Christian Forssén,
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THEORETICAL NUCLEAR PHYSICS RESEARCH IN SWEDEN
1. How does the nuclear chart emerge from the underlying interactions?

2. Achieving a unified description of all nuclei

3. The precision era of nuclear theory

4. Towards consistent reaction theory

5. Computational challenges to reach the scientific goals of nuclear physics

6. Training the next generation of researchers in nuclear physics
NUCLEAR THEORY GROUPS IN SWEDEN (LOW-ENERGY)

Chalmers University of Technology, Göteborg

Christian Forssén, Professor
Andreas Ekström, Ass. Professor

- 3 phd students
- Daniel Gazda (postdoc)
- Michail Zhukov (Prof. Emer.)
- Håkan T. Johansson (Research eng.)
- Master and Bachelor students

http://fy.chalmers.se/subatom/tsp/

Lund University

Sven Åberg, Professor
Ingemar Ragnarsson, Professor
Gillis Carlsson, Assoc. Professor
+1 incoming

- 1 phd student (+2 incoming)
- 1 incoming postdoc
- Ikuko Hamamoto (Prof. Emer.)
- Master and Bachelor students

Royal Institute of Technology, Stockholm

Ramon Wyss, Professor
Chong Qi, Assoc. Professor

- 1 phd student (+1-2 incoming)
- Monika Patial (postdoc)
- Roberto Liotta (Prof. Emer.)
- Jan Blomqvist (Prof. Emer.)
- Master and Bachelor students
# CHALMERS: THEORETICAL NUCLEAR PHYSICS

## Effective field theory
- Chiral EFT, nuclear interactions
- Halo effective field theory
- EFT for dark matter-nucleon interactions

## Few-body physics
- Ultracold atoms
- Two-proton radioactivity
- Halo nuclei

## Ab initio methods
- Computational many-body methods
- From QCD to nuclear physics
- Theoretical uncertainty quantification

## Funding agencies
- European Research Council (erc)
- Knut och Alice Wallenbergs Stiftelse
- STINT

… at the technology frontier
- Computational physics
- Computational hardware
- Computational algorithms
Consider an A-nucleon system described by a well defined microscopic Hamiltonian.

Ab initio methods solve the relevant QM many-body equations without uncontrolled approximations.

Controlled approximations, e.g. number of channels, are allowed as they can be systematically improved.

Converged results are considered precise ab initio results.

Ab initio methods: No-Core Shell Model, Coupled clusters, Green’s function Monte Carlo, In- Medium SRG, Lattice EFT.
CHALMERS: AB INITIO APPROACH TO NUCLEAR PHYSICS

TECHNOLOGY EXAMPLE: LARGE-SCALE MATRIX DIAGONALIZATION

- Current limit: $N_{\text{dim}} = 10^{10}$
- Sparse, BUT: $N_{\text{non-zero}} = 5 \times 10^{14}$, equivalent to 6 PB data
- In effect, we perform $2.5 \times 10^9$ multiplications / sec / machine

PHYSICAL REVIEW LETTERS

Optimized Chiral Nucleon-Nucleon Interaction at Next-to-Next-to-Leading Order
Phys. Rev. Lett. 110, 192502 – Published 7 May 2013

PHYSICAL REVIEW C™

Infrared length scale and extrapolations for the no-core shell model
K. A. Wendt, C. Forssén, T. Papenbrock, and D. Säaf
Phys. Rev. C 91, 061301(R) – Published 3 June 2015
CHALMERS: UNCERTAINTY QUANTIFICATION WITH EFFECTIVE FIELD THEORY

NN and piN scattering in chiral-EFT

Effective field theory + ab initio methods = systematic improvable ⇒ uncertainty quantification

$^{16}\text{O}(p,\gamma)^{17}\text{F}^*$ in Halo-EFT

$S$-factor (keV b)

$E$ (keV)

Annals of Physics
Volume 367, April 2016, Pages 13–32

Range corrections in proton halo nuclei

Emil Ryberg, Christian Forssén, H.-W. Hammer, Lucas Platter
**CHRISTER FORSSÉN, JÖRGEN LINDGREN, JIMMY ROTUREAU, JONATHAN LARSSON, DAVID LIDBERG**

**New Journal of Physics**

**Fermionization of two-component systems in a one-dimensional trap**

E J Lindgren, J Rotureau, C Forssén, C Lundmark, J Larsson, D Lidberg

Department of Fundamental Physics, Chalmers University of Technology, Göteborg, Sweden

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New Journal of Physics 16 (2014) 063003

doi:10.1088/1367-2630/16/6/063003

**STATISTICAL MECHANICS OF ULTRACOLD ATOMS IN TRAPS**

**Few-Body Systems**

**Strongly Interacting Few-Fermion Systems in a Trap**

Christian Forssén, Rikard Lundmark, Jimmy Rotureau, Jonathan Larsson, David Lidberg

May 2015

Date: 05 May 2015

**Quantum magnetism in strongly interacting one-dimensional spinor Bose systems**

Amin Dehkharghani, Artem Vologin, Jonathan Lindgren, Jimmy Rotureau, Christian Forssén, Dmitri Fedorov, Aksel Jensen, & Nikolaj Zinner

Received: 30 October 2014

Accepted: 13 April 2015

Published: 15 June 2015

**Rapid Communication**

Tunneling theory for tunable open quantum systems of ultracold atoms in one-dimensional traps

R. Lundmark, C. Forssén, and J. Rotureau

Phys. Rev. A 91, 041601(R) – Published 13 April 2015
THEORETICAL NUCLEAR STRUCTURE, 
DIVISION OF MATHEMATICAL PHYSICS, LTH

LUND UNIVERSITY
Structure of the nucleus
Neutron induced fission

Predictions of Fission fragment distributions for poorly explored regions of the nuclear chart.

Energy of incoming neutron changes the distributions. (FRLDM + mic. Lev.dens.)

Lund-Los Alamos-Berkley-NBI collaboration
Combining nuclear and atomic structure models. What can be learned about the nucleus from electron energies?

Atomic fieldshifts predicted by nuclear DFT + MCDHF
Structure of nuclei
Search for new elements

Heavy elements decay through alpha emission and fission.

First observation of excited states in decay chain of Z=115 (2013)

Chart of the Nuclides

- Island of stability?

- Chains end with spontaneous fission of unknown isotopes:
  How to determine their proton number?

- $T_{1/2} = 4.8(8) \text{ s}$  
  $Q_\alpha = 10.15(1) \text{ MeV}$  
  $E_\alpha = 9.77(1) \text{ MeV}$  
  $HF = 35(9)$
The structure of nucleus
Search for new elements

Alpha-decay lifetimes for superheavy nuclei.
Including hindrance factors

Here we may find decay to excited states

Nuclear DFT + R-matrix approach

Lund Theory-Experiment Collaboration
Summary of activities

Ongoing activities involve:

Spectra of rotating nuclei, Supernova neutrino crossections, Nuclear properties for atoms, Alpha-decay, Description of fission/fusion, Nuclear leveldensities, Nuclear models for attractively interacting cold atoms, DFT from ab initio forces.

Next five years:

More focus on new element research particularly alpha-deacys and accurate modeling of heavy nuclear systems.
Scientific Mission

In general: Understanding the strong force as a manifestation in nuclear properties.

- What are the limits for the existence of nuclei?
- How do weak binding and extreme proton-neutron asymmetry affect nuclear properties?
- How are complex nuclei built from their basic constituents?
- What are the origins of the elements?
**KTH: NUCLEAR THEORY GROUP**

*Strong cooperation with experimentalists (Spirit of Copenhagen School)*
*Leading theoretical development*

- **Goal:** Develop **high accuracy** nuclear shell model and mean field models for intermediate-mass and heavy nuclei
- **Focus areas:** isovector and isoscalar properties of effective forces - decay from exotic nuclei - Symmetry Energy - Continuum - Nuclear Masses
- **Strategic outlook:** Leading expertise in complete shell model (bound and unbound providing insight to clustering and exotic structures)
- **Synergies:** e-science (SRA); nuclear astrophysics;

- Graduate education: ZhenXiang Xu (PhD, thesis autumn 2012), Sara Changizi (PhD, 2017), Alexander Arzhanov (Master 2013), Jonatan Alvelid (Bachelor, 2015)
- Incoming postdoc and 1-2 new PhD students (2016, 2017)
- ~3-5 short-term guest researchers/year
- Summer job students and Master students

Output >10 papers/year
Cooperation with leading theory groups in EU, China, India and elsewhere
Recent Highlights (selection)

Pairing and neutron-proton correlations
C. Qi, R. Wyss, Physica Scripta 91, 013009 (2016)

Large-scale configuration interaction approach, truncation algorithms and nuclear structure
H Jiang, C Qi, Y Lei, R Liotta, R Wyss, YM Zhao, Phys. Rev. C 88, 044332 (2013); 89, 014320 (2014)

Alpha decay, (di-)proton decay and the effect of isovector and isoscalar pairing
C. Qi, Reviews in Physics 1, 77 (2016)

Nuclear masses, shell evolution, deformation and effective nuclear force
KTH: NUCLEAR THEORY GROUP

Main external Funding:
• VR project 2014-2017, "Theory of loosely bound nuclei", 2.6MSEK
• VR young researcher grant 2013-2016, "A novel many body approach for unstable nuclei", 3.4MSEK
• Göran Gustafsson award for young researchers, 2016-2019, 2.5 MSEK

Teaching:
• Modern physics, Theoretical nuclear physics plus several PhD courses
• Development of new courses (Computational quantum mechanics, 2016)
• >50 Bachelor students chose our group for their one-month research projects within modern physics in 2016.
OUTLOOK

- Three nuclear-theory groups with rather complementary research profiles: *ab initio* from light to medium-mass at Chalmers; shell and mean-field models at KTH, Stockholm; DFT and heavy nuclei at Lund University.

- Well positioned to play a leading role in very exciting research opportunities: *ab initio* for heavier systems; theoretical uncertainty quantification; new elements.

CHALLENGES

- Still very small research groups; Base funding from the universities is lacking and project funding from the research council is very limited.

- Sweden does not (yet) have a working tenure-track system making it difficult to attract young talent.

- Computer resources are rather small on an international scale.