HK 23: Nuclear Astrophysics II

Zeit: Dienstag 14:00–16:15 Raum: F 33

Gruppenbericht HK 23.1 Di 14:00 F 33

Chiral nuclear equation of state for neutron-star and supernova simulations — •Corbinian Wellenhofer[1], Jeremy W. Holt[2], Nobert Kaiser[1], and Wolfram Weise[1] — [1]Technische Universität München — [2]Texas A-M University

Chiral effective field theory (χEFT) provides the basis for the description of the nuclear interaction in terms of a systematic low-energy expansion. In this talk, we review recent research efforts headed towards the construction of a χEFT-based nuclear equation of state (EoS) to be used in astrophysical simulations of core-collapse supernovæ and binary neutron-star mergers. The finite-temperature EoS of isospin-asymmetric nuclear matter has been computed using chiral low-momentum two- and three-nucleon interactions in many-body perturbation theory (MBPT), and the results have been benchmarked against available empirical constraints and thermodynamic consistency. At low temperatures, MBPT gives rise to a nonanalytic form of the dependence of the EoS on the isospin asymmetry. The implications of this regarding explicit parametrizations of the isospin-asymmetry dependence are investigated, and we discuss initial results concerning the construction of global EoS tables for astrophysical applications.

HK 23.2 Di 14:30 F 33

Constraining the nuclear equation of state through the moment of inertia of neutron stars — •Svenja Kim Greif[1,2], Kai Hebeler[1,2], and Achim Schwenk[1,2,3] — [1]Institut für Kernphysik, Technische Universität Darmstadt — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH — [3]Max-Planck-Institut für Kernphysik, Heidelberg

The recent discovery of 2 $M_\odot$ neutron stars yields systematic constraints on the nuclear equation of state. Neutron star masses can be measured very precisely, their radii are, however, inherently difficult to measure due to the influence from large systematic uncertainties. A prospective moment of inertia measurement using pulsar timing observations will provide a promising alternative. We present a theoretical framework for calculating neutron star masses, radii, and moments of inertia microscopically. We use state–of–the–art equations of state up to nuclear densities based on chiral effective field theory interactions. For high densities, we expand the equations of state and take the requirements of causality and of reproducing 2 $M_\odot$ neutron stars into account. Our approach allows us to generate a large set of equations of state that predicts different possible combinations of masses, radii, and moments of inertia. Based on our results, we investigate how a moment of inertia measurement constrains the radius and thus the equation of state.

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HK 23.3 Di 14:45 F 33

Expansion of the equation of state of neutron-rich nuclear matter from χEFT beyond quadratic order — •Susanne Strohmeier and Norbert Kaiser — Technische Universität München

Based on chiral effective field theory, the equation of state of neutron-rich nuclear matter is investigated systematically. The contributing diagrams up to three-loop order include one- and two-pion exchange together with three-body terms arising from virtual $\Delta(1232)$-isobar excitations. The expansion of the energy per particle in the proton fraction δ for the nuclear many-body system with neutron density $\rho_n = k_f^3(1-\delta)/3\pi^2$ and proton density $\rho_p = k_f^3\delta/3\pi^2$ is performed analytically up to quadratic order: $\bar{E}(k_f,\delta) = \bar{E}_n(k_f) + \delta B_1(k_f) + \delta^{5/3}B_{5/3}(k_f) + \delta^2 B_2(k_f) + \ldots$. Yet higher orders in the δ-expansion are necessary for a reasonable description of the equation of state for proton fractions above 20%. The evaluation of a S-wave contact interaction to second order establishes a non-analytical $\delta^{7/3}\ln\delta$-term. The higher order coefficients of the expansion are determined by a least-squares fit. With terms up to order $\delta^{8/3}$ a good description is obtained from pure neutron matter ($\delta = 0$) up to symmetric nuclear matter ($\delta = 0.5$).

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HK 23.4 Di 15:00 F 33

Long-time hydrodynamical simulations of core-collapse supernovae — •Carlos Mattes[1], Almudena Arcones[1,2], Sean Couch[3], and Albino Perego[1] — [1]Institut für Kernphysik, TU Darmstadt — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [3]Department of Physics and Astronomy, Michigan State University, USA

Core-collapse supernovae are one of the major contributors to the chemical enrichment in the universe. These explosions eject elements that were synthesized during the life of stars (e.g., oxygen and carbon) and they produce new and heavier elements (e.g., 1/3 of the iron in our galaxy).

We will present long-time hydrodynamic simulations of core-collapse supernovea with the multi-scale and multi-physics code FLASH [1] that follow the supernova explosion from the collapse phase to several seconds after bounce.

[1] Couch S.M. 2013, ApJ, 775, 35
[2] Perego A. 2016, ApJS, 223, 22

HK 23.5 Di 15:15 F 33

Investigation of thermal effects on the equation of state and radii of neutron stars — •Sabrina Schäfer[1,2], Carlos Mattes[1], Almudena Arcones[1,3], and Achim Schwenk[1,2,4] — [1]Institut für Kernphysik, Technische Universität Darmstadt — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [4]Max-Planck-Institut für Kernphysik, Heidelberg

Recently, a set of cold representative equations of state have been derived from calculations based on chiral effective field theory, combined with constraints from neutron star observations. This made it possible to derive an uncertainty band for the equation of state and the radius of cold neutron stars. In this work, we study finite temperature effects on realistic equations of state of hot and dense matter and the resulting proto–neutron star behavior following a core–collapse supernova. Using a method for including thermal effects in the equation of state, we investigate the impact of finite–temperature microphysics on the radii of neutron stars and the contraction behavior of the proto–neutron star during the explosion.

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HK 23.6 Di 15:30 F 33

Simulation of neutrino-driven winds from core-collapse supernovae — •Maximilian Witt[1] and Almudena Arcones[1,2] — [1]Institut für Kernphysik, TU Darmstadt, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Neutrino-driven winds occur after core-collapse supernovae, when the hot proto-neutron star cools by radiating neutrinos. Within the continuous mass outflow that is ejected at supersonic velocities, heavy elements up to silver may form [1].

We have developed a steady-state model that was used to compare to our 1D and 2D hydrodynamic simulations. We have investigated the conditions which lead to a neutrino-driven wind and will discuss how this affects the nucleosynthesis in core-collapse supernovae.

[1] A. Arcones, F.-K. Thielemann, J.Phys. G 40 (2013) 013201

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HK 23.7 Di 15:45 F 33

Nuclear reaction network for hydrodynamical simulations — •Moritz Reichert[1], Dirk Martin[1], Julia Bliss[1], and Almudena Arcones[1,2] — [1]Institut für Kernphysik, TU Darmstadt — [2]GSI Helmholtzzentrum GmbH

Core-collapse supernovae mark the end of the life of stars with at least eight solar masses. These explosive events are very complex to model and involve multidimensional hydrodynamics, neutrino interactions and transport and general relativity to describe the evolution of matter under extreme conditions. An exciting outcome from supernova explosions is the formation of new elements which can be produced only in such a cataclysmic event. Taking all physical aspects into account makes the description of supernovae ultimately challenging and also computationally expensive. Reducing the computational cost is an essential part of supernova simulations. So far, there are no hydrodynamical simulations that use a nuclear reaction network which contains all involved and synthesized elements. We provide an accurate and precise nuclear reaction network that includes only a fraction of nuclei in a well chosen area of the nuclear chart considering all important reactions. This network is able to keep track of nuclear composition and energy generation.

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HK 23.8 Di 16:00 F 33

Short gamma ray bursts triggered by neutrino-antineutrino annihilation⋆ — •Hannah Yasin[1], Albino Perego[1], and Almudena Arcones[1,2] — [1]Institut für Kernphysik, TU Darmstadt, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Gamma ray bursts (GRB) are one of the most energetic events in the universe. Neutron star mergers are the most favourable candidate for the subclass of GRBs that last less than two seconds. It has been suggested that the annihilation of neutrino-antineutrino pairs emitted by the hot and dense merger remnant could be enough to launch a relativistic jet, producing such a burst [1]. We calculate the energy deposition by neutrino-antineutrino annihilation based on the results of a Newtonian simulation of the aftermath of a binary neutron star merger [2]. In addition, we investigate the role of the central object.

[1] D. Eichler, M. Livio, T. Piran, and D. N. Schramm, Nature 340 (1989) 126.
[2] A. Perego, S. Rosswog, R. M. Cabezon, O. Korobkin, R. Käppeli, A. Arcones, and M. Liebendörfer, MNRAS 443 (2014) 3134.

⋆ Supported by Helmholtz-University Young Investigator grant No. VH-NG-825 and the Deutsche Forschungsgemeinschaft through grant SFB 1245.