# HK 2: Nuclear Astrophysics I

Time: Monday 16:45–18:30 Location: HBR 14: HS 4

**Group Report** HK 2.1 Mon 16:45 HBR 14: HS 4
**The Super-FRS Ion Catcher: towards the Early- and First-Science experiments at FAIR** — •Daler Amanbayev, the FRS Ion Catcher Collaboration, and the Super-FRS Experiment Collaboration — II. Physikalisches Institut, Justus-Liebig-Universität Gießen, Gießen, Germany

The Super-FRS Ion Catcher (Super-FRS-IC) at the Super-FRS at FAIR will play a crucial role in shaping experiments envisaged for the Early- and First-Science programs. The first experiments aim to measure $\beta$-delayed neutron emission probabilities $P_{\mathrm{xn}}$ – important input for r-process calculations, but reliable data are scarce, especially for x>1. In addition, they aim to study multi nucleon transfer (MNT) reactions driven by secondary beams as a promising avenue for accessing heavy neutron-rich nuclei. At a later stage, the Super-FRS-IC will enable experiments of MATS and LaSpec collaborations at the Low-Energy Branch.

At the Super-FRS-IC, beams of exotic nuclei produced at relativistic energies will be thermalized by a newly developed Cryogenic Stopping Cell (CSC) and analyzed via the Multiple-Reflection Time-of-Flight Mass Spectrometer (MR-TOF-MS). A unique combination of characteristics, e.g., high areal density and rate capability of the CSC (up to 40 mg/cm$^2$ and at least $10^7$ ions/s, correspondingly), and broad mass range and high sensitivity of the MR-TOF-MS enable conducting experiments in new and effective ways.

This contribution presents the Super-FRS-IC setup and provides an overview of the aforementioned experiments and methods.

HK 2.2 Mon 17:15 HBR 14: HS 4
**Determining proto neutron stars' minimal mass with a chirally constrained nuclear equation of state** — •Selina Kunkel and Jürgen Schaffner-Bielich — Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, Germany

We study the minimal masses and radii of proto-neutron stars during different stages of their evolution. The main focus lies on the stages directly after the supernova explosion, where neutrinos are captured in the core and the lepton per baryon ratio is approximately $Y_L = 0.4$ and a few seconds after the supernova, when all neutrinos have left the star. All equations of state used for this purpose fulfill *Chiral Effective Field Theory* constraints at $T = 0$. We find for the neutrino-trapped cases higher minimal masses than for the neutrino-free cases. Thermal effects, in this work a higher constant entropy per baryon, also rise the minimal mass. The masses for the cases studied all lie between $M_{min} = 0.11M_{\odot} - 0.73M_{\odot}$. The minimal mass depends linearly on the lepton fraction for values of $Y_L = 0.1 - 0.4$. Hence, proto-neutron stars can exhibit higher minimal masses than their cold, catalyzed form during all stages of their evolution.

HK 2.3 Mon 17:30 HBR 14: HS 4
**Neutron matter properties from Fermi liquid theory** — •Faruk Alp[1,2,3], Kai Hebeler[1,2,3], and Achim Schwenk[1,2,3] — [1]Department of Physics, Technische Universität Darmstadt — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH — [3]Max-Planck-Institut für Kernphysik, Heidelberg

Fermi liquid theory is a powerful framework to describe interacting Fermi systems at low temperatures. Employing this formalism we calculate Landau parameters from chiral effective field theory interactions and determine properties of neutron matter such as the speed of sound and effective mass. Calculations are performed using many-body perturbation theory based on two- and three-body interactions. The goal is to obtain a comprehensive understanding of the systematic uncertainties of the Landau parameters and investigate possible ways to extrapolate the equation of state to higher densities.

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HK 2.4 Mon 17:45 HBR 14: HS 4
**Correlations between nuclear matter parameters and the gravitational wave frequency emitted by a neutron star merger remnant** — •Mario Jakobs[1,2], Andreas Bauswein[1], and Gabriel Martínez-Pinedo[1,2] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [2]Institut für Kernphysik, Fachbereich Physik, TU Darmstadt, Darmstadt, Germany

With upcoming detectors, we will be able to observe gravitational waves (GW) emitted even after the merging of two neutron stars. The merger remnant has a dominant oscillation frequency that depends strongly on the nuclear equation of state (EOS). Here we quantify this dependency using simulations. Once post-merger GW observation data are available, this will enable us to derive properties of the nuclear EOS that are not well constrained today. To achieve this, we develop an EOS meta model allowing us to vary a single EOS parameter without altering others simultaneously. By using a meta model, we can reproduce a range of different available EOS models in a single framework. We then explore its parameter space by conducting general relativistic hydrodynamics simulations of the merger event. In our analysis we find, for instance, a clear correlation between the dominant frequency and the slope of the nuclear symmetry energy at saturation. This work was funded by Deutsche Forschungsgemeinschaft - Project-ID 279384907 - SFB 1245 and - Project-ID 138713538 - SFB 881. Support by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreements No. 759253 and No. 885281 is acknowledged.

HK 2.5 Mon 18:00 HBR 14: HS 4
**Geant4 Monte Carlo Simulation of the $^{12}C(\alpha,\alpha')$ reaction** — •Timo Biesenbach[1], David Werner[1], Peter Reiter[1], Konrad Arnswald[1], Maximilian Droste[1], Pavel Golubev[2], Rouven Hirsch[1], Hannah Kleis[1], Nikolas Königstein[1], Dirk Rudolph[2], Alessandro Salice[1], Joe Roob[1], Madalina Ravar[1,3], and Luis Sarmiento[2] — [1]University of Cologne, Institute for Nuclear Physics, Cologne — [2]Lund University, Department of Physics, Lund, Sweden — [3]TU Darmstadt, Institute of Nuclear Physics, Darmstadt

The branching ratios of the three-particle decay of the Hoyle state in $^{12}$C provide a crucial probe for the inner structure of $^{12}$C and they are very relevant for the topic of stellar nucleosynthesis. To study the decay modes, a $^{12}\mathrm{C}(\alpha,\alpha')$ reaction at 27 MeV beam energy was performed at the 10 MV FN-tandem accelerator at the Institute for Nuclear Physics of the University of Cologne using the Lund-York-Cologne-Calorimeter. The reaction and experimental setup were rebuilt using the Geant4 simulation-framework. Detailed Monte-Carlo simulations of the experiment were performed to determine the setup's sensitivity and detection efficiency for the scattered $\alpha$ and the three decay $\alpha$'s. The impact of the data analysis on the identification of the sequential and direct decay modes of the Hoyle state but also states at higher excitation energy is scrutinized in detail by comparing simulated with experimentally obtained data. The preliminary results include Dalitz plots and sensitivity limits for the identification of the individual $\alpha$ decay branches.

HK 2.6 Mon 18:15 HBR 14: HS 4
**Gaussian processes for the nuclear equation of state** — •Hannah Göttling[1,2], Jonas Keller[1,2], Kai Hebeler[1,2,3], and Achim Schwenk[1,2,3] — [1]Technische Universität Darmstadt, Department of Physics — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH — [3]Max-Planck-Institut für Kernphysik, Heidelberg

The nuclear equation of state (EOS) characterizes the properties of matter as a function of density, temperature, and proton fraction, and thus connects microscopic strong interaction calculations with descriptions of compact objects in astrophysics. Focusing on the low-energy regime, chiral effective field theory (EFT) provides a systematically improvable description of nuclear systems. With Gaussian processes (GPs) we introduce a tool to realize non-parametric evaluations of the EOS, considering correlations along independent variables. Besides constructing an emulator we use GPs for a statistical description of chiral expansion coefficients and apply Bayesian statistics to assess the EFT truncation errors. The evaluation of observables with GPs enables us to further calculate derivatives. With that we are able to provide the pressure and other thermodynamic quantities of pure neutron matter and symmetric nuclear matter with propagated chiral truncation uncertainties.

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