Kandidatexamensarbeten 2024 Fysik

Ämnesansvariga:

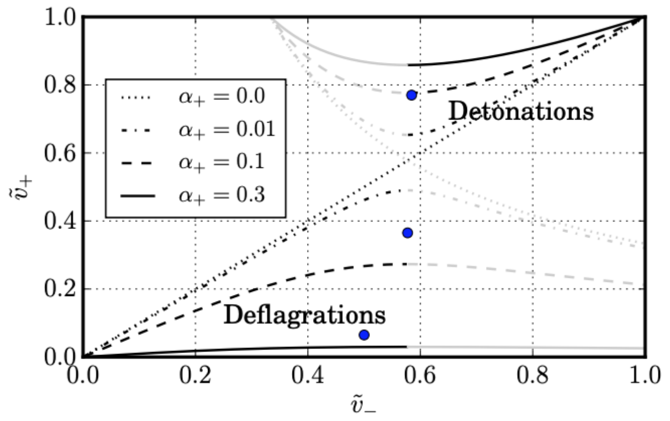
Jack Lidmar
jlidmar@kth.se

Josefin Larsson
josla@kth.se

Thermodynamics of First Order Phase Transitions: From Shock-Waves to Detonations

Supervisor: Marco Merchand Medina <marcomm@kth.se>

The search for a stochastic background of gravitational waves in the millihertz (mHz) frequency range will be a major scientific undertaking in unraveling the physics of the early universe. One potential production mechanism for such a background involves sound waves generated within the primordial plasma following a first-order phase transition. These highly energetic processes are predicted to arise in numerous theories that extend beyond the Standard Model, establishing a deep connection with the fundamental particles described by the Standard Model. Understanding the thermodynamic properties and dynamics of these phase transitions, from the formation of shock waves to the emergence of detonations, can provide significant insights into the conditions of the early universe and guide future experimental searches.
In this project you will learn fundamental concepts on the relativistic theory of hydrodynamic shock-waves and their connection to first order phase transition in cosmology. Basic knowledge of special relativity and thermodynamics is required.



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).

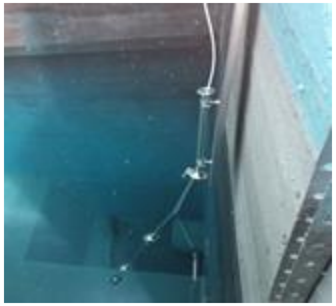
Development of data analysis and methodology for data collection from a detector network designed to measure radon in groundwater prior to an earthquake

Supervisors: Ayşe Ataç Nyberg and Torbjorn Bäck

Forecasting 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 be able to join a multidisciplinary collaboration of scientists working on different aspects of a project called artEmis, coordinated from KTH.
Within artEmis project, a large number of gamma-ray detectors are being produced and used in order to measure radioactivity from radon and its daughter products, in the groundwater. During the first months of 2024, we successfully installed six prototype sensor units in fault zones in wells, springs and tunnels in Italy, Greece and in Switzerland. The prototype units contain gamma-ray detectors as well as PHT sensors (pressure, humidity, temperature, humidity), accelerometers and microphones.

We offer bachelor (KEX) projects for up to three student groups this year, focusing on some of the following tasks (the precise project tasks will be decided after discussion, and will depend on both students interest and of the status of the artEmis project in the Spring of 2025). Possible project task/focus:

- Monitoring and analysis of the data measured by the artEmis sensor units, correlation of the data measured by different sensors in each unit and with available seismic data.
- Development of machine-learning models and tools, including development of graphical user interfaces, for analysis of data.

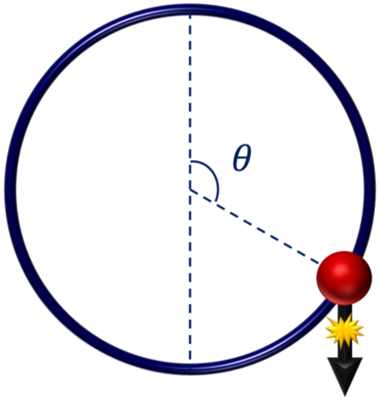


Sensor installations in Gran Sasso Region in Italy, Feb 2024.

For this project, it is valuable of you have some experience in Python programming.

Decoherence effects in quantum kicked rotor

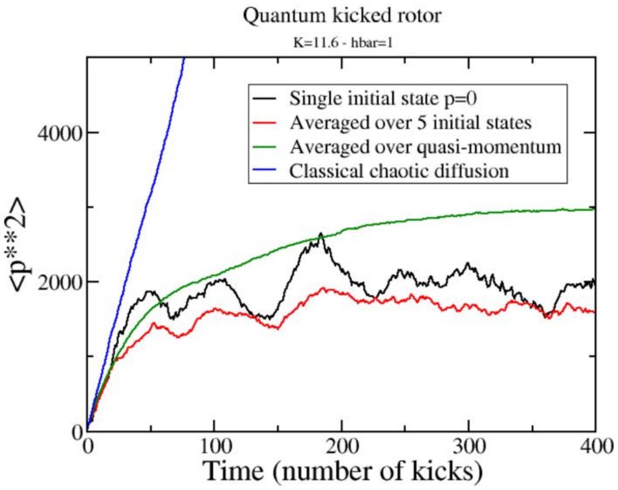
supervisor: Yunxiang Liao (yliao2@kth.se)



The kicked rotor model is an important paradigm for the study of chaos and localization. It can be thought of as a particle moving on a ring with periodic external driving, governed by the Hamiltonian

$$H = \frac{p^2}{2} + K\cos\theta \sum_{n=-\infty}^{\infty} \delta(t-n)$$

where θ and p represent the angular position and angular momentum, respectively.



In the classical regime, the kicked rotor displays chaotic dynamics for strong kick strength K, leading to the diffusive growth of the average value of p^2. In the quantum regime, the kicked rotor exhibits dynamical localization, where the quasienergy eigenstates are localized in momentum space, causing the growth of $\langle p^2 \rangle$ to saturate at long times. Dynamical localization is a quantum interference effect. Interactions with the external environment or with other rotors (the latter being a special case of the former) can destroy quantum coherence, which in turn leads to the breakdown of dynamical localization.

This project aims to investigate the decoherence effects of the environment on various variants of the quantum kicked rotor.

[1] D. Delande. "Kicked rotor and Anderson localization." *Boulder School on Condensed Matter Physics* (2013)
[2] E. Ott, T. M. Antonsen, and J. D. Hanson, Phys. Rev. Lett. 53, 2187 (1984).
[3] S. Fishman, D. R. Grempel, and R. E. Prange, Phys. Rev. Lett. 49, 509 (1982)

Improving the performance of a space-based X-ray telescope using Machine Learning

Supervisors: Mózsi Kiss and Mark Pearce <pearce@kth.se>

The astroparticle physics group in the Physics Department develops X-ray telescopes for the study of high-energy sources of radiation in the universe, such as black-holes and pulsars. The Earth's atmosphere readily absorbs X-rays. Observations are therefore conducted at 40 km altitude with the telescope suspended under an enormous helium-filled balloon, which is launched from the Esrange Space Centre in Northern Sweden. Understanding the response of the telescope to incident X-rays is a key ingredient in ensuring the scientific results are reliable and free from systematic effects.

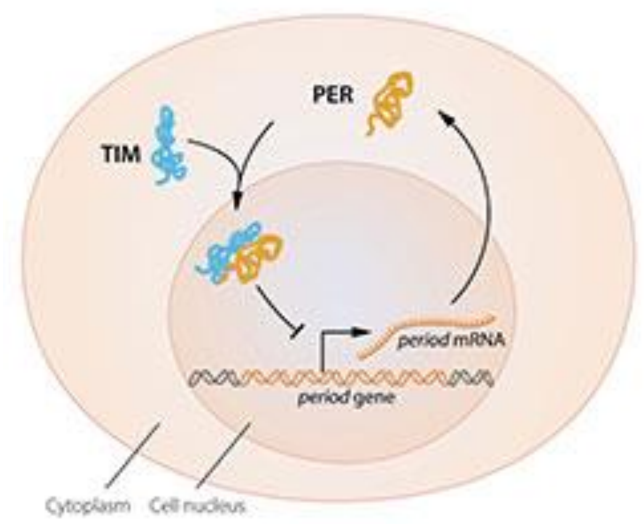
In this project, you will evaluate the potential of Machine Learning (colloquially referred to as Artificial Intelligence) tools to improve understanding of the telescope response.

The project requires the manipulation of large sets of simulated telescope data, and has a focus on coding and data visualisation. The project is aimed at students who are competent programming in Python or C++, and an interest in instrumentation.

Cirkadisk rytm och synkronisering

Handledare: Jack Lidmar (jlidmar@kth.se)

I stort sett alla organismer innehåller någon form av biologisk klocka, och upptäckten av de molekylära mekanismerna som styr denna sk cirkadiska rytm belönades precis med Nobelpriset i fysiologi eller medicin (2017). I detta projekt studeras enkla modeller av gennätverk med återkoppling som ger upphov till oscillationer, t ex den sk represselatorn. Formulera och simulera en matematisk modell av detta och undersök egenskaper såsom stabilitet och synkronisering.



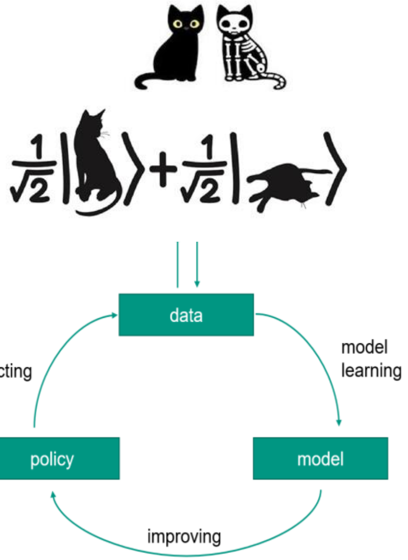
Referens: *A synthetic oscillatory network of transcriptional regulators*, M.B. Elowitz & S. Leibler, Nature **403**, 335-338 (2000).

Solving the Schrödinger equation with neural quantum states

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

Various machine learning algorithms have been applied recently to solve complex quantum systems which otherwise can be difficult to do even by supercomputers. In this project we are interested in applying the Neural Network (or the so-called neural quantum states,(NQS) as introduced recently) to solve quantum many-body problems for atomic and nuclear systems. The study can choose to study one of the following two directions or explore other possibilities:

- Apply NQS to find the energy minimum of the quantum system. In that case we can start by reformulating the Schrödinger equation in variational Monte Carlo or similar approaches.
- Apply neural network to solve PDEs and nonlinear equations. Certain quantum systems can be transformed into a large set of nonlinear equations which we still find it difficult to solve with existing packages in Python and Mathematica.

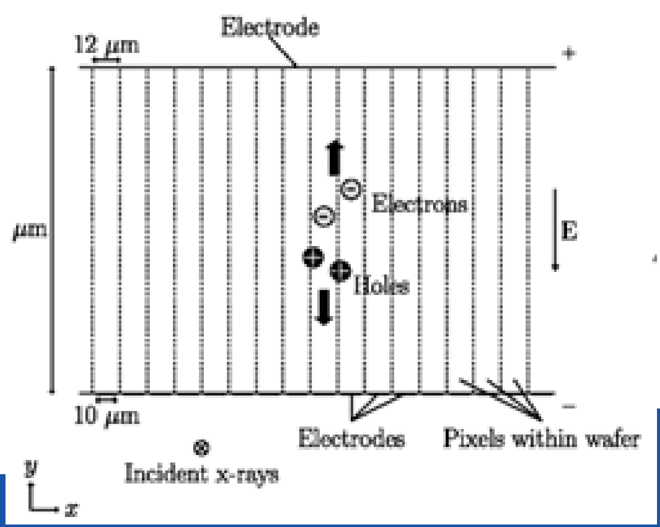


*The physics models will be provided as Python (or Mathematica) codes.

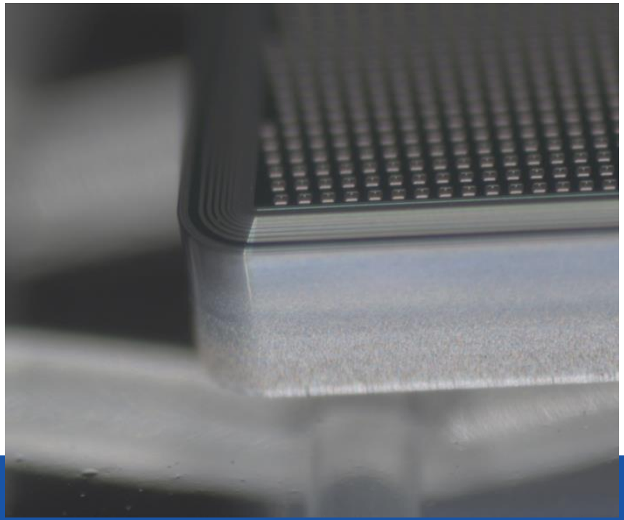
Förbättrade modeller för simulering av halvledardetektorer för medicinska bilder

Handledare: Mats Persson, mats.persson@mi.physics.kth.se

Vid KTH Fysik utvecklar vi halvledarbaserade röntgendetektorer för framtidens medicinska bildgivande system, speciellt datortomografi (skiktröntgen). För att jämföra olika detektorkonfigurationer behöver man detaljerade simuleringsmodeller, men de mjukvarupaket som vi använder för att simulera halvledardetektorer klarar i dagsläget inte av att modellera vissa fysikaliska effekter, som elektrostatiska krafter mellan laddningar som rör sig i materialet eller effekter av att laddning ansamlas i halvledarmaterialet. Projektet går ut på att implementera en simuleringsmodell för laddningstransport i halvledare som tar hänsyn till dessa effekter och utvärdera vilken effekt de har på kvalitén på den uppmätta signalen, för vanliga halvledarmaterial som kisel, kadmiumtellurid och kadmiumzinktellurid. Om projektet är framgångsrikt kan det leda till att vi tar fram en simuleringsmetod som kan komma att bli vanligt använd inom forskningsfältet och ge nya och bättre insikter om hur man kan konstruera bättre teknik för röntgenavbildning och på så sätt hjälpa sjukvården.



C Sundberg et al. Journal of Medical Imaging, Vol. 8, Issue 6, 063501



R Brunskog et al. Journal of Medical Imaging, Vol. 11, Issue 1, 013503

Simulering av medicinsk röntgenavbildning med faskontrast

Handledare: Mats Danielsson, md@mi.physics.kth.se

Medicinsk avbildning med röntgenstrålar används idag för att diagnostisera en lång rad olika sjukdomstillstånd, men den teknik som används idag använder bara en del av den information som finns i röntgenstrålningen. Nästa stora framsteg väntas bli faskontrastavbildning, där man inte bara mäter intensiteten på röntgenstrålningen utan också hur vågornas fas förskjuts. En viktig men ännu obesvarad forskningsfråga är hur många röntgenfotoner som man behöver uppmäta för att kunna uppmäta fasförskjutningen. Finns det en undre gräns, eller försämras prestandan bara gradvis när man sänker stråldosen? Uppgiften blir att utreda detta i en simuleringsstudie, och resultatet av denna utredning kommer att bli indata till utvecklingen av ett system för faskontrastavbildning som vi håller på att utveckla.

Det här projektet ligger vid forskningsfronten inom medicinsk fysik och ger en möjlighet att delta i utvecklingen av en ny bildgivande teknik som kan ge ett nytt fönster in i människokroppen.

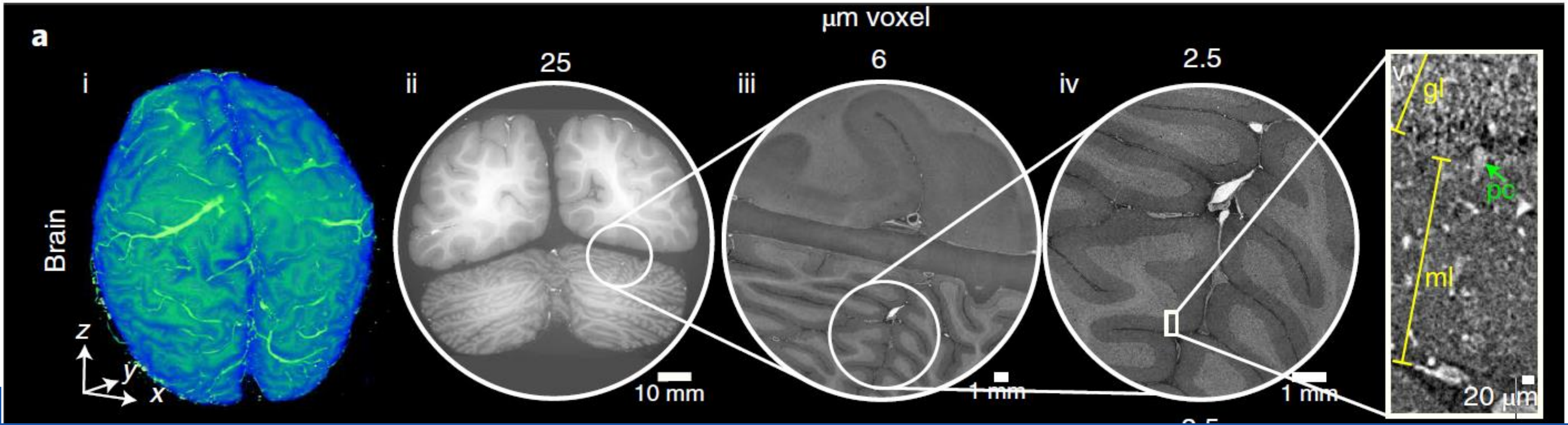


Bild från C. L. Walsh et al. Nature Methods 18, 1532-1541 (2021)

Studier för rymdsolparasoll för global temperaturkontroll

Handledare: Christer Fuglesang, cfug@kth.se

Ett möjligt sätt att motverka en för stor global temperaturökning från utsläpp av växthusgaser vore att placera solparasoll el. dyl. i rymden för att minska solinstrålningen en aning. Detta har studerats på KTH på olika sätt under ett flertal examensarbeten de senaste åren (se lista nedan). Ett ledde till en publicerad artikel där tanken är parasoll i form av solsegel som reflekterar och absorberar solljus [1]. Ett alternativ som skulle kunna leda till att totalt sett mindre massa behöver skickas upp från jorden vore att använda diffraktiva skärmar. Det vill säga att solljuset avleds en aning så att det "missar" jorden. Anledningen till att det kan bli mindre massa då är att kraften från solljustrycket blir mindre och det behövs mindre massa för att balansera med gravitationskraften från solen. Ett tidigt koncept på en diffraktiv lösning presenterades av Angel 2006 [2]. Rent teoretiskt kan man dock tänka sig lösningar där solljustrycket blir ännu mindre, se t.ex. [3]. Till skillnad mot lösningen som presenterades i [1] så är det dock tveksamt om solsegling kan användas för att manövrera i rymden och alternativa transport-och kontrollmetoder torde leda till att uppskjutingsmassan ökar men kanske inte så mycket att det ändå totalt blir en lättare lösning.

KEX-jobb erbjuds som studerar olika frågor för hur ett rymdparasollsystem skulle realiseras. En specifik fråga som föreslås är att beräkna hur mycket extra massa som behövs för bränsle om en parasollösning a lá [3] används.

Referenser:

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

[2] Angel, R., "Feasibility of cooling the Earth with a cloud of small spacecraft near the inner Lagrange Point (L1)", In: Proceedings of The National Academy of Sciences of the USA 103.46 (2006), pp. 17184–17189.

[3] Borgue, O. and Hein, A.M., "A Zero-Radiation Pressure Sunhade for Supporting Climate Change Mitigation", arXiv:2112.13652v3 [physics.space-ph] (visited 25-9-2022)

Hubbard models on small lattices

Supervisor: Edwin Langmann <langmann@kth.se>

Hubbard models are fundamental in condensed matter physics. They describe fermions on a lattice with certain interactions and, despite of the apparent simplicity of the Hamiltonian defining such a model, they are very challenging from a mathematical point of view. In particular, the one-dimensional Hubbard model is exactly solvable by a technique known as Bethe ansatz, and the two-dimensional Hubbard model is famous as proto-type model describing high-temperature superconductors - understanding the latter is one of the outstanding problems in theoretical physics today.

In this project, you learn the mathematical background to these models, and I have several suggestions (suitable for up to 3 different groups) to explore special topics. These special topics include:

P1: Hubbard model on small lattices. If the lattice has N sites, the Hamiltonian defining a Hubbard model is a matrix of size 4^Nx4^N - for small N (like N=2 or 3), this can be diagonalized brute-force on a laptop. I suggest some such models, and to compare exact results with results from approximation method. One important such approximation method is Hartree-Fock theory - a possible project could be to learn about Hartree-Fock theory and to test it for some particular Hubbard models on small lattices.

P2: Study the Hubbard model on a triangle, square, pentagon, hexagon. Use exact diagonalization and/or Hartree-Fock results. (This could be in collaboration with the group doing P1 - I encourage the different groups working on the same project interact and learn together; when coming to writing up the theses, we can decide on which group emphasizes what).

P3: Look into the boson fermion of the Hubbard model on small lattices (I will have to think about to make this more specific to make this to a suitable project; one possibility would be to study Hartree-Fock theory for this, and to test this on small lattices).

To get more background on what this is about, you can check out the Wikipedia page on “Hubbard model” - but this might look much more scary than what the project will be: on a small lattice, one does not need much more than linear algebra and matrix diagonalization to solve such a model.

Orthogonal polynomials and exactly solvable models in quantum mechanics

Supervisor: Edwin Langmann <langmann@kth.se>

Many famous exactly solvable models in quantum mechanics have solutions given by orthogonal polynomials - famous examples include the harmonic oscillator with eigenfunctions given by the Hermite polynomials, or the Pöschl-Teller Hamiltonian related in a similar way to the Jacobi polynomials.

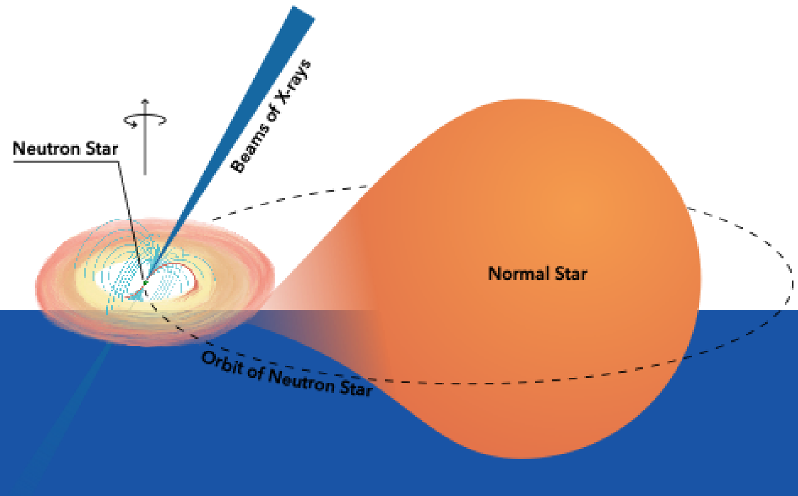
There are known discretized quantum mechanical models related to orthogonal polynomials which have names like Meixner or Hahn polynomials. The project will be about these discrete quantum mechanical models and the beautiful mathematics behind these orthogonal polynomials (which are a special case of Askey-Wilson polynomials). Depending on the interest of the group, this project can go more in a math direction (exploring e.g. the mathematical theory of Askey-Wilson polynomials) or in a physics direction (concentrating more on discrete quantum mechanics) or numerics (testing analytic results numerically).

To get more background you can google some catch words in the text above.

Cosmic Lighthouse: Exploring X-ray Pulsars in Python

Supervisor: Inga Saathoff (saathoff@kth.se)

Massive stars (i.e. stars more massive than about 8 solar masses) end their lives in a cataclysmic event known as a supernova. But the death of the star is not necessarily the end of the story: What is sometimes left after the explosion is a neutron star - a compact object of extraordinary density. Because of the conservation of angular momentum during the supernova explosion, neutron stars are usually fast-spinning, small objects with very strong magnetic fields. They are of great interest because they provide some of the most extreme laboratories in the Universe for extreme physics. Even more interesting is when a neutron star is part of a binary system, orbiting another normal star. In this situation, the neutron star can accrete material from the normal star (for example, if its stellar wind is very strong).
As the material approaches the neutron star, it cannot fall directly onto its surface, but is stopped by the intense magnetic dipole field and redirected towards the magnetic poles of the neutron star. The material therefore reaches the surface at the two magnetic poles, where it releases its gravitational potential energy mainly in the form of X-rays. Since the magnetic axis is generally not aligned with the rotational axis, the X-rays are observed as pulsations from a great distance, similar to the pulses of light seen from a lighthouse. This is called an X-ray pulsar.
In this project, you will learn more about these extreme objects that are X-ray pulsars. You will create a simple toy model of such a cosmic lighthouse in the Python programming language. You will create an intuitive user interface to explore the influence of different parameters (such as the geometry of the neutron star) on the observable pulsations and their properties, and compare your results with real observational data.



Reactivity impact study of core melt relocation in boiling water nuclear reactors

Supervisor: Björn Engström bjorengs@kth.se

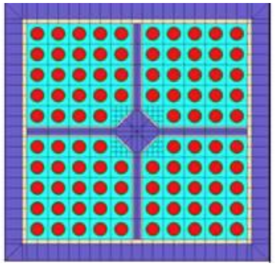


Figure 1: SVEA-96 BWR fuel assembly in Polaris [SCALE 6.3.2 User Manual, Oak Ridge National Laboratory 2024]

Background/Problem formulation:
The risk of recriticality (i.e. uncontrolled nuclear fission) in a situation where a severely damaged boiling water reactor (BWR) core is reflooded with coolant is still poorly understood.
One question concerns the impact of relocated core debris and melt on the intact fuel reactivity. Relocated debris can absorbed neutrons and will decrease the moderator/fuel fraction which will decrease the reactivity but to what extent is not well known. If the reactivity impact of relocated debris and melt in a single fuel assembly is known, the conditions for recriticality can be better understood when analysing coolant injection during a severe accident in BWR.
Project description:
The project will investigate the neutronic parameters such as neutron multiplication factors for different geometries and parameters with the 2D neutronics code Polaris in the SCALE code package. The geometries and parameters calculated with Polaris will be determined by the relocation of core materials predicted by the integral severe accident progression code MELCOR. The obtained neutronics parameters will provide insight on the impact of core degradation on reactivity and can be used in the future for calculations with the core-level codes (e.g. PARCS or SIMULATE) or used directly for simple approximations.
Due to licensing issues, the calculations need to be performed by the Nuclear Safety research group. However, the bachelor student can help with assembling input data, data processing, results analysis, and reporting.

The projects relationship to physics programme:
The project will entail nuclear reactor physics and nuclear reactor engineering.

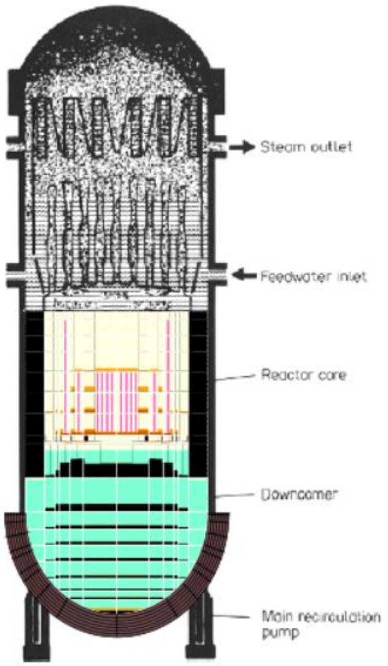


Figure 2: Boiling water reactor meltdown animation in SNAP calculated with MELCOR [Björn Engström 2024]