<u>Project Title</u>:

From Atomic Nuclei to Neutron Stars: Same Physics Across All Scales

1. Introduction

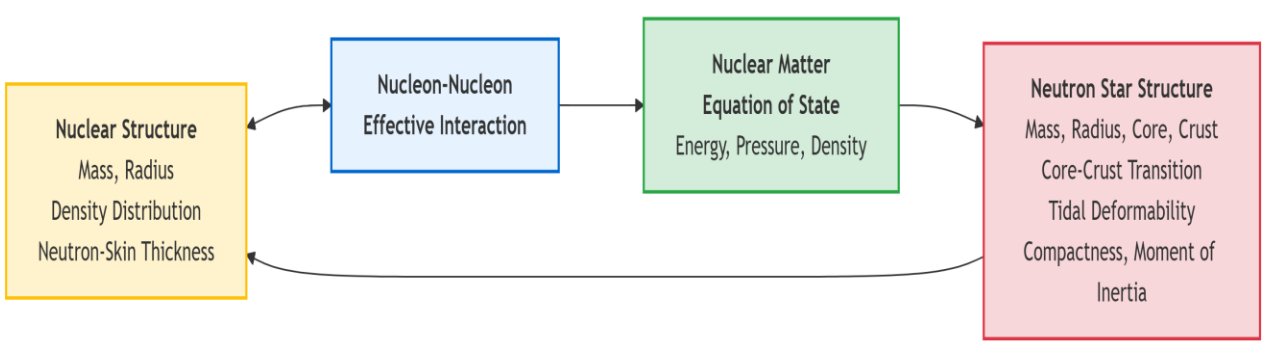
The equation of state (EoS) of asymmetric nuclear matter serves as a fundamental link between finite atomic nuclei and compact astrophysical objects such as neutron stars (NSs). A central challenge in modern nuclear physics is to understand how nuclear properties, including symmetry energy, incompressibility, and nucleon-nucleon interactions, simultaneously govern the stability of atomic nuclei and the macroscopic characteristics of neutron stars (mass, radius, tidal deformability, …etc). Recent multimessenger observations, particularly gravitational wave events, have placed stringent constraints on NS properties, calling for a consistent microscopic description. This training course bridges topics related to the structure and properties of both finite nuclei and neutron stars, using the same nuclear equation of state under normal and extreme conditions.

2. Main Part (What the Student Will Learn)

The participant will learn:

- **Nuclear structure:** Mass, radius, density distribution, neutron-skin thickness, and related observables.
- **Nucleon-nucleon interaction: P**roperties of the strong nuclear force, effective interactions and their density dependence.
- **Nuclear matter equation of state**: From symmetric matter to neutron-rich matter, and saturation properties.
- **Neutron star structure**: Mass-radius relation, crust-core transition, tidal deformability, compactness, moment of inertia, and other macroscopic properties.
- **Solving the Tolman-Oppenheimer-Volkoff (TOV) equations** – numerical methods for computing neutron star structure from a given EoS.

3. <u>Description of the Project Work</u>



3.2. Measurement procedure (what the student needs to do)

Week 1**: Nuclear structure:** Mass, radius, density distribution, neutron-skin thickness, and related observables and **Nucleon-nucleon interaction: P**roperties of the strong nuclear force, effective interactions and their density dependence.

Week 2: Nuclear matter equation of state: From symmetric matter to neutron-rich matter, and saturation properties, and Neutron star structure: Mass-radius relation, crust-core transition, tidal deformability, compactness, moment of inertia, and other macroscopic properties.

Week 3: How to solve the Tolman-Oppenheimer-Volkoff (TOV) equations to find the NS properties, and linking the NS properties to observables, to nuclear structure.

3.3. Form of presentation of results

A final report (6-10 pages) including:

- Plots of binding energy per nucleon vs. density for different isospin asymmetries.
- Mass-radius diagram with NS constraints.
- Dependences of the NS properties on the defining quantities of the nuclear equation of state.
- A 10-minute oral presentation at the end of the internship.

4. Requirements for the Student's Level of Preparation

- Basic knowledge of quantum mechanics and nuclear physics (at the level of an undergraduate student).

- Familiarity with mathematics and simulation.

- Ability to read scientific literature in English.

5. Recommended Literature in English

1. N. K. Glendenning, *Compact Stars: Nuclear Physics, Particle Physics, and General Relativity* (Springer, 2000).
2. P. Haensel, A. Y. Potekhin, & D. G. Yakovlev, *Neutron Stars 1: Equation of State and Structure* (Springer, 2007).
3. D. Blaschke & T. Klähn, *Astrophysics of Neutron Stars* (Springer, 2020).
4. W. M. Seif, W.M. & A. S. Hashem, "Neutron Star Core-Crust Transition and Crustal Moment of Inertia: Systematic Implications of Higher-Order Symmetry Energy," *Physical Review C* **112**, 065802 (2025).
5. W. M. Seif, A. S. Hashem, & H. A. Abualhamd, H.A., "Density curvature, skewness, and kurtosis of the nuclear symmetry energy and their impact on the compactness and tidal deformability of neutron stars," *Physical Review C* **111**, 035806 (2025).

6. Number of Project Participants

Up to 3 students – can work individually or as a team. Each student can produce his own final report (M. Sc students), or collaborated report (for undergraduates).

7**. Project Manager from JINR**

Dr. **Walaa M. Seif Hammouda**

Professor of Theoretical Nuclear Physics

Leading Researcher at **Bogoliubov Laboratory of Theoretical Physics (**BLTP).

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