistent description of matter having a first-order phase transition to quark matter at finite temperatures, we will demonstrate what imprint a hadron-quark phase transition would leave on the gravitational-wave signal. We will conclude by showing that a hot and dense core of quark matter is formed in such a simulation and will also briefly comment on how this is related to the phase diagram of quantum chromodynamics.

Additionally, we will report on recent results of neutron star mergers with spin and show how part of the mass ejection in a neutron star merger can be suppressed when the neutron stars have spins $\simeq 0.28$.

## Keywords

Compact Object Mergers

**Primary author:** MOST, Elias

**Presenter:** MOST, Elias

**Session Classification:** Mergers

Contribution ID: **19** Type: **Oral Contribution**

# Nucleon-nucleon bremsstrahlung in core-collapse supernova simultations

*Monday, 12 August 2019 14:00 (20 minutes)*

Neutrinos are the main vector of energy transport in the revival process of a stalled supernova shock. The treatment of their interactions with the medium is therefore an important part of our simulations. One of those interactions is the nucleon-nucleon bremsstrahlung which will create or annihilate a neutrino/anti-neutrino pair. In this talk, I will present the results for a finer treatment of this process in the GR1D supernova evolution code. I will talk about simulations from two different progenitors, one of which producing a successful explosion. Those simulations showed that the way of treating nucleon-nucleon bremsstrahlung and electron-positron pair production can have a significant impact on the shock evolution as well as on the neutrino luminosities.

## Keywords

Core-Collapse Supernovae

**Primary author:** BETRANHANDY, Aurore (Stockholm University)

**Co-author:** O'CONNOR, Evan (Stockholm University)

**Presenter:** BETRANHANDY, Aurore (Stockholm University)

**Session Classification:** Neutrinos

Contribution ID: **21** Type: **Oral Contribution**

# r-process nucleosynthesis in compact object mergers

*Friday, 16 August 2019 09:00 (30 minutes)*

Thirty years after both the light and neutrino emission was observed from SN1987A, the neutron star merger event GW170817 demonstrated the power of new tools in multi-messenger astronomy. Since LIGO/VIRGO gravitational wave detection enables identification and pointed electromagnetic follow-up of merger events, new insights into these rare and interesting systems can be gained. The observations of the GW170817 electromagnetic counterpart suggested the production of heavy elements via the rapid neutron capture process (r process) due to the light curve compatibility with the presence of high opacity elements such as the lanthanides. However lanthanide production in r-process nucleosynthesis is subject to large uncertainties from nuclear physics and astrophysics unknowns. For instance the rare-earth abundance peak, a feature of enhanced lanthanide production at A~164 seen in the solar r-process residuals, is not robustly produced in r-process calculations when nuclear physics inputs are varied. Nuclear and astrophysics uncertainties also make it difficult to know if merger events are responsible for populating the heaviest observed nuclei, the actinides. An r process which reaches the actinides is also likely to host fission, which is largely experimentally uncharted for neutron-rich nuclei, further compounding the difficulty in predicting the nucleosynthetic outcome in merger events. Here we will review what can be gleaned regarding heavy element production from this merger event with an emphasis on how nuclear physics unknowns can affect such conclusions. We will discuss a potential direct signature of actinide production in merger environments as well as the potential for future experimental and theoretical efforts to refine our knowledge of fission in the r process. The question of where nature primarily produces the heavy elements can only be answered through such collaborative efforts between experiment, theory, and observation.

## Keywords

Nucleosynthesis

**Primary authors:** VASSH, Nicole; SURMAN, Rebecca (University of Notre Dame); MUMPOWER, Matthew (Los Alamos National Laboratory); MCLAUGHLIN, Gail (North Carolina State University)

**Presenter:** VASSH, Nicole

**Session Classification:** Nucleosynthesis

Contribution ID: **22** Type: **Oral Contribution**

# Inhomogeneous Galactic Chemical Evolution of r-process Elements

*Friday, 16 August 2019 11:30 (20 minutes)*

The origin of the heaviest elements is still a matter of debate. For the rapid neutron capture process ("r-process"), multiple sites have been proposed, e.g., neutron star mergers and (sub-classes) of supernovae. R-process elements have been measured in metal-poor halo stars. Galactic archaeology studies show that the r-process abundances among these stars vary by over two orders of magnitude. On the other hand, abundances in stars in the Galactic disk do not differ greatly. This leads to two major open questions:
1. What is the reason for such a huge abundance scatter of r-process elements in the early Galaxy?
2. While the large scatter at low metallicities might point to a rare production site, why is there barely any scatter at Solar metallicities?
We use the high resolution ((20 pc)^3 /cell) inhomogeneous Galactic chemical evolution tool "ICE" to study the role of the contributing sources of r-process elements. Our main findings are that additionally to neutron star mergers, a second, early acting site is necessary. We assume "magnetorotationally driven supernovae" can act as this additional and earlier r-process site and conclude that our simulations with an adequate combination of these two sites successfully reproduce the observed r-process elemental abundances in the Galactic halo. Finally, we discuss the potential role of neutron star-black hole mergers as alternative earlier r-process site.

## Keywords

Nucleosynthesis

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**Presenter:** WEHMEYER, Benjamin (Konkoly Observatory & Univ. of Hertfordshire)

**Session Classification:** Nucleosynthesis

Contribution ID: **25** Type: **Oral Contribution**

# Neutrino Quantum Kinetics in Compact Objects

*Monday, 12 August 2019 10:15 (30 minutes)*

Neutrinos play a critical role of transporting energy and changing the lepton density within core-collapse supernovae (CCSNe) and neutron star mergers. The possibility of flavor or angular instabilities in the neutrino distributions have the potential to revolutionize our understanding of the CCSN explosion mechanism and neutrino signals. However, understanding these effects will require yet-undeveloped technology to simulate the neutrino quantum kinetic equations (QKEs). I will present a method for extending existing neutrino interaction rates long used in CCSN/merger simulations to full QKE source terms for use in numerical calculations. To demonstrate the effects of a complete set of neutrino interaction physics, I will show the results of simulations of the full isotropic QKEs in conditions relevant to CCSNe and neutron star mergers. I will demonstrate that in isotropic calculations, electron scattering, nucleon-nucleon bremsstrahlung processes, and four-neutrino processes dominate flavor decoherence in the protoneutron star (PNS), absorption dominates near the shock, and all of the considered processes except elastic nucleon scattering are relevant in the decoupling region. Finally, I will present an effective decoherence opacity that at most energies predicts decoherence rates to within a factor of 10 in our model PNS and within 20% outside of the PNS.

## Keywords

Neutrinos

**Primary authors:** RICHERS, Sherwood (University of California, Berkeley); MCLAUGHLIN, Gail (North Carolina State University); KNELLER, Jim (NC State University); Dr VLASENKO, Alexey (North Carolina State University)

**Presenter:** RICHERS, Sherwood (University of California, Berkeley)

**Session Classification:** Neutrinos

Contribution ID: **26** Type: **Oral Contribution**

# The Impact of GR Hydrodynamics in CCSN Simulations

*Tuesday, 13 August 2019 14:00 (20 minutes)*

Numerical simulations of core collapse supernovae (CCSNe) must balance numerical accuracy with computational cost in order to produce numerous, high-fidelity simulations. The FLASH code architecture leverages advanced neutrino treatments and a general relativistic effective potential (GREP) to efficiently simulate CCSNe. These explosive, high energy events are prolific sources of gravitational waves (GWs) and would be detectable with current age GW detectors, in the case of a Galactic event. While the GREP has the advantage of speed, it has been shown to misrepresent certain aspects of the GW signal from CCSNe. Here will be a review of current GW studies using FLASH and an outline to integrate GR hydrodynamics into its framework.

## Keywords

Core-Collapse Supernovae

**Primary author:** PAJKOS, Michael (Michigan State University)

**Co-authors:** Dr COUCH, Sean (Michigan State University); Dr PAN, Kuo-Chuan (National Tsing Hua University); Dr O'CONNOR, Evan (Stockholm University)

**Presenter:** PAJKOS, Michael (Michigan State University)

**Session Classification:** Core-Collapse Supernovae

Contribution ID: **27** Type: **Oral Contribution**

# Nucleosynthesis in core-collapse supernovae

*Friday, 16 August 2019 10:15 (30 minutes)*

Core-collapse supernovae (CCSNe) are one of the most important sites of element synthesis in the universe and drive the chemical evolution of galaxies. A major goal of CCSN nucleosynthesis studies is to determine how nucleosynthesis outcomes depend on progenitor properties (e.g. mass and metallicity) and the explosion details. Traditional calculations do not account for neutrino-matter interactions, thus omitting key microphysics relevant for both the explosion and the explosive nucleosynthesis. In this talk, I will review our current understanding of nucleosynthesis in core-collapse supernovae. I will also present nucleosynthesis yields for progenitors of different masses and metallicities exploded using PUSH. The PUSH method is based on the neutrino-driven mechanism and follows the evolution of the proto-neutron star as well as the electron fraction of the ejecta. This allows a more accurate treatment of nucleosynthesis in the innermost stellar layers. I will focus especially on the synthesis of iron group elements, which are produced in these innermost layers and are therefore quite sensitive to the explosion details. I will contrast our results with more traditional calculations. Finally, I will compare our predicted yields to observationally derived values for supernovae and metal-poor stars. This complete set of isotopic yields provides an essential input for modeling galactic chemical evolution.

## Keywords

Nucleosynthesis

**Primary author:** CURTIS, Sanjana

**Presenter:** CURTIS, Sanjana

**Session Classification:** Nucleosynthesis

Contribution ID: **28** Type: **Oral Contribution**

# Towards 3D Simulations of Theoretical CCSNe Populations

*Tuesday, 13 August 2019 10:15 (30 minutes)*

Using Fornax, we have provided a broad suite of almost a dozen high-fidelity 3D simulations of core-collapse supernovae, spanning $9-60$ $M_{\odot}$ in progenitor mass. Such a plethora of simulations, many through one second postbounce, allows us to probe the detailed dependence of explosion outcome on progenitor profile, grid resolution, and neutrino microphysics as well as study emergent neutrino and gravitational wave signatures. Building on communal efforts, we are now poised to transition from individual case studies to population studies of CCSNe phenomenology in 3D.

## Keywords

Core-Collapse Supernovae

**Primary author:** Mr VARTANYAN, David (Princeton)

**Presenter:** Mr VARTANYAN, David (Princeton)

**Session Classification:** Core-Collapse Supernovae

Contribution ID: **29** Type: **Oral Contribution**

# The Hadronic Equation of State for Neutron Stars

*Wednesday, 14 August 2019 09:00 (30 minutes)*

The equation of state (EoS) of dense hadronic matter is of crucial importance for the description of the static and dynamical properties of neutron stars. In this talk I will review the current status of the hadronic EoS for neutron stars, from the point of both ab-initio many-body approaches and phenomenological models. The theoretical predictions for the hadronic EoS will be compared to the data coming from both nuclear physics experiments and astrophysical observations, providing insights for future research.

## Keywords

Nuclear Theory

**Primary author:** Dr TOLOS, Laura (Institute for Theoretical Physics, Goethe University )

**Presenter:** Dr TOLOS, Laura (Institute for Theoretical Physics, Goethe University )

**Session Classification:** Equation of State

Contribution ID: **30** Type: **Oral Contribution**

# General Relativistic Multidimensional Flux-Limited Diffusion Scheme for Neutrino Transport

*Monday, 12 August 2019 11:00 (20 minutes)*

We present the new code NADA-FLD to solve multi-dimensional neutrino-hydrodynamics in full general relativity (GR) in spherical polar coordinates. The neutrino transport assumes the flux-limited diffusion (FLD) approximation and evolves the neutrino energy densities measured in the frame comoving with the fluid. Operator splitting is used to avoid multi-dimensional coupling of grid cells in implicit integration steps involving matrix inversions. Terms describing lateral diffusion and advection are integrated explicitly with the Allen-Cheng or the Runge-Kutta-Legendre method, which remain stable even in the optically thin regime. We discuss several toy-model problems in one and two dimensions to test the basic functionality and individual components of the transport scheme. We also perform fully dynamic core-collapse supernova (CCSN) simulations in spherical symmetry. For a Newtonian model we find good agreement with the M1 code ALCAR, and for a GR model we reproduce the main effects of GR in CCSNe already found by previous works.

## Keywords

Neutrinos

**Primary author:** Mr RAHMAN, Ninoy (Max Planck for Astrophysics)

**Presenter:** Mr RAHMAN, Ninoy (Max Planck for Astrophysics)

**Session Classification:** Neutrinos

Contribution ID: **31** Type: **not specified**

# Stephan Rosswog - TBA

**Session Classification:** Mergers

Contribution ID: **32** Type: **not specified**

# Albino Perego - TBA

**Session Classification:** Mergers

Contribution ID: **33** Type: **not specified**

# Welcome & Intro

*Monday, 12 August 2019 08:45 (15 minutes)*

**Session Classification:** Logistics

Contribution ID: **34** Type: **not specified**

# TBA

**Session Classification:** Core-Collapse Supernovae

Contribution ID: **35** Type: **Oral Contribution**

# Simulations of Core-Collapse Supernovae

*Tuesday, 13 August 2019 09:00 (30 minutes)*

Simulations of Core-Collapse Supernovae rely on four important ingredients: An efficient and reasonably accurate implementation of equation of state and reaction rates, a spatially and temporally well-resolved evolution of shock-roof magneto-hydrodynamics, a multidimensional parallel implementation of neutrino transport approximations with a well-defined pinch of relativistic effects and conservation laws, and an ever-growing toolbox for the analysis of output data. I will discuss the performance of the Isotropic Diffusion Source Approximation (IDSA) in 3D supernova models and compare the results of our code "Elephant" with other 3D supernova codes. Remarks on the future and availability of Elephant are also given.

**Keywords**

**Presenter:** LIEBENDOERFER, Matthias (University of Basel)

**Session Classification:** Core-Collapse Supernovae

Contribution ID: **36** Type: **Oral Contribution**

# From merger to electromagnetic emission

*Thursday, 15 August 2019 09:00 (30 minutes)*

The recent GW+EM detection of a neutron star merger has underlined the multitude of physical processes that are needed for a reliable prediction of multi-messenger signals. In the talk I will discuss the various processes that lead from the merger to the electromagnetic emission. Particular attention will be payed to topics where our understanding is incomplete and more progress is needed.

**Presenter:** Prof. ROSSWOG, Stephan (Stockholm University)

**Session Classification:** Mergers

Contribution ID: **37** Type: **Oral Contribution**

# Modelling on neutron star mergers: status and open issues

*Thursday, 15 August 2019 10:15 (30 minutes)*

A robust and quantitative understanding of neutron star mergers requires detailed numerical simulations. The latter must include all the relevant physics, resolve the necessary lenght scales, and cover all the important temporal phases. The key role of all fundamental interactions makes this task extremely challenging. In this talk, I will briefly summarize the present status of the field and highlight our present understanding. Despite the many insights achieved in the last years, many open issues remain, including the properties of hot nuclear matter and the relevance of weak interaction. The exploration and the solution of these open questions are essential to interpret past and future multimessenger detections from neutron star mergers.

**Presenter:** Dr PEREGO, Albino (University of Trento)

**Session Classification:** Mergers