PHY-989 Special Topics in Nuclear Physics SS2021

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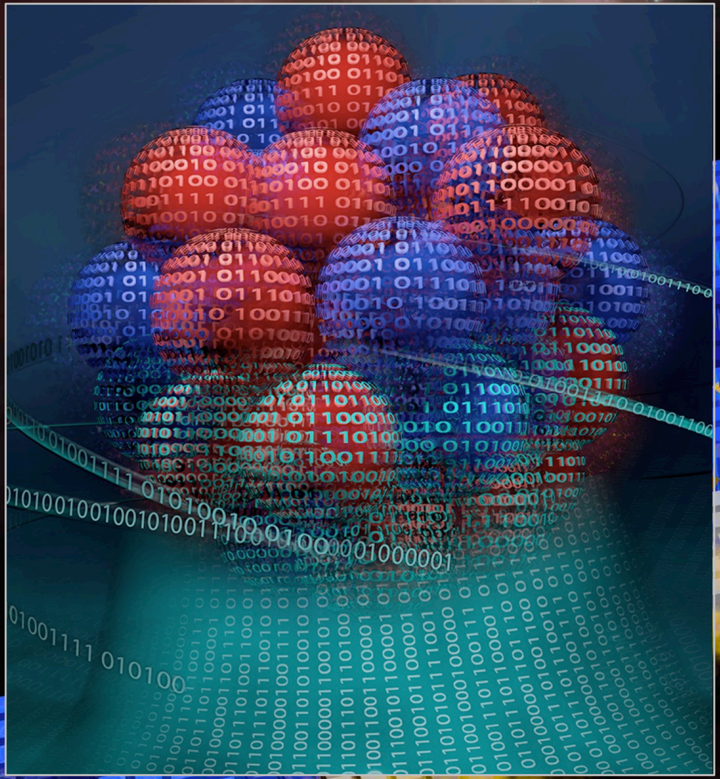
Tue, Thu 1-2pm (2x50min/week)



Introduction

- Material covered
- Guiding principles

Teaching philosophy

- "I have never let my schooling interfere with my education." (*Mark Twain)*
- The key objective: provide insights, guidance, and sound foundations. Meticulous derivations can be carried out outside classroom (…by algebraic computation).
- Connecting the dots.
- Interdisciplinary connections, universal concepts. Many scientific breakthroughs were made by recognizing broad connections with other disciplines. (*Phil Anderson, Aage Bohr*)
- Productive discourse in the classroom.
- Hands-on projects that are simple to solve and hone students' skills and intuition.

Communication tool: D2L platform

Grading Procedure: Grades will be based on the following:

- Homework - 50% (HW assignments will be given approximately every two weeks)
- Final presentation/project - 40%.
- Class participation – 10%

You are expected to interrupt with questions!

Office hours: Tuesdays 2pm?

Helpful textbooks:

- Nuclear Many Body Problem" Ring & Schuck, 3rd printing, 2004 Springer, ISBN: 3-540-212
- "Theory of Nuclear Systems", Jacek Dobaczewski (unpublished). Original (in Polish): https://people.nscl.msu.edu/~witek/Classes/NP622/Jacek-skrypt/Czesc057d.pdf
- Energy Density Functional Methods for Atomic Nuclei, ed. By. N. Schunck, IOP 2019, download from https://iopscience.iop.org/book/978-0-7503-1422-0 (you can copy the book from D2L)

Theoretical concepts covered

- Fock spaces; Wick's theorem; Product states; Quasiparticles; Density matrices; Coherent states
- Bogoliubov transformation; Thouless theorem; Hartree-Fock (HF) theory; Hartree-Fock-Bogoliubov (HFB) theory; Ring and Schuck theorem; HF stability conditions; Polarization effects and effective charges
- Nuclear density functional theory (DFT); Spontaneous symmetry breaking in nuclei; Jahn-Teller effect and nuclear deformations; Shell structure and classical orbits in mesoscopic systems; Multi-reference DFT (Generator coordinate method); Time-dependent HF (TDHF)
- Symmetry restoration by projection; Random Phase Approximation; Collective models; Adiabatic and diabatic collective motion; Landau-Zener problem and Berry connection; Theories of large-amplitude collective motion (ATDHFB, TDHFB);
- Many-body continuum; Continuum space of HFB; Continuum shell model; Complex-energy approaches (Gamow shell model, complex scaling)
- Uncertainty quantification for nuclear theory (regression techniques and Bayesian inference including the Bayesian model mixing).

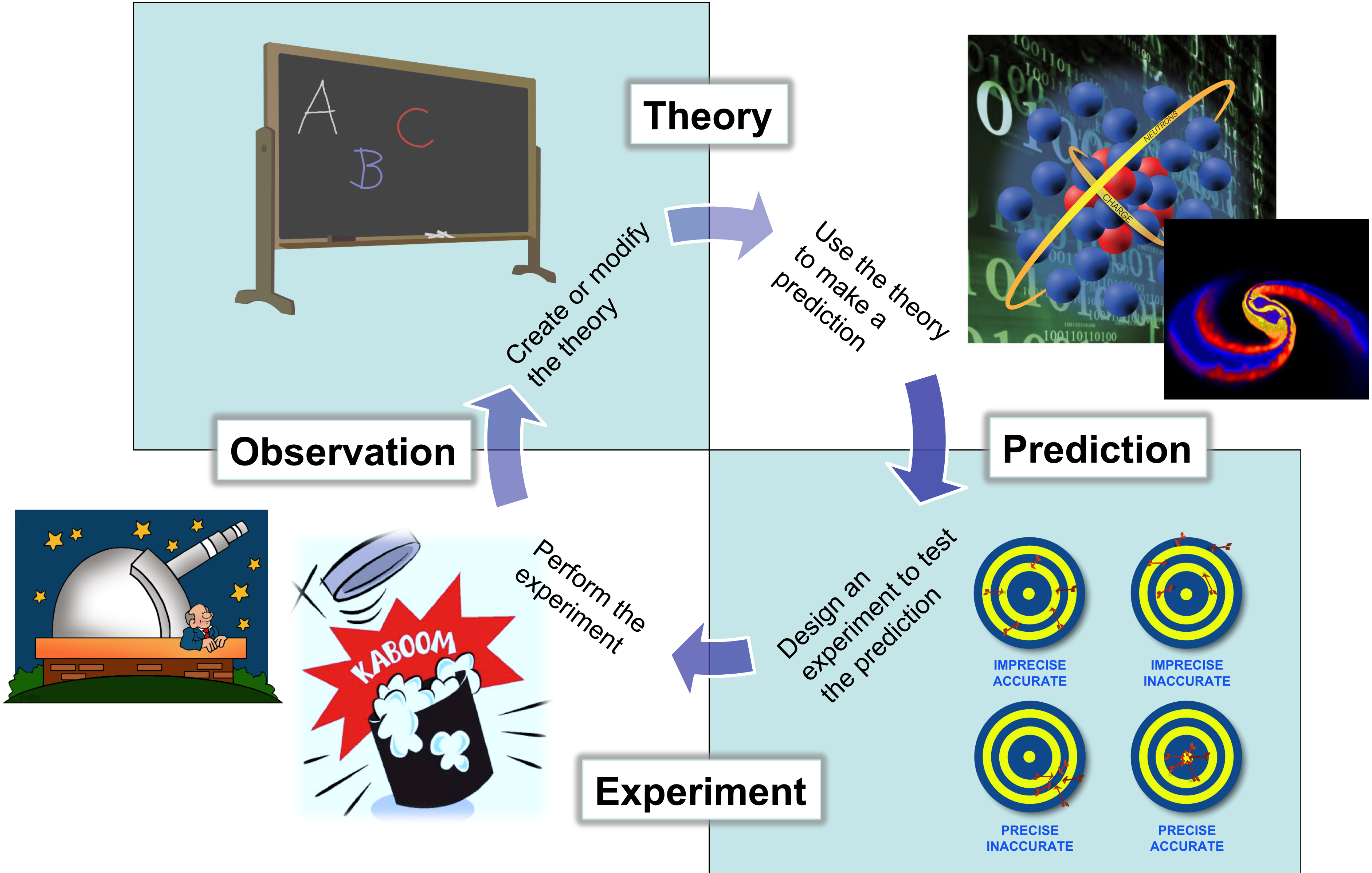
Question: Is there anything else you would like me to cover?

Areas/phenomena covered: global properties of atomic nuclei; spectra (including unbound states); fission; shell structure; nuclear deformations; nucleonic superfluidity (isoscalar and isovector pairing); coexistence phenomena; rapid nuclear rotation; clusters in nuclei; superheavy nuclei and superheavy elements; nuclear matter equation of state; nuclear physics of neutron stars; theoretical extrapolations for r-process nucleosynthesis.

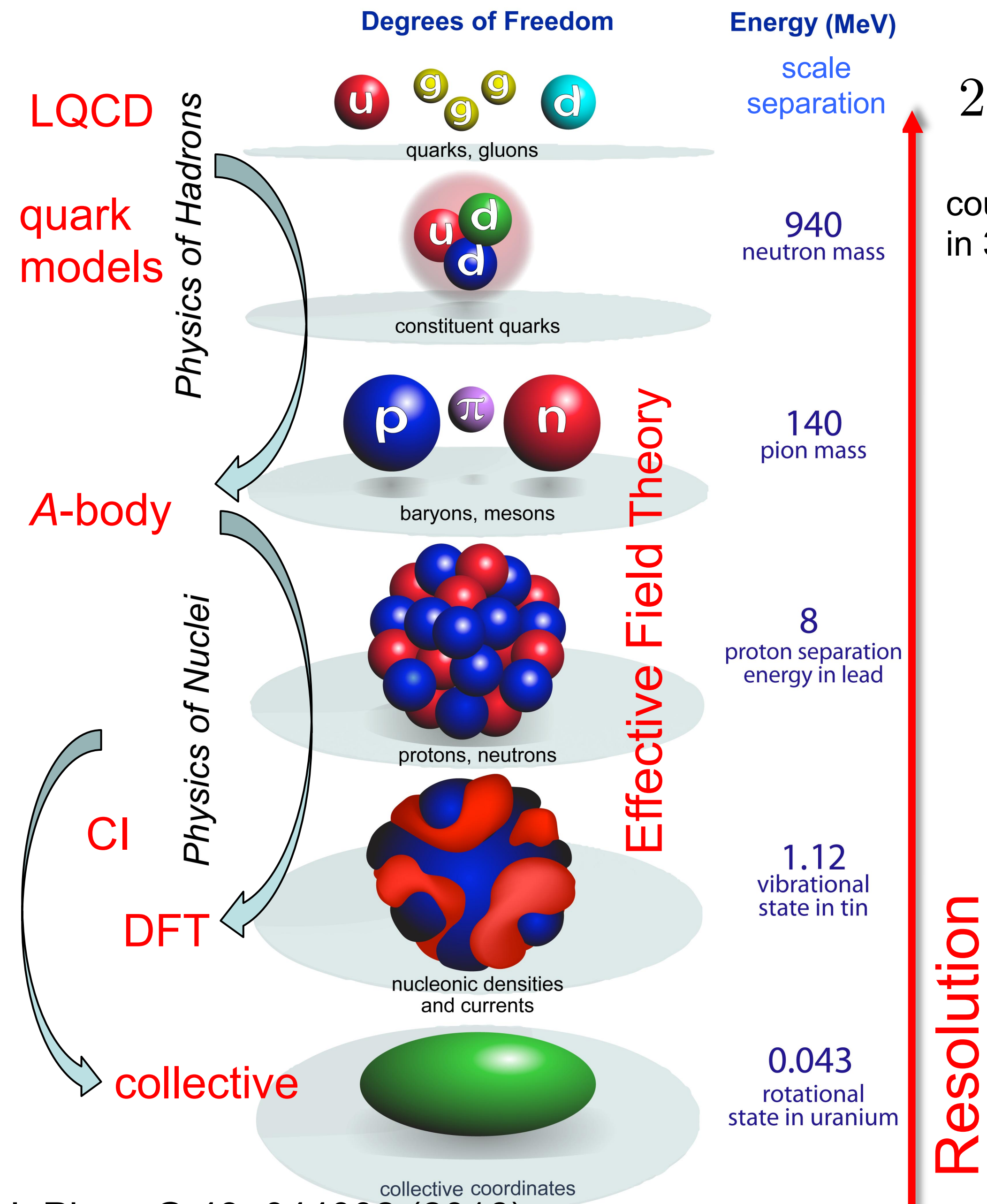
Exactly solvable many-body models:

- Lipkin model (+Hartree-Fock version, +GCM version)
- Seniority model
- Two-level model
- Richardson model

Guiding principle: the scientific method…



J. Phys. G 43, 044002 (2016)



$$2^A \times \frac{A!}{N!Z!}$$

coupled equations in 3A dimensions

Hilbert-space truncations necessary

J. Phys. G 43, 044002 (2016)

Most *efficient* approach: resolving power of a theoretical model taken as low as reasonably possible for the question at hand

Nuclear models must reproduce physical reality: phenomenology

Weinberg's Laws of Progress in Theoretical Physics

From: "Asymptotic Realms of Physics" (ed. by Guth, Huang, Jaffe, MIT Press, 1983)

First Law: "The conservation of Information" (*You will get nowhere by churning equations*)

Second Law: "Do not trust arguments based on the lowest order of perturbation theory"

Third Law: "You may use any degrees of freedom you like to describe a physical system, but if you use the wrong ones, you'll be sorry!"

What is a Model?

In the context of this class, it is useful to clarify the notion of a "model". Here, by a model I will understand the combination of a raw theoretical model (i.e., mathematical framework), the calibration dataset used for its parameter determination, and a statistical model that describes the error structure.

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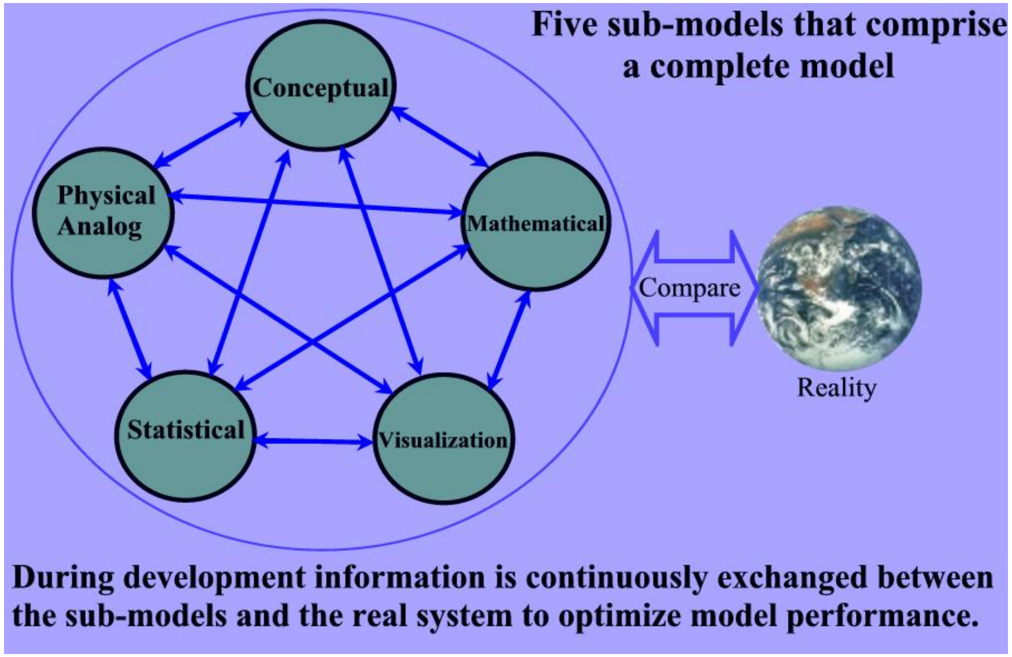

- Physics
- Mathematics
- Computer science
- Statistics