# Kandidatexamensarbeten 2022

## Fysik

### Samordnare:

Jack Lidmar
<jlidmar@kth.se>
Fysikinstitutionen
AlbaNova
(A4:1081)
0737-652021

# A1 The Supernova Population of Interacting Galaxies

*Supervisor: Tuomas Kangas (tuomask@kth.se)*

Supernovae (SNe), the explosions of massive stars, are among the most luminous events in the universe and accompany the births of the most extreme objects such as black holes and neutron stars. In addition, they are a major source of information about the dying stars themselves and their evolution. One important piece of this puzzle is the link between different SNe and their progenitor stars, whose ages and masses can be examined through their locations within their host galaxies. In this project you will use statistical methods to analyze the connection between different SNe and strongly star-forming regions in their interacting and merging host galaxies, with atypical environmental conditions and, according to recent evidence, a similarly atypical SN population. You will then compare the results to normal galaxies; this way the differences between the SN populations can beprobed, which can give us more information on the progenitor stars and the environments they are born in.

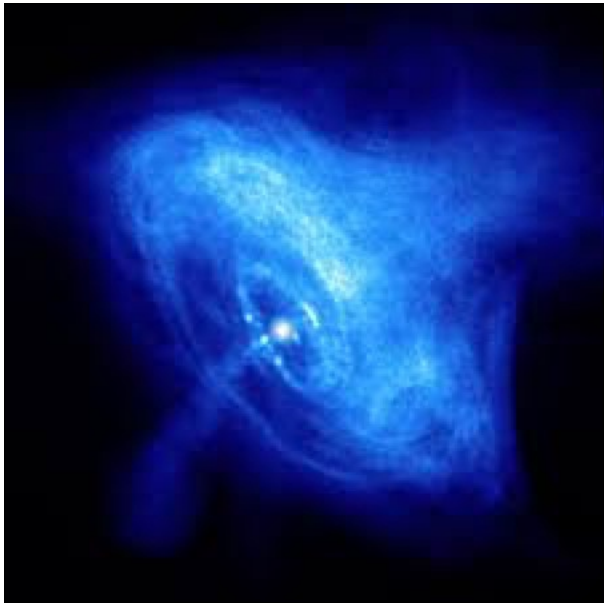
Reference:

Anderson, J. et al. 2012: *Progenitor mass constraints for core-collapse supernovae from correlations with host galaxy star formation,* MNRAS, 424, 1372 (https://arxiv.org/pdf/1205.3802.pdf)

# A2 Nybildade kompakta objekt

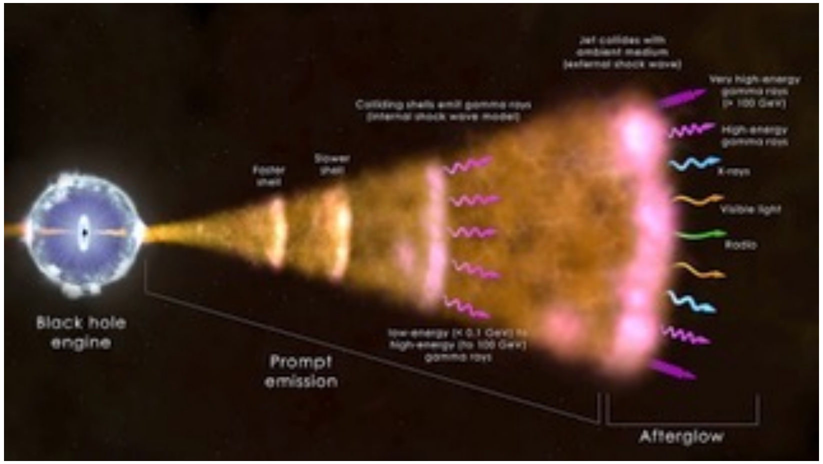
*Handledare: Josefin Larsson (josla@kth.se)*

När en stjärna exploderar som en supernova bildas ett kompakt objekt - en neutronstjärna eller ett svart hål. Vi har dock begränsad kännedom om vad det nybildade kompakta objektet har för egenskaper och hur dessa kopplar till själva explosionen. Det här projektet syftar till att adressera den här frågan med hjälp av röntgenobservationer av supernovor. Arbetet kommer innefatta analys av röntgenspektra med specialiserad astronomimjukvara, tillämpning av statistiska metoder, enklare programmering samt jämförelse av resultaten med teoretiska modeller.



# A3 Fotosfärisk strålning från gamma-blixtar

*Handledare: Felix Ryde & Filip Samuelsson (fryde@kth.se)*
Svarta hål föds bl.a. när tunga stjärnor kollapsar. I födsloögonblicket skickas enorma mängder gamma-strålning ut, som ibland träffar jorden. Om vi lyckas mäta dessa gammablixtar kan vi analysera dem och lära oss mer om vad som hände. Strålningen bildas i en jetstråle som rör sig med nästan ljusets hastighet rakt mot oss. Det är blixten från från fotosfären vi oftast ser. I det här projektet kommer olika typer av strålning från jet-fotosfären att studeras och jämföras med det vi ser. I praktiken kommer projektet innebära enklare programmering (Pythonskripts) och analys av data från gammastrålningteleskop.



# A4 Elektrisk framdrivning av satelliter som del av rymdsolparasollprojekt

*Handledare: Christer Fuglesang (cfug@kth.se)*

Ett möjligt sätt att motverka en för hög temperaturökning på jorden p.g.a. klimatförändring vore att placera solparasoll mellan solen och jorden, i närheten av den så kallade Lagrangepunkten L1 [1]. De skulle byggas på jorden och skickas upp i låg bana runt jorden. Hur man därifrån tar sig på bästa sätt till L1 är inte helt klart. Solsegling kan vara ett sätt, men troligen vore det bättre att åtminstone delvis använda elektrisk framdrivning (eng.: electrical propulsion) [2]. KEXet går ut på att jämföra effektiviteten av att använda elektrisk framdrivning för att komma ut ur jorden gravitationsfält jämfört med solsegling (som beskrivs i [1]). Hur mycket tyngre blir farkosterna? Tidsåtgång? Ev. andra aspekter.

[1] C. Fuglesang & M. Garcia de Herreros Miciano, Realistic sunshade system at L1 for global temperature control. Acta Astronautica 186 (2021) 269-279

[2] ESA - What is Electric propulsion?

# A5 Experimentella test av den allmänna relativitetsteorin

*Handledare: Tommy Ohlsson (tohlsson@kth.se)*

År 1915 publicerade Albert Einstein sina banbrytande arbeten om den s.k. Relativistiska teorin för gravitation numera känd under namnet "den allmänna relativitetsteorin" (GR). Medan Einsteins teori har en matematisk skönhet och naturlighet, har den också kunnat förklara fakta om naturen som till viss del redan var kända på den tiden och delvis har bekräftats av experiment senare. Uppgift är att studera experimentella fakta och teoretiska argument som övertygade fysiker om att GR är korrekt.

Frågor som bör besvaras är: När kan GR approximeras väl med Newtons klassiska teori för gravitation? Ge exempel där avvikelser är väntade. Teoretiska förutsägelser av sådana avvikelser och bekräftelser av sådana förutsägelser med hjälp av experiment. Klassiska test av GR, som bör diskuteras, inkluderar: Merkurius perihelium-precession, deflektion av ljuset p.g.a. solen, och gravitationell rödförskjutning av ljuset. Teoretiska frågor som bör studeras är: Principer för GR, det relativistiska Kepler-problemet och dess lösning, newtonska gränsen för GR och korrektioner till den.

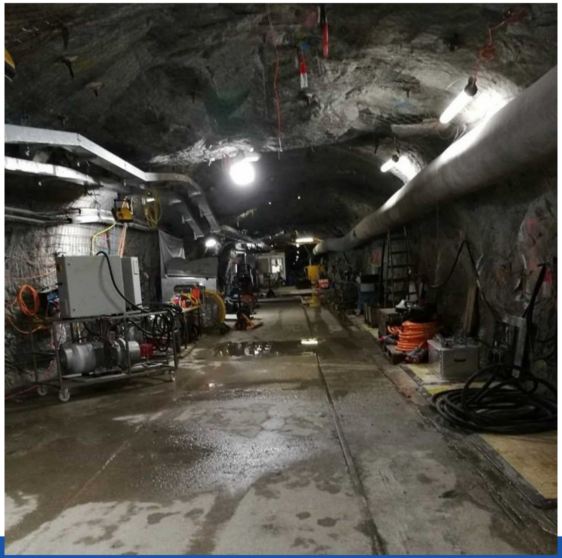
Referenser: T.-P. Cheng, Relativity, Gravitation, and Cosmology. A Basic Introduction, 2nd ed., Oxford (2010), M. Guidry, Modern General Relativity, Cambridge (2019), R.M. Wald, General Relativity, Chicago (1984).

# N1 Development of a detector system which can register the enhancement of radon gas prior to an earthquake

*Supervisor: Ayşe Ataç Nyberg (ayseatac@kth.se)*

Prediction of earthquakes is an unresolved scientific problem which requires cross disciplinary research. The ultimate goal is to develop a reliable, effective warning system with respect to location and magnitude with a time window of 2-3 days. One of the precursor signals which has a potential of giving early warning signals, is also very interesting from the nuclear physics point of view. It has been repeatedly reported that there is an enhancement of radon gas in groundwater and soil prior to an earthquake. Radon ($^{222}$Rn) is a naturally occurring radioactive gas which is part of the uranium decay series. Together with its carrier gases ($CO_2$, $N_2$ etc. ) it can migrate upwards from the deep layers of the crust and their concentration is enhanced during large scale seismic movements.

In this work, you will design a gamma-ray detector system that will measure radioactivity from radon and its daughter products in the ground water. The system will be developed by using the simulation toolkit Geant4 and it will later be tested at the Gran Sasso Underground Nuclear Physics Laboratory in Italy and at the Bedretto Underground Laboratory for Geosciences and Geoenergie in Switzerland. Both laboratories are located in tunnels under the Alps.

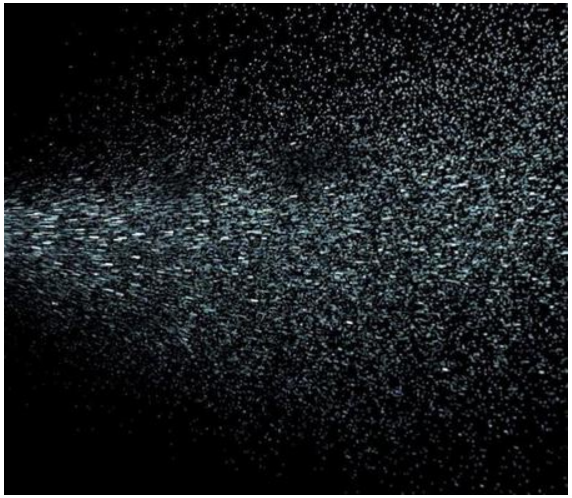


# N2 Modelling of aerosol transport and behavior in a containment of a heavy liquid metal cooled reactor

*Supervisors: Prof. Pavel Kudinov (pkudinov@kth.se), Dr. Dmitry Grishchenko (dmitrygr@kth.se)* from the division of Nuclear Engineering.

**Project description**

Lead Fast Reactor technologies aim to support Europe's pursuit of a sustainable and low-carbon future. The advanced nuclear reactors ALFRED (demonstrator) and MYRRHA (irradiation facility) - both using a liquid metal as a primary coolant - will be essential milestones to foster this objective. One of the safety premises of lead and LBE cooled nuclear reactors is the possibility for retention of fission products in the coolant. Such retention is sensitive to a possible transport of the contaminated coolant in the form of aerosols inside and outside of a reactor containment. The EU project PASCAL aims to address the issue of aerosol transports and supports an experimental and modelling platforms aiming to develop and validate required modelling tools.



The goals of this project is to develop modeling approaches for the assessment of  aerosol generation (in case of leakage from the primary coolant system) and behavior in the containment, including coagulation, transport and deposition.

Approach: The modelling will be carried out using GOTHIC 8.3 containment thermal-hydraulic analysis code and will be aligned with issues addressed in the ongoing EU-PASCAL project.

# N3 Pre and post – test analysis of transients in a large scale thermohydraulic facility HWAT

*Supervisors: Prof. Pavel Kudinov (pkudinov@kth.se), Dr. Dmitry Grishchenko (dmitrygr@kth.se*) from the division of Nuclear Engineering.

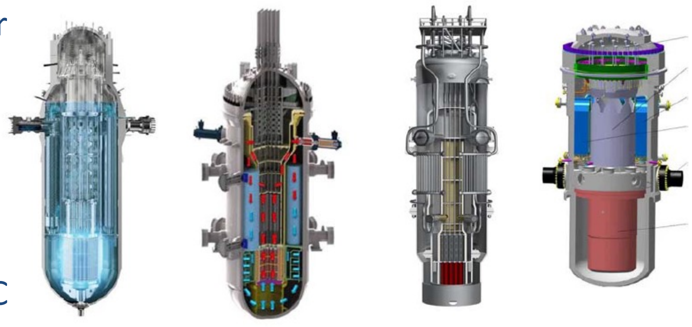
**Project description**

Light Water Small Modular Reactors (LW-SMRs) are the most likely nuclear technology to be deployed in the nearest future. LW-SMRs offer modular design, component shelf availability; factory-based manufacture, improved safety and rely on several decades of experience from conventional light water reactors. The most advanced LW-SMRs that are currently under licensing or construction (e.g., NuScale, CAREM, SMART) are of PWR type with integral design in which the core, the primary loop, the pressurizer, and steam generators are located inside a single pressure vessel and in nominal conditions the primary flow is single phase. PWR type provides single phase flow in nominal conditions in the core (and in steam generators) with large margin to DNB. However, there are several potentially challenging transients that can lead to DNB or CHF in the core. To study the phenomena a new high-pressure experimental loop (HWAT) is under construction at KTH under EU-McSAFER and SSM-CAT projects.

In this work the student will design and carry-out pre-test analysis for simulation transients in the new facility. The goals of this project:

- To develop suggestions for selection of experimental conditions relevant to Small Modular Reactor phenomena and scenarios.
- To assess validity of the TH codes in predicting experimental results from HWAT.

Approach: The modelling will be carried out using TRACE and GOTHIC 8.3 containment thermal-hydraulic analysis codes.



CAREM (Argentina) SMART (Korea) NuScale (USA) F-SMR (France)

# N4 CFD modelling in support of the design of experimental facilities for investigation of flow accelerated corrosion erosion of structural material in liquid metal cooled reactors

*Supervisors: Prof. Pavel Kudinov (pkudinov@kth.se), Dr. Dmitry Grishchenko (dmitrygr@kth.se*) from the division of Nuclear Engineering.

**Project description**

Flow-accelerated corrosion and erosion at high temperatures (FAC/E-HT) is one of the main challenges for design of the critical components of a heavy liquid metal (HLM) cooled fast reactor, e.g. pumps, fuel cladding, core support structures, welding. The FAC/E rate is known to be affected by flow velocity, the Reynolds number, wall shear stress and turbulence level, as well as wall roughness which develops as a result of FAC/E. Unfortunately, data on FAC/E with HLM especially at prototypically high temperatures and controlled/known turbulence conditions is very scarce. A set of experimental facilities is currently under construction at KTH in the framework of SSF-SUNRISE project with the objective to provide experimental data for development and validation of FAC/E modelling for HLM. The aim of this project is to provide analytical support to the design, pre- and post-test analysis of the experiments.

Goals:

- To analyze liquid metal flow in the configurations relevant for separate effect and component test facilities that are currently being designed at NE division in the framework of SUNRISE SSF project (https://www.reactor.sci.kth.se/sunrise).
- To contribute in the optimization of the design and definition of the test conditions.

Approach: CFD codes (ANSYS-CFX) an specialized CFturbo software will be used to

- Select design and assess performance of a pump for a Swedish liquid metal cooled research reactor.
- Select and analyze flow conditions in a separate effect and component (pump) test facilities.

Review available approaches for prediction of flow accelerated corrosion/erosion phenomena, including the effect of turbulence.

# N5 Development of the approach to and analysis of heat extraction from a NPP for coupling with Direct Air Capture of $CO_2$

*Supervisors: Prof. Pavel Kudinov (pkudinov@kth.se), Dr. Dmitry Grishchenko (dmitrygr@kth.se)* from the division of Nuclear Engineering.

Humankind has to urgently find solutions to two major and tightly coupled problems: (i) transition to CO2-free energy and (ii) mitigation of climate change. Both problems are targeted in the UN sustainable development goals and must be achieved by 2030. Four scoping scenarios aiming to limit global temperature rise to 1.5ºC were summarized by the 2015 Intergovernmental Panel on Climate Change. All of the scenarios rely on two- to six-fold increase by 2050 in nuclear energy production and require mass deployment of negative emission technologies, i.e. greenhouse gas capture (GGC). Mass deployment of the GGC technology will need a source of a CO2-free electric power and high-temperature heat. Nuclear energy can provide both.

The goal of this project is to assess feasibility of using heat produced by Nordic NPPs for large scale implementation of direct air capture (DAC) of $CO_2$.

To achieve the goal the following tasks will be pursued:

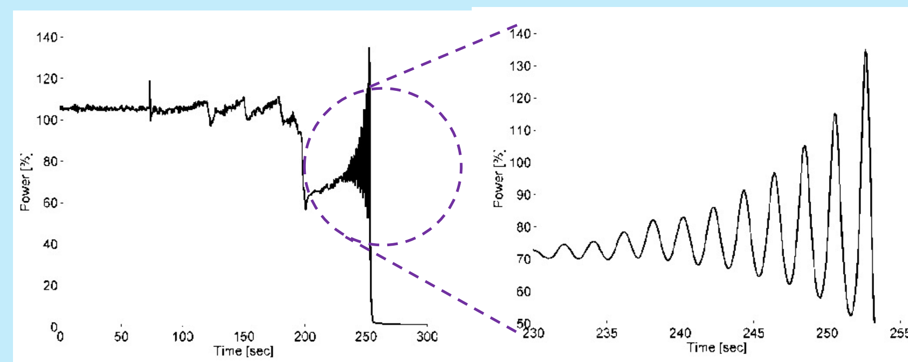
- To review existing DAC technologies and identify those most promising for coupling with a nuclear power plant.
- To assess energy requirements for DAC.
- To review NPP design and identify possibilities for extraction of thermal energy/steam needed for DAC.
- To consider implementation and optimization of different approaches (e.g. use of ejectors, compressors etc.) to extraction of low grade heat from the NPP and coupling it with DAC.

# N6 Predicting Reactor Instability with Machine Learning

*Supervisor: Vasily Arzhanov (arzhanov@kth.se)* Nuclear Engineering division

**Project description**: Boiling Water Reactors are prone to instability due to the nature of the two-phase thermal-hydraulics. An example of an instability event is the transient that occurred in Oskarshamn-2 in 1999. A combination of low-probable events culminated in diverging power oscillations which triggered automatic scram at high power. The power evolution for the event is shown below.

A good indicator of the stability status is the so called decay ratio, DR. When DR > 1, as in this example, the situation is very dangerous.



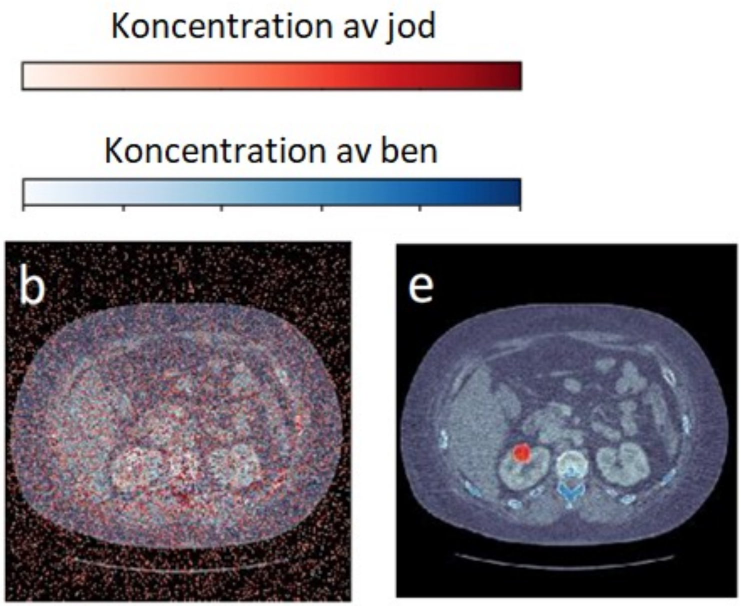

Several steps are planned to complete the project: (a) Find DR numerically with high precision; (b) Search literature for suitable Machine Learning methods; (c) Generate training examples and train the selected Machine Learning methods; (d) Compare the effectiveness of the selected Machine Learning methods as applied to the instability event in Oskarshamn-2.

# X1 Utvärdering av en djupinlärningsbaserad bildrekonstruktionsmetod för fotonräknande datortomografi

*Handledare: Mats Persson (mats.persson@mi.physics.kth.se)*

Vid institutionen för fysik vid KTH har vi utvecklat nästa generations medicinska röntgenutrustning, en spektral datortomograf, som kan utnyttja energiinformationen i strålningen för att ge bättre röntgenbilder. Nu experimenterar vi med nya bildrekonstruktionsmetoder baserade på neurala nätverk som tränas för att räkna ut hur patienten ser ut inuti utifrån rådata.

I det här projektet kommer vi att använda matematiska modeller för bildkvalitet för att genomföra en systematisk utvärdering av en sådan djupinlärningsbaserad bildrekonstruktionsmetod. Projektet ligger vid frontlinjen inom ett mycket aktivt forskningsfält och kan bidra till bättre medicinska diagnoser i framtiden, av en rad sjukdomar såsom stroke, cancer eller Covid-19.



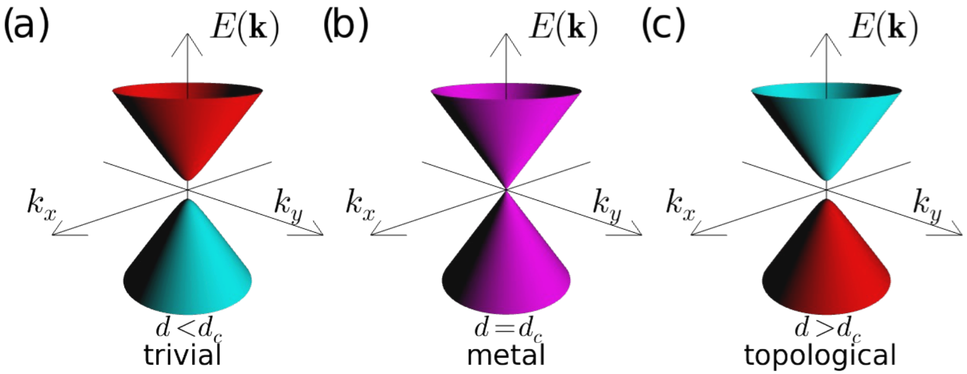

Konventionell rekonstruktion

Djupinlärnings-rekonstruktion

# Q1 Domain wall states in topological quantum matter

*Supervisors: Julia Hannukainen and Jens H Bardarson (bardarson@kth.se)*

In this project we will explore the physics of boundary states in topological insulators. A topological insulator is a material that is insulating in the bulk but has robust metallic surface states. We will explore the connection of these boundary states to the Berry phase of the bulk fermion states by exploring a two dimensional model of a massive Dirac fermion. First we will see how the Dirac fermion is characterised by a topological quantum number, which is the so-called Chern number, which is a certain integral of the Berry phase. This Chern number depends only on the sign of the mass of the Dirac fermion. In a system where this mass can vary in space, one can have a domain wall between a region of positive mass and negative mass. We will study how there are necessarily massless states that appear at this domain wall.
Reference: János K. Asbóth, László Oroszlány, András Pályi, A Short Course on Topological Insulators, https://arxiv.org/abs/1509.02295



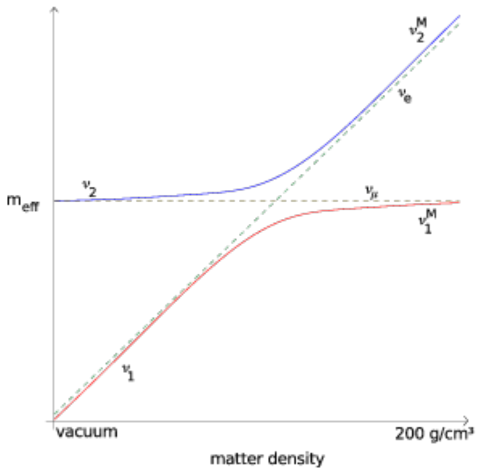
# Q2 Dirac-ekvationen

*Handledare: Tommy Ohlsson*
Studera relativistisk kvantmekanik och undersök speciellt Dirac-ekvationen. Härled denna ekvation för en väteatom eller väteliknande atom samt ta fram dess lösning analytiskt. Diskutera lösningen numeriskt för ett antal exempel och jämför resultaten med experimentella resultat för väteatomer och väteliknande atomer. Diskutera även olika korrektioner till denna lösning.
Referenser: T. Ohlsson, Relativistic Quantum Physics – From Advanced Quan-tum Mechanics to Introductory Quantum Field Theory, Cambridge (2011) och W. Greiner, Relativistic Quantum Mechanics – Wave Equations, 3rd ed., Springer (2000).

# Q3 Mikheyev-Smirnov-Wolfenstein-effekten

*Handledare: Tommy Ohlsson (tohlsson@kth.se)*

Studera fenomenet neutrinooscillationer i materia. Härled den s.k. MSW-effekten och diskutera i vilka experimentella sammanhang som den är väsentlig. Illustrera med några exempel där den är av avgörande betydelse. Undersök speciellt neutrinooscillationer för solneutriner men även för neutriner som propagerar genom jorden.




Referenser:


- M. Blennow and A.Y. Smirnov, Neutrino propagation in matter, 1306.2903
- E.K. Akhmedov, R. Johansson, M. Lindner, T. Ohlsson, and T. Schwetz, Series expansions for three-flavor neutrino oscillation probabilities in matter, hep-ph/0402175
- E.K. Akhmedov, Neutrino physics, hep-ph/0001264
- C.W. Kim and A. Pevsner, Neutrinos in physics and astrophysics, Harwood Academics (1993)
- C. Giunti and C.W. Kim, Fundamentals of neutrino physics and astrophysics, Oxford (2007).

# S1 Fysiken bakom gejsrar

*Handledare: Tommy Ohlsson (tohlsson@kth.se)*

Gejsrar är springkällor som med jämna mellanrum slungar ut hetvatten och ånga, vilka bland annat finns på Island. Studera den bakomliggande fysiken för gejserutbrott i litteraturen och försök att skapa en enkel modell för en gejser med hjälp av kunskaper från fysikens matematiska metoder samt numeriskt med hjälp av t.ex. finita elementmetoder. Använd modellen för en specifik gejser (t.ex. gejsern Strokkur på Island) för att se om den fungerar. Kan modellen beskriva gejserns periodicitet och hur högt vattnet slungas ut?

Referenser:

- M. Brandendourger et al., Physics of a toy geyser, 1603.04925
- A. Nechayev, About the mechanism of geyser eruption, 1204.1560
- H. Kagami, The mathematical model that describes the periodic spouting of a geyser induced by boiling, Proc. of SPIE, 10169, 101692K (2017).
- K.D. O’Hara and E.K. Esawi, GSA Today 23, 4 (2013).
- E.P.S. Eibl et al., Geophys. Res. Lett. 47, e2019GL085266 (2020).
- L. Karlstrom et al., J. Geophys. Res. [Solid Earth] 118, 4048 (2013).
- T.S. Coffey, Diet Coke and Mentos: What is really behind this physical reaction?, Am. J. Phys. 76, 551 (2008).

# S2 Modelling the popularity distribution of chess openings in the AI era


*Supervisor: Chong Qi, (chongq@kth.se)*

In recent years statistical physics tools have been applied in understanding social behaviours as well as decision taking processes including stock investments and board game playing. In 2007 it was found that the frequency of the most common opening moves in chess follow the so-called Zipf's law. In this project we would like to carry out a quantitative analysis on chess opening moves from three sources: human-played chess databases, chess engines, and the recent artificial intelligence (AI) chess programs.
We humans have only explored a tiny portion of all possible opening moves in chess. Computer chess engines were programmed by humans who decide the evaluation system to choose the best one from all legal moves. Ironically, it is becoming more and more common among both the top pro chess players and amateurs to mimic moves from chess engines at the expense of creativity and dynamism. The AI chess program differs fundamentally from traditional chess engines in the sense that it learns strategy by itself through an artificial-intelligence or machine learning technique.

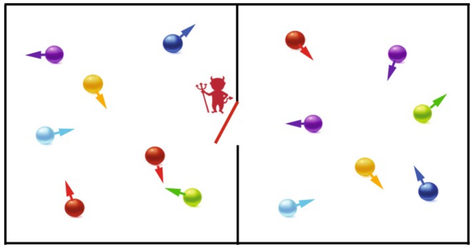
We will investigate how the human behaviours have been influenced by chess engines in the past decade. One question that one may explore from those analysis is how to evaluate the creativity in chess moves and whether chess engines or computers in general, can be creative.

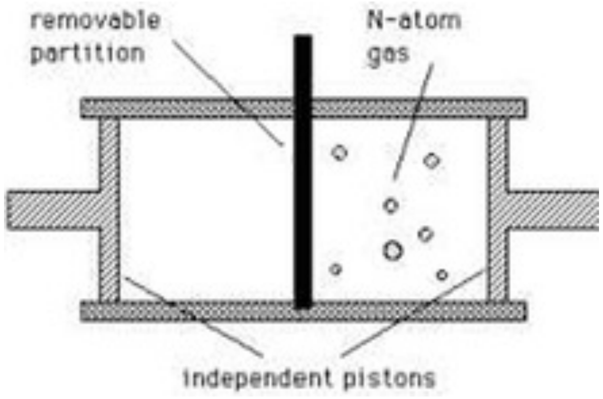
Background information:
In 1997, the chess engine Deep Blue from IBM defeated the then–world champion Garry Kasparov.
In 2017, the artificial intelligence program AlphaZero become the strongest chess program.
In 2020, chess emerged as one of the most popular online games

# S3 Kan man bryta mot termodynamikens andra lag? Simulering av Szilard maskinen

*Handledare: Jack Lidmar (jlidmar@kth.se)*

Termodynamikens andra lag säger att entropin för ett slutet system inte kan minska med tiden. En ekvivalent formulering går ut på att energin i termiska fluktuationer inte kan användas för att utföra arbete. Tittar man noggrannare på detta så gäller dessa dels bara i medel och dels om man bortser från eventuella informations flöden.
I detta projekt ska du använda Monte Carlo simuleringar för att studera hur man kan utvinna arbete ur jämviktsfluktuationer med hjälp av den sk Szilard maskinen.






Referens:
Colloquium: The physics of Maxwell's demon and information
Koji Maruyama, Franco Nori, and Vlatko Vedral
Rev. Mod. Phys. 81, 1 (2009).

# S4 Thermal conductivity from nonequilibrium molecular dynamics simulations

*Supervisor: Anatoly Belonoshko (anatoly@kth.se)*

Thermal conductivity is an important property of material often hard to measure. It can be computed using non-equilibrium molecular dynamics (NEMD). In that method one starts simulation with an introduced temperature gradient and calculates the changes of temperature profile with time. This process can be described by the solution of the equation of heat transfer, and the heat conductivity can be derived from the match of the NEMD temperature profile and the one computed with the heat transfer equation. This method works quite nicely when the NEMD system is large. When the NEMD system is small the process of finding the heat conductivity becomes problematic due to temperature fluctuations and random noise. The error propagation of the raw NEMD data into calculating the heat conductivity is the process that needs to be quantified.