HK 7: Nuclear Astrophysics I

Time: Monday 16:15–18:15 Location: PHIL A 602

Group Report HK 7.1 Mon 16:15 PHIL A 602

Equation of State: From Ultracompact Objects to Color Superconductivity in Proto-Neutron Stars — •Ishfaq Ahmad Rather, Selina Kunkel, Sarah Pitz, and Jürgen Schaffner-Bielich — Institute of Theoretical Physics, Goethe University, Frankfurt am Main

We present a comprehensive overview of our group's recent research on the properties of compact stars, probing the equation of state (EoS) across dark matter, hadronic, and quark matter regimes. We explore the impact of scalar fields and dark sector, showing that modified scalar potentials and self-interacting bosonic dark matter can lead to the formation of ultracompact boson stars and alter the macroscopic properties of neutron stars, potentially mimicking black holes. We utilize EoS constrained by chiral effective field theory to analyze the early evolution of compact stars, determining the minimal masses of proto-neutron stars (PNS) and highlighting the role of thermal effects on stability limits. Employing a renormalization group consistent NJL model, we analyze the stability windows of color-superconducting (CSC) phases, demonstrating that stable color-flavor-locked (CFL) cores are consistent with current astrophysical constraints. Furthermore, we investigate the phase diagram and analyze the trajectories of constant entropy per baryon to identify which CSC phases are accessible at maximum central densities throughout various evolutionary stages of PNS characterized by different entropies and lepton fractions.

Funded by DFG through the CRC-TR 211-Project No. 315477589 TRR 21, and the Alexander von Humboldt Foundation.

HK 7.2 Mon 16:45 PHIL A 602

Proto-Neutron Stars with Color Superconductivity — •Selina Kunkel[1], Ishfaq Ahmad Rather[1], Marco Hofmann[2], Hosein Gholami[2], and Jürgen Schaffner-Bielich[1] — [1]Institut für Theoretische Physik, Goethe Universität, Frankfurt am Main, Germany — [2]Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany

At high densities and low temperatures, hadronic matter is expected to undergo a first-order phase transition into a color-superconducting state. While such conditions occur in neutron stars, studies focusing only on cold neutron stars are not fully conclusive because they neglect the evolutionary processes that may influence the appearance of color-superconducting phases. A proto-neutron star, however, describes the earliest evolutionary stages during the first seconds to minutes after core collapse and therefore has different thermodynamic properties compared to a cold neutron star - in particular higher temperatures and trapped neutrinos. To address this, we incorporate proto-neutron star conditions into the equation of state. Since the total baryon number of a neutron star is conserved during its early evolution, tracking stellar configurations from the maximum mass of the hot proto-neutron star to the final cold neutron star allows us to investigate whether color-superconducting phases can form at any point along this trajectory.

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HK 7.3 Mon 17:00 PHIL A 602

Experimental Studies of Proton Capture Reactions on Stable Rb Isotopes — •Svenja Wilden, Benedikt Machliner, Martin Müller, and Andreas Zilges — University of Cologne, Institute for Nuclear Physics, Germany

The p nuclei - stable neutron-deficient isotopes not produced via neutron-capture - are synthesized through photodisintegration reactions in the γ process. Since many of the relevant reactions involve unstable nuclei and cannot be measured directly, Hauser-Feshbach calculations are essential, and experimental data are needed to constrain the nuclear inputs. Proton-induced reactions therefore play a central role in improving γ-process models.

In this work, the cross sections for the ^{85}Rb$(p,\gamma)^{86}$Sr and ^{87}Rb$(p,\gamma)^{88}$Sr reactions were measured using the in-beam method at the HORUS spectrometer at the University of Cologne. The results extend the database of proton-capture reactions around $A \approx 85$, and the ^{87}Rb study nearly completes the systematic investigation of the stable $N = 50$ isotones [1].

Comparisons with Hauser-Feshbach calculations show significant deviations for both isotopes, indicating deficiencies in the proton optical model potential, while variations in nuclear level densities and γ-strength functions have only minor effects. The new data provide constraints for improving statistical-model predictions and refining reaction rates.

Supported by the DFG (ZI 510/12-1).

[1] S. Wilden *et al.*, Eur. Phys. J. A 61 (2025) 142.

HK 7.4 Mon 17:15 PHIL A 602

Stacked target experiments for nuclear astrophysics — •Martin Müller, Benedikt Machliner, Svenja Wilden, and Andreas Zilges — University of Cologne, Institute for Nuclear Physics, Germany

The study of nucleosynthesis processes brings together cutting-edge science performed in a wide variety of fields. One of the main contributions from experimental nuclear physics is the determination of reaction cross sections and reaction rates. While many different techniques exist, the activation technique is among those that have been used the most over the decades, due to the relative simplicity with which high precision results can be obtained. However, since cross sections at energies relevant to nuclear astrophysics are tiny, long irradiation times at high intensities are required. This can be remedied by using the stacked target technique, in which multiple targets are irradiated at the same time. The energy projectiles loose while passing through each target layer enables cross section measurements at multiple energies at once. The price to pay for this is an increased energy uncertainty. In order to reduce these uncertainties, precise knowledge of target thicknesses are needed. This contribution will introduce a new setup for Rutherford Backscattering spectrometry commissioned at the University of Cologne, a Geant4 based simulation of energy losses, that is capable of propagating the uncertainties in the target thicknesses, as well as cross sections determined using the stacked target method. Studied reactions include ^{170,172}Yb(α,γ), ^{170,172}Yb(p,γ), ^{55}Mn$(\alpha,(2)n)$, and ^{58}Fe(p,n). Supported by the DFG (ZI 510/12-1).

HK 7.5 Mon 17:30 PHIL A 602

Nuclear two-photon decay investigation of 98Mo in the ESR Heavy Ion Storage Ring — •Carlo Forconi for the E0018 Experiment-Collaboration — GSI Darmstadt, Germany

The nuclear two-photon or double gamma (2γ) decay is a rare second-order electromagnetic process in which an excited nucleus emits two gamma rays simultaneously. Its branching ratio is significantly lower than that of competing first-order processes such as internal conversion, pair creation, or single-photon emission, making its experimental observation extremely challenging. However, in the ESR at GSI, these competing decay modes can be suppressed by storing fully ionised ions and selecting a 0+ - 0+ transition with excitation energy below the electron-positron pair creation threshold (1022 keV). Under these conditions, the two-photon decay becomes the only available decay channel. In this talk, I will report on the current status of the analysis of an experiment investigating the 2γ decay of 98Mo, which has a first excited 0+ state at 734.75keV. The experiment was performed at the GSI facility in Darmstadt, where fully stripped 98Mo ions were produced using the projectile fragmentation of 100Mo primary beam on 9Be target in the transfer line. These ions were then transported and stored in the ESR, operated in the isochronous mode. Two non-destructive Schottky detectors were used, allowing for precision measurement of the ions revolution frequencies and extraction of both the nuclear half-life and mass. Preliminary results indicate that the measured half-life of 98Mo is consistent with the expected theoretical extrapolation estimates from previously studied 0+ - 0+ nuclear transitions.

HK 7.6 Mon 17:45 PHIL A 602

Towards including hyperons in many-body perturbation theory calculations of dense matter — •Samet Dokur[1,2], 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, 64291 Darmstadt, Germany — [3]Max-Planck-Institut für Kernphysik, Heidelberg

We investigate the so-called "hyperon puzzle" by systematically analyzing the impact of hyperons on the properties of dense matter. To this end, we employ systematically improvable interactions derived from chiral effective field theory and compute the corresponding equation of state using many-body perturbation theory. Our aim is to incorporate hyperon-nucleon and hyperon-nucleon-nucleon interactions up to next-to-leading order using the decuplet saturation approximation in our current many-body framework, which is already capable of describing dense matter with nucleon-nucleon and three-nucleon interactions up to next-to-next-to-next-to-leading order. We will outline the many-body approach, address the conceptual and technical challenges associated with hyperonic forces and present first results for the equation of state of neutron-rich matter including calculations of chemical potentials in beta equilibrium.

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HK 7.7 Mon 18:00 PHIL A 602

Dark matter effects on the properties of hybrid and twin stars
— •Harish Chandra Das — Goethe-Universität Frankfurt am Main, Institut für Theoretische Physik, Frankfurt, 60438, Germany

We investigate the influence of dark matter (DM) on the structure and stability of hybrid and twin stars within a two-fluid framework in which DM interacts with baryonic matter purely through gravity. The baryonic sector is described using relativistic mean-field theory for nucleonic matter and a constant sound-speed parametrization for quark matter, while the DM component is modeled as self-interacting fermions. We find that the presence of DM suppresses the emergence of hybrid and twin star branches compared with DM-free configurations. The degree of suppression depends sensitively on the phase-transition pressure and the energy-density discontinuity for fixed sound speed, as well as on the DM particle mass and fractional abundance. Stars featuring DM-dominated cores or halos are governed primarily by DM properties, whereas the emergence of twin or hybrid configurations remains controlled by the quark-matter equation of state. Incorporating current observational constraints further narrows the allowed parameter space for twin stars in both scenarios.