Nuclear Physics courses, MSU/FRIB theory center and nuclear TALENT

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Motivation

- Develop structured modules which will provide our students with a modern education in nuclear physics
- Modules/courses should contain a high-level of synchronization
- A computational perspective is essential
- They should form a basic curriculum to be integrated with the coming FRIB theory center
- Coordination with Talent initiative and other Northern American institutions to be elaborated

We have at MSU a basic survey course PHY802 and three basic nuclear physics courses structure, reactions and dynamics and **Nuclear Astrophysics**. These three basic courses have a duration each of 30-40 hours (2-3 credits).
They can be taught as a regular one-semester course or half-semester course. There are also experimental courses not discussed here.

The basic courses/modules (theory) taught at MSU

BASIC Nuclear survey course

Nuclear Structure

Nuclear Reactions

Nuclear astro physics

These are basis NP modules.
a 30 hours each

Nuclear structure course/module PHY981

- Experimental information
- Single-particle properties and mean-field
- second quantization
- Hartree-Fock theory
- Nuclear forces (?) Can be taken out since we have an advanced Talent module on this
- Shell model
- Transitions (EM and β-decays
- Computational elements: build a Hartree-Fock code and/or a shell model code (diagonalization)

Nuclear dynamics course/module PHY982

- Direct reaction theory and applications
- Reactions of light and heavy ions, from low to relativistic energies
- Single-channel scattering
- Integral forms for scattering. Generalizing to many channels
- Collective couplings. Single-particle couplings. Coupling to the continuum
- Transfer reactions. Breakup reactions
- Adiabatic reaction models. Semiclassical approximations (Eikonal and time-dependent approaches)
- Capture and fusion reactions
- R-matrix methods
- Microscopic models for reactions
- Several computational exercises

Nuclear astrophysics course/module PHY983

- Neutrinos
- Equation of state for dense matter
- Masses - Stability and Decay
- Reaction Rates
- Beta decay Rates
- The Life of Stars: Stellar burning stages, Hydogen burning, Other burning stages
- The Death of Stars: Supernovae, Neutron Stars and White Dwarfs
- Beyond Iron I: r-process, s- and p-process
- Hydrogen burning at the extremes, the rp process

Advanced modules, Nuclear Talent

- Nuclear forces (INT 2013, new version 2017)
- Many-body methods (**GANIL July 2015**)
  - Many-body perturbation theory
  - Similarity renormalization group theory
  - Coupled cluster theory
  - Green's function theory
  - FCI (Shell model)

Advanced modules, Nuclear Talent

- Few-body methods for nuclear physics (**ECT* July-August 2015**)
  - Forces and nuclear models
  - The Faddeev and Faddeev-Yakubowsky Equations
  - Methods based on Basis expansions
  - Few-nucleon reactions with external probes

Advanced modules, Nuclear Talent

- Density functional theory and self-consistent methods (ECT* 2014 and **York 2016**)
- Theory for exploring nuclear structure experiments (GANIL 2014)
- Theory for exploring nuclear reaction experiments (GANIL 2013)

Advanced modules, Nuclear Talent

- Nuclear theory for astrophysics (MSU 2014 and **INT 2015**)
  - Stellar evolution, supernova and neutron stars.
  - Observations and basic properties of neutron stars and supernovae.
  - Brief review of nuclear forces and nuclear models.
  - Review of thermodynamics and statistical mechanics.
  - Basic notions in dense matter theory.
  - Simple models, the equation of state, and linear response theory.
  - Homogeneous dense nuclear matter.

Advanced modules, Nuclear Talent

- Nuclear theory for astrophysics (MSU 2014 and **INT 2015**)
  - Homogeneous dense nuclear matter.
  - Tolman Oppenheimer Volkoff equations and neutron star structure.
  - Physics at sub-nuclear density and the properties of the neutron star crust.
  - Superfluidity and superconductivity in neutron stars.
  - Phase transitions at high density.
  - Neutrino processes in dense matter and neutron star cooling.
  - Transport properties of degenerate matter.
  - Accreting neutron stars.
  - Supernova neutrinos.
  - Gravitational waves from neutron star.

Advanced modules, Nuclear Talent

- Theoretical approaches to describe exotic nuclei (planned for 2016, Chalmers, Gothenburg)
- High-performance computing and computational tools for nuclear physics
  - ECT* 2012, Shell model and variational Monte Carlo
  - LANL/ORNL in 2016, Monte Carlo methods

Discussion

- How many basic courses can an institution offer, and which courses should be offered?
- How can the coming FRIB theory center be used to coordinate an advanced training in nuclear physics?
- Can we integrate the (*ad hoc*) Nuclear Talent courses/initiative in our education?
- Most courses offered are theoretical ones. We need a better coordination between theory and experiment. Should we think of an experimental Talent initiative?