HK 33: Nuclear Astrophysics IV

Time: Thursday 13:45–15:45 Location: PHIL A 602

HK 33.1 Thu 13:45 PHIL A 602

Systematic Study of EOS Effects in BNS Mergers — •Maximilian Jacobi — Friedrich-Schiller-Universität, Jena, Germany

Observations of binary neutron star (BNS) mergers are among the most promising opportunities to constrain the nuclear equation of state (EOS) at intermediate to high density with multi-messenger astronomy. Vice versa, it is crucial to understand how observables such as gravitational waves and the ejection of matter depend on the EOS. However, most BNS merger simulation studies employ a relatively small number of EOS models chosen in an arbitrary fashion due to the limited availability of EOS models. Therefore, derived relations between observables and EOS properties are usually given in terms of single parameters such as the tidal polarizability or the radius of a cold neutron star of a characteristic mass. In this talk I will present a set of BNS merger simulations employing a set of microphysical EOS with systematically varied properties. This approach allows us to study the impact of the EOS properties at high and intermediate densities independently and derive a more detailed understand of the interplay between BNS mergers and nuclear physics.

HK 33.2 Thu 14:00 PHIL A 602

Binary neutron stars: multi-messenger analyses to constrain equation of state — •Giulia Huez — Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743, Jena, Germany

Binary neutron star mergers are exceptional laboratories for probing the properties of nuclear matter at supranuclear densities. To extract the physical parameters of these systems and gain insights into the underlying physics, Bayesian parameter estimation techniques have been extensively employed in multi-messenger observations of gravitational waves, kilonovae, and gamma-ray bursts. In this talk, I will present results from a joint and coherent multi-messenger analysis of GW170817, the first observed binary neutron star merger. This comprehensive approach enables tighter constraints on the extrinsic parameters of the system, such as distance and inclination, while also incorporating numerical-relativity-informed relations that connect observable quantities to the intrinsic binary properties. Through this kind of analysis, we achieve improved precision in the inference of neutron star equation of state. Furthermore, I will discuss how these results highlight key areas where future numerical-relativity simulations should focus to improve our phenomenological models, particularly for kilonovae, postmerger gravitational waves, and numerical-relativity-informed relations, thereby enhancing the accuracy and robustness of future analyses.

HK 33.3 Thu 14:15 PHIL A 602

Quantifying uncertainties for the nuclear equation of state in β-equilibrium — •Hannah Göttling[1,2], Luis Hoff[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-density regime, chiral effective field theory (EFT) provides a systematically improvable description of nuclear systems. With Gaussian processes (GPs) we construct an emulator to realize non-parametric evaluations of the EOS considering correlations among independent variables and calculate derivatives to provide thermodynamic quantities. Moreover, we employ GPs for a statistical description of chiral expansion coefficients and apply Bayesian statistics to assess the EFT truncation errors. This leads to a range of the EOS for nuclear matter in β-equilibrium with propagated EFT truncation uncertainties.
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HK 33.4 Thu 14:30 PHIL A 602

Probing Energetic Supernovae Through Nebular Phase Modeling — •Giacomo Ricigliano — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, Heidelberg 69117, Germany

Energetic supernovae are promising sites for heavy element nucleosynthesis and exhibit a wide range of explosion mechanisms, yet the observational signatures of these processes remain difficult to interpret. In particular, the presence of r-process material in non-merger transients is still uncertain, and the physical engines powering the most energetic stripped-envelope supernovae (such as central engine activity or ejecta-CSM interaction) are not yet well constrained. Nebular phase observations offer a direct way to address these questions, as they probe the inner ejecta where nucleosynthesis products and explosion physics are most clearly imprinted. We model optically thin nebular plasmas in full NLTE, including compositions extending up to the third r-process peak. We find that even modest amounts of heavy neutron-rich material generate distinct forbidden fine-structure emission in the near- to mid-IR, making this wavelength range highly sensitive to r-process signatures. In parallel, we examine how variations in ionization structure, line strengths, and line profiles can serve as diagnostics of central engine activity or ejecta-CSM interaction. Together, these results highlight the diagnostic potential of late-time IR and optical spectroscopy for uncovering both heavy element production and the physical mechanisms driving extreme stellar explosions.

HK 33.5 Thu 14:45 PHIL A 602

Role of composition and neutrino spectra in the collapse of massive stars — •Justin Schäfer[1,2], Gabriel Martínez-Pinedo[1,2], and Oliver Just[2] — [1]Institut für Kernphysik (Theoriezentrum), TU Darmstadt — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt

The collapse of massive stars after iron core formation is determined by electron captures on a broad range of nuclei. To understand this, a description of electron captures and accurate determination of the composition is crucial. In this work we aim to explore the impact of compositional changes on the deleptonization rate, most important nuclei, and neutrino luminosities. We show that different treatments of partition functions, which govern the distribution of nuclear states at given temperatures and densities, influence the individual composition, and thus most important nuclei, substantially. However, the deleptonization rate and therefore the evolution of the collapsing star is rather unaffected by the detailed composition of matter, leading to similar neutrino luminosities. It turns out that the neutrino spectra, rather than precise rates, determine the final conditions in the core. This work is supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 279384907 - SFB 1245, and MA 4248/3-1 and the European Research Council (ERC) under the European Union*s Horizon 2020 research and innovation programme (ERC Advanced Grant KILONOVA No.885281).

HK 33.6 Thu 15:00 PHIL A 602

Super-FRS Ion Catcher - Overview and Progress — •Jamie Harkin for the Super-FRS Experiment-Collaboration — Justus-Liebig-Universität Gießen

The Super-FRS Ion Catcher (Super-FRS-IC) setup will enable the measurements of beta-delayed (multiple-)neutron emission probabilities (Pxn) i.e., data for r-process nucleosynthesis models that is lacking the most. Moreover, the setup will study multi-nucleon transfer (MNT) reactions driven by secondary beams as a promising method for accessing the unexplored heavy neutron-rich nuclei. These topics will be in focus in the Early- and First-Science programs at the Super-FRS at FAIR. The Super-FRS-IC will also provide thermalized, low emission beams to the LaSpec and MATS experiments. With the Super-FRS-IC, the exotic nuclei produced at relativistic energies and separated in-flight will be thermalized in the Cryogenic Stopping Cell (CSC), transported over a radio frequency quadrupole (RFQ) beamline and analyzed in the Multiple-Reflection Time-Of-Flight Mass-Spectrometer (MR-TOF-MS). This contribution presents the status of the construction of the Super-FRS-IC and an outlook to the experiments to be performed.

HK 33.7 Thu 15:15 PHIL A 602

The DT neutron generator in Dresden: Fusion reactor studies, neutron activation analyses and nuclear astrophysics — •Steffen Turkat[1], Toralf Döring[2], Axel Klix[3], Björn Lehnert[1], Max Osswald[1], Frederik Uhlemann[1], and Kai Zuber[1] — [1]Institut für Kern- und Teilchenphysik, TU Dresden —

[2]Helmholtz-Zentrum Dresden-Rossendorf — [3]Institut für Neutronenphysik und Reaktortechnik, Karlsruher Institut für Technologie

The Deuterium-Tritium neutron generator of TU Dresden delivers proton and deuteron beams of several milliamperes with energies of up to 350 keV. So far, its primary application was focused on the generation of 14 MeV neutrons via the $^{3}H(d,n)^{4}He$ reaction, achieving rates of up to 10^{12} neutrons per second. It is therefore Europe's most intense facility of its kind, dedicated mainly to fusion reactor research and neutron activation analyses.

In addition, the laboratory's scope extends to an even broader range of activities, including cross-section measurements, implantation studies, nuclear astrophysics, neutrino physics and others. This contribution will focus on the facility's relevance for fusion reactor studies, but also trace its past, present, and future, as it transitions into a multi-purpose laboratory.

HK 33.8 Thu 15:30 PHIL A 602

Background radiation measurements and muon simulations for nuclear astrophysics in the new low seismic lab of the DZA — •Simon Vincent[1,2], Daniel Bemmerer[3], Günther Hasinger[1,2], Michèle Heurs[4,2,5], Mike Lindner[2], and Konrad Schmidt[3] — [1]TU Dresden — [2]Deutsches Zentrum für Astrophysik (DZA) — [3]Helmholtz-Zentrum Dresden-Rossendorf (HZDR) — [4]Leibniz-Universität Hannover — [5]DESY Zeuthen

The German center for astrophysics (DZA, Deutsches Zentrum für Astrophysik) plans to build, among other projects, a 200 m deep underground facility. The facility is called the Low Seismic Lab (LSL) and will be placed in Lusatia, at a precise location still to be determined. Here we report on studies relevant to future nuclear and astroparticle experiments in LSL, in order to estimate the remaining cosmic-ray induced radiation background. The specific natural radioactivity of samples of several ∼250 m deep drill holes called DZA02, DZA03, and DZA05, respectively, has been determined using γ-ray spectroscopy at the Felsenkeller underground lab (Dresden), with a non-destructive technique including sample geometry modelling. In addition, GEANT4-based simulation studies of cosmic muon propagation have been performed to calculate the muon and neutron flux in LSL.