



JOINT EUROPEAN MASTER IN NUCLEAR PHYSICS

Academic Year 2025/2026

MASTER THESIS PROPOSAL

TITLE: First principles nuclear theory for structure, astrophysics, and new physics searches

SUPERVISOR(S): Jason D. Holt

SUPERVISOR(S) contact- email: jholt@triumf.ca
email:

Telephone: +1 604 222 7371
Telephone:

UNIVERSITY/RESEARCH CENTER: TRIUMF: Canada's Particle Accelerator Centre

ABSTRACT

(just few lines 5-10 explaining briefly the idea of the proposed work and the place where it will be developed).

This project will focus on the development and application of powerful theoretical methods to explore fundamental questions on the structure of exotic nuclei, or more far-reaching connections searches for physics beyond the standard model: new neutrino properties, dark-matter detection, neutron star physics, or searches for violation of fundamental symmetries of nature. The student will first gain familiarity and build confidence working with the basic ingredients of such calculations: nuclear forces and their connection to the underlying theory of strong interactions (quantum chromodynamics), and nuclear many-body theories to predict properties of nuclei at the extremes of existence. Depending on particular interests, the student will have the exciting opportunity either to design and implement an extension to the existing computational infrastructure, work on computationally optimizing existing codes, or perform a series of calculations which will confront directly with experiments being performed at TRIUMF or other prominent experimental facilities across the world searching for physics beyond the standard model.

Work is planned to take place on-site at TRIUMF, Canada's particle accelerator centre, which is located at the south end of the UBC campus in Vancouver



ERASMUS MUNDUS JOINT MASTER IN NUCLEAR PHYSICS

Academic Year 2026/2027

MASTER THESIS PROPOSAL

TITLE: Development of a Magnetic Field Mapping System for the TUCAN Neutron EDM Experiment

SUPERVISOR(S): Noah Yazdandoost

SUPERVISOR(S) contact- email: noah.yazdandoot@triumf.ca Telephone: +12369989985
email: Telephone:

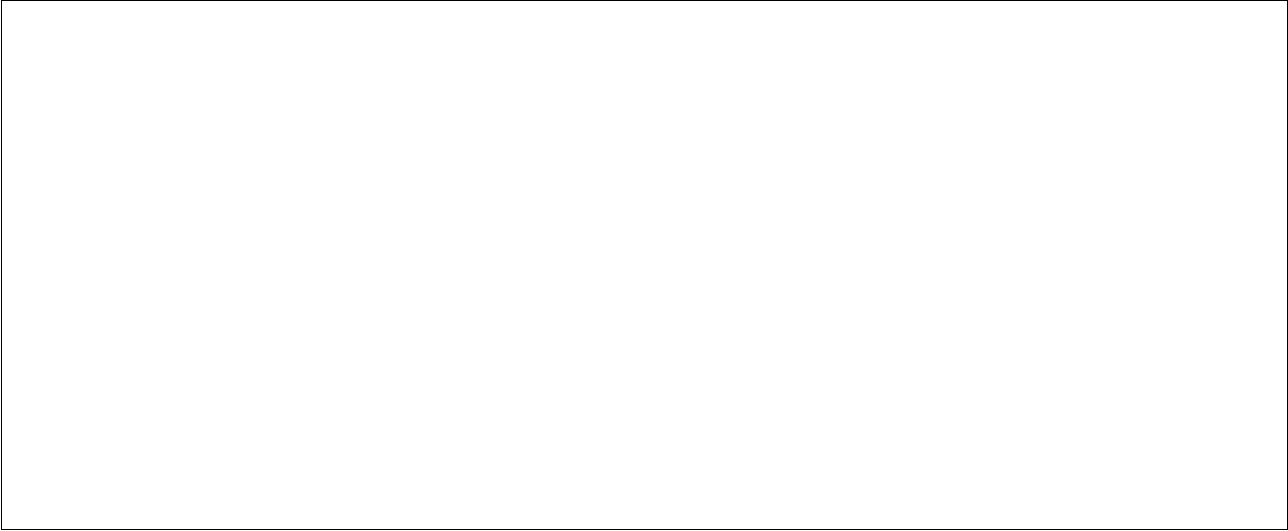
UNIVERSITY/RESEARCH CENTER: TRIUMF - Canada's Particle Accelerator Centre,
Vancouver, Canada

ABSTRACT

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One of the major open questions in fundamental physics is why the Universe contains much more matter than antimatter. Searches for a permanent electric dipole moment of the neutron provide a highly sensitive probe of new sources of Charge-Parity violation that could help address this question. The TUCAN experiment at TRIUMF is developing a next-generation neutron electric dipole moment measurement using ultracold neutrons and requires extremely precise control of magnetic fields.

This project will focus on the development and commissioning of a magnetic-field mapping system for the experiment's main B0 coil. The student will work on magnetometer measurements, automated positioning and data acquisition, magnetic-field simulations, and the study of how mechanical displacements of individual coil sections affect the field uniformity. The project combines fundamental physics, experimental instrumentation, magnetic-field modelling and data analysis within the international TUCAN collaboration at TRIUMF.





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ABSTRACT

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Low-lying spectroscopy of exotic nuclei: coupling EDFs and algebraic models

Large-scale models of nuclear structure that aim to describe different properties of thousands of nuclei within a single framework arguably form the best test of our global understanding of nuclear properties. The most advanced global models today describe a nucleus microscopically in terms of its constituent nucleons, whose interaction is modeled by means of an energy density functional (EDF). Such large-scale models are crucial to provide nuclear data to simulations in astrophysics, from neutron stars to nucleosynthesis; the challenge for nuclear theory is to build models that can reliably extrapolate to the extremes of isospin, baryon density and excitation energy [1]. Recent developments have extended large-scale EDF-based models to include triaxial deformation as a collective degree of freedom, enabling more realistic descriptions of complex nuclear shapes [2].

To tackle the nuclear many-body problem, EDFs rely on the mean-field approximation. This is what allows their global application, but it also limits their applicability to nuclear spectroscopy due to spontaneous symmetry breaking and the resulting loss of quantum numbers. In turn this limits their description of the nuclear level density (NLD) at low excitation energy, a crucial quantity in the estimation of reaction rates for exotic nuclei. Today, this deficiency is papered over with a simplistic phenomenological modeling of collective excitations.

Algebraic models, on the other hand, capture collective and spectroscopic properties more naturally by exploiting symmetry principles and group-theoretical structures. Unfortunately, their extrapolation to exotic nuclei is not straightforward as such models often rely on nucleus-specific parameters. It is therefore advisable to feed them with phenomenological parameter sets coming from EDF tailored to a large portion of the nuclear chart.

In this topic, the student will investigate to what extent EDF methods and algebraic models can be deployed simultaneously to study nuclear low-lying excitations and their role in NLDs. In a first step, the student will use EDF predictions for triaxial potential energy surfaces to determine the parameters of algebraic models for thousands of exotic nuclei along the lines of Ref. [2]. In a second step, a detailed comparison between the resulting spectra and the state-of-the-art phenomenological NLD modelling based solely on EDFs will identify the limitations of the latter.

This thesis subject is a joint effort between the theoretical nuclear physicists at the Department of Physics and Astronomy of the Università di Padova and the Institut d'Astrophysique et Astronomie (IAA) at the Université libre de Bruxelles. The latter currently consists of 6 permanent staff members and about 15 early career researchers and is recognized internationally as a center of excellence in nuclear astrophysics – with dedicated research programs in stellar evolution, chemical abundance determination of stars, nucleosynthesis, neutron stars and nuclear data.

- [1] M. Arnould and S. Goriely, Prog. Part. Nucl. Phys. **112**, 103766 (2020).
- [2] G. Scamps et al., Eur. Phys. J. A **57**, 333 (2021).
- [3] K. Nomura et al., Phys. Rev. Lett. **14**, 142501 (2008)