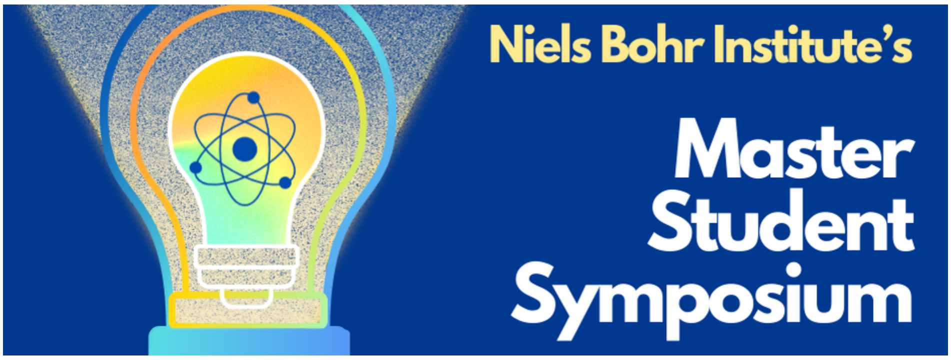
4th Annual Niels Bohr Institute MSc. Student Symposium

Friday 14 March 2025 - Friday 14 March 2025

H.C. Ørsted Institute



Book of Abstracts

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Presentations / 1

Quantifying the Reduction in Carbon Footprint of Physics-Informed Machine Learning in the Pursuit of Greener Artificial Intelligence Practices

Author: Sophia Wilson[1]

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This thesis explores the potential reduction in the carbon footprint of machine learning (ML) models by integrating physical constraints into their design. Traditional ML models rely on large datasets and extensive parameter optimization, leading to significant computational costs and associated carbon dioxide (CO_2) emissions. However, by adopting a physics-informed approach, it may be possible to achieve substantial improvements in efficiency and sustainability during both model development and deployment.

The study uses simulated data governed by equations that describe atmospheric physical processes. These processes are crucial for accurate weather and climate modeling but occur at scales too small to be directly resolved by traditional models. Recent ML-based approaches have been employed to capture these subgrid processes, but they often discard fundamental physical knowledge in favor of purely data-driven methods. Physics-informed ML offers a promising alternative by bridging the gap between conventional physics-based models and modern ML techniques, potentially both increasing performance and reducing environmental impact.

This work provides concrete evidence of the CO_2 emission advantages of physics-informed ML. By comparing the carbon footprint of benchmark models with those incorporating physical constraints, the study quantifies the reduction in emissions. The analysis considers key trade-offs, including dataset size, model performance, computational efficiency, and environmental sustainability.

Ultimately, this thesis contributes to the growing field of sustainable artificial intelligence by demonstrating how integrating physical constraints can lead to more environmentally friendly ML models. The findings offer valuable insights for future ML development and encourage the adoption of energy-efficient practices in the field.

Field of study:

Computational Physics

Supervisor:

Jens Hesselbjerg (NBI) and Raghavendra Selvan (DIKU)

Poster session: Enjoy the posters! / 2

The physics and chemistry of the cold dust and gas around protostars

Author: Anna Manou[1]

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Current studies on star and planet formation suggest that many molecules form on the surfaces on icy grains in molecular clouds from where they are then accreted onto the emerging protoplanetary disk and in some cases sublimate due to the heating by the young star. However, it remains unclear what role the surrounding environment and/or its evolution plays in regulating the chemistry.

The main goal of this work is to extract the physical and chemical parameters of the cold dust and gas around protostars, further exploring the role of the environment in the formation of complex organic molecules. This is achieved using recently obtained spectroscopic data from the ALMA's Compact Array (ACA) provided by the COMPASS ALMA Large Program for a set of protostars for which complex organic molecules are seen. Online catalogues are used to identify the species present in the observations, and comparisons with developed synthetic spectra help calculate physical parameters like the excitation temperature and the upper column density. Also, zeroth and first moment maps are produced to map the intensity and velocity range of each species, identifying the ones with interesting emission features; like the overly extended methanol emission present.

Moving forward, we can implement the same methods described above to other sources for further comparison. Eventually, the same regions will also be observed with JWST targeting the ices, aiming for a revelation of the complex interplay between the gas and ice species.

Field of study:

Astrophysics

Supervisor:

Jes Kristian Jørgensen

Presentations / **3**

Exploring nematic behaviour in systems with polar symmetry.

Author: Niels de Graaf Sousa[None]

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Active matter encompasses a wide range of systems, from bird-flocks to bacterial colonies. Two main formalisms describe these systems based on individual particle symmetries: polar and nematic. Each formalism leads to unique behaviours, the most significant being the appearance of half and full integer topological defects for nematic and polar respectively. However, recent advances in the experimental manipulation of active matter have revealed that particles with purely polar symmetry can create half-integer topological defects, a phenomenon that is not anticipated by the polar equations. To address this discrepancy, we will revisit the nematic formulation and introduce particle self-propulsion. Introducing this symmetry breaking term that changes the particle movement from immobile shakers to self-propelled particles along the fluid flow. Some preliminary results on this effect are: change in the instability onset (Linear Stability Analysis), self-propulsion can regulate the systems order, creates various active turbulence regimes and creates anisotropy in the flow field.

Field of study:

Biophysics

Supervisor:

Amin Doostmohammadi

Poster session: Enjoy the posters! / 4

Machine learning prediction of climate multi-stability

Author: Sune Halkjær[1]

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Due to the co-existence of different stable states (multi-stability), various climate components, such as the Amazon forest, the West African monsoon or the Atlantic meridional overturning circulation (AMOC), may undergo catastrophic regime shifts at varying levels of global warming. As a result, our uncertainty in future greenhouse gas emissions renders possible a variety of storylines with drastically different climatic conditions. Assessing the relative likelihood of each storyline by ensemble simulations with realistic climate models is computationally extremely expensive. This could be alleviated with machine learning (ML) models trained on simulation data. But a fundamental challenge is that future regime shifts likely correspond to dynamical regimes that have not been observed in the training data, whether generated from observations or state-of-the-art climate models. Thus, ML predictions of long-term climate change may be unreliable if they only capture the physics of previously observed climate states.

This be overcome by data-efficient and physics-informed ML methods, such as 'Next-Generation Reservoir Computing' (NG-RC), which has has shown promise in the task for simpler dynamical systems. We test this approach on extensive model output previously generated from the global ocean model 'Veros', which features various co-existing dynamical regimes that may be attained under future climate change, including a collapsed ocean circulation. We use system identification methods, such as regularized orthogonal least squares on Veros simulation data, to design functional forms of the nodes in the output layer. Then, we train the customized NG-RC model is on various sub-sets of simulation data and validate on initial conditions that belong to unobserved dynamical regimes. The resulting autonomous system shows great predictive ability, even across several chaotic timescales and shows promise in prediction of unseen stable dynamical states.

Field of study:

Computational Physics

Supervisor:

Johannes Jakob Lohmann

Presentations / 5

Neutron Star properties through Collider experiments

Author: Andreas Vitsos[1]

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With the advent of multimessenger astronomy, neutron stars are studied through multiple observational methods. These observations, combined with data from collider experiments such as those at the LHC at CERN, help constrain the Equation of State (EoS) of neutron matter. The symmetry energy parameter (Lsym) in the EoS is of great interest due to its connection with the neutron skin thickness of heavy nuclei. The rising field of nuclear structure, -including neutron skin properties- in collider physics has emerged to improve the understanding of the initial conditions in heavy-ion collisions.

Neutron-rich and spherically symmetric nuclei such as ^{48}Ca and ^{208}Pb serve as ideal testbeds for investigating nuclear structure effects and their implications for astrophysical systems. Recent neutron skin measurements from the CREX and PREX-II experiments have revealed a significant discrepancy in the extracted Lsym values for ^{48}Ca and ^{208}Pb, respectively, leading to ongoing discussions about nuclear structure and the EoS. We aim to motivate the study of the neutron skin of ^{48}Ca in collider experiments by assessing its sensitivity to various observables.

Field of study:

Astrophysics

Supervisor:

You Zhou

Poster session: Enjoy the posters! / 6

Developing methods for measureing clumped oxygen

Author: Esben Skovhus Ditlefsen[1]

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Oxygen trapped in ice cores provides information about past climate. This research has largely been concerned with single substituded oxygen, where one of the two oxygen atoms is substituted for an either O-17 or O-18. Much rarer and harder to measure is clumped oxygen, where both atoms are of rare isotopes. Clumped oxygen has the potential to provide information about the upper atmosphere in Earth's past.
As part of the Green2Ice project, two new mass spectrometers have been acquired. One of these is set to become the third in the world capable of measuring clumped oxygen from ice cores. As long as isobaric interference is taken care of, we observed very stable measurements under most conditions boding well for ice core measurements to follow.

Field of study:

Earth & Climate Physics

Supervisor:

Thomas Blunier and Michael Döring

Poster session: Enjoy the posters! / 7

Searching for axions in the gamma-ray sky

Author: Rikke Stougaard Klausen[1]

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Extreme astrophysical environments may produce axion-like particles (ALPs), whose interactions could leave observable imprints on astronomical spectra. If they exist, ALPs may be a viable candidate for dark matter. In this project, we search for axion-induced spectral features in gamma-ray observations of active galactic nuclei (AGNs) that are aligned with galaxy clusters along the line of sight. We assess the impact of AGN variability on spectral signatures and perform a stacked analysis of 29 AGN-cluster pairs. Our goal is to place competitive constraints on ALP parameters. While our results are still preliminary, they appear promising.

Field of study:

Quantum Physics

Supervisor:

Oleg Ruchayskiy

Presentations / 8

Effects of non-linear excitation on the propagation of light

Author: Deniz Adigüzel[None]

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With the increasing number of nuclear-resonant photons per pulse at x-ray free electron lasers (XFELs), achieving higher excitation levels experimentally becomes feasible. This development makes it particularly compelling to investigate light propagation and dynamics beyond the low-excitation regime (LER) and around population inversion. Thus, in my thesis, we examined the time response of resonant nuclear scattering of x-rays beyond the LER. In the LER, it is possible to obtain an analytical solution for light propagation, which becomes not possible beyond this regime. To study dynamics beyond the LER, we employ numerical methods to analyze propagation effects and nuclear dynamics. We implement the method of lines (MOL) to solve the Maxwell-Bloch equations.

In this talk, I would like to present the results of my thesis. Here we discovered interesting phenomena, such as time shifts in the minima of the observed coherently scattered light intensity and transitions around population inversions. We proposed an experimental signature to detect nonlinear excitations by calculating the relative time shifts as a function of target thickness. Finally, we analyze our model in the non-decaying limit ($\gamma = 0$) and find good agreement with the results from Burnham and Chiao [BC69], concluding that spontaneous decay plays a major role in the creation of transitions around population inversions.

[BC69] BURNHAM, DAVID C. and CHIAO, RAYMOND Y., “Coherent Resonance Fluorescence Excited by Short Light Pulses”. In: physical review 188.2 (1969)

Field of study:

Quantum Physics

Supervisor:

Jörg Evers

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Gravitational waves lensing by the strong field of a black hole

Authors: Conor Dyson[1]; Jaime Redondo-Yuste[1]; Juno Chan[1]; Luka Vujeva[1]; Matilde Garcia[1]

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The first detection of gravitational waves (GWs) in 2015 opened the door to GW physics, which has allowed us to test Gravity with unprecedented precision.

When emitted by a source, usually a merging binary of compact objects such as black holes (BHs), gravitational waves propagate moslty unaltered through the cosmos. However, if they encounter objects in their path that are massive/compact enough, those will act as cosmic lenses, to affecting their properties. Lensing offers a unique probe of both the large-scale structure of the Universe and the fundamental properties of GW propagation.

This project studies the case in which GWs are affected by wave optics effects due to the fact that their wavelength is comparable to the size of the lens. While this regime has been well studied in the Newtonian approximation, the role of strong gravitational
fields remains largely unexplored. This is particularly relevant for lensing by intermediate and supermassive BHs, which can occur near active galactic nuclei or in compact triple systems. In this work, we analyze the lensing of GWs by a non-rotating BH considering a strong field and compare our results to the Newtonian point-mass approximation.

Field of study:

Astrophysics

Supervisor:

Jose Maria Ezquiaga

Poster session: Enjoy the posters! / 10

Decrypting AGN Spectra

Author: Liam de Búrca[1]

[1] *University of Copenhagen*

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(Presentation and/or progress poster)

I am developing software to decrypt the complex UV-optical spectra of the gaseous region surrounding accreting supermassive black holes (SMBHs), such that we may advance our understanding of central SMBHs further. Emission from these regions is cryptic at best. Due to the highly energetic environment, physical gas components which contribute to the UV-optical spectrum move at high speeds, causing severe emission line blending. It is therefore necessary to investigate how these complex spectra may be decomposed using techniques which have both physical and statistical grounds, while also ensuring that the software is fast enough to compete with its other well-established counterparts. Although the resultant code has many moving parts, relying on even more statistical tests, the poster/talk will describe the overall approach to tackling a central problem which after 60 years has not been properly addressed.

Field of study:

Astrophysics

Supervisor:

Marianne Vestergaard

Presentations / 11

Diatoms - A novel sea-ice proxy

Author: Johanna-Sophia Köberl[None]

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The Climate Crisis is one of the major challenges facing humanity today. To understand and predict how the Earth's climate will respond to ongoing anthropogenic forcing, it is essential to first examine the dynamics of the climate system and its past variability. Ice sheets covering Greenland and Antarctica serve as crucial archives of past climate conditions, preserving proxies for temperature, precipitation, and, particularly relevant to this study, sea ice variability.
Sea ice plays a fundamental role in the Earth's climate system, influencing heat exchange between the ocean and atmosphere and affecting the planet's albedo. These processes contribute to Arctic Amplification, where warming occurs more rapidly in the Arctic than in other regions. Furthermore, sea ice extent has been linked to potential climate tipping points, underscoring the importance of reconstructing its past variability. Ice cores provide high temporal-resolution climate records, making them valuable for investigating sea ice changes.
Several sea-ice proxies have been proposed, each with unique advantages and limitations.
Bromine enrichment (Br) and Methanesulphonic Acid (MSA) are widely used, with Br particularly effective for tracking first-year sea ice. A more recent approach involves utilizing diatoms—unicellular algae typically found in aquatic environments—as potential proxies for sea ice variability. Diatoms can be transported from the upper ocean layers to the ice sheets and preserved in the ice matrix, suggesting their potential to serve as indicators not only of sea ice extent but also of past wind strength.
This study focuses on cataloging diatoms found in Greenland ice cores and investigating their origins —whether from freshwater or seawater sources—to assess their suitability as a climate proxy. Future analysis will examine whether seasonal patterns in diatom abundance correspond to environmental changes, potentially providing new insights into past climate dynamics. To better understand the transport mechanisms of diatoms, HYSPLIT backtrajectory models will be used to trace air mass movements above the deposition sites, allowing for an analysis of how diatom records vary based on their source regions. To further establish the reliability of this method, comparisons will be made with well-established sea-ice proxies, such as bromine enrichment (Br) and methanesulphonic acid (MSA).

Field of study:

Earth & Climate Physics

Supervisor:

Helle Astrid Kjær

Poster session: Enjoy the posters! / 12

Understanding Denmark's Changing Precipitation Through Explainable Machine Learning

Author: Jonathan Ortved Melcher[1]

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Precipitation in Denmark arises from different mechanisms across seasons. In winter, large-scale dynamics driven by the North Atlantic storm track dominate, while summer precipitation involves large-scale systems and local convective processes. Current climate models predict changes in these patterns, but since 2000, Denmark has experienced precipitation exceeding model predictions. Suggesting a gap in our understanding.

The North Atlantic Oscillation (NAO), characterized by pressure differences between Iceland and the Azores, represents the dominant mode of atmospheric variability in the North Atlantic. While traditional analysis shows its strong influence on European precipitation patterns, particularly in winter, its signal appears muted in the normalized CMIP6 data used for this study.

Using Feed-Forward Neural Networks analyzed with Layerwise Relevance Propagation (LRP), my research investigates which atmospheric patterns drive precipitation anomalies. The analysis reveals distinct seasonal behaviours in the model's predictions. The LRP analysis shows that local pressure patterns are important predictors across seasons. However, contrary to traditional understanding, the NAO pressure patterns are not prominently used by the neural network in either winter or summer predictions. For summer precipitation, the model additionally identifies connections to local temperature variations, suggesting different driving mechanisms between seasons. These findings highlight the potential and current limitations of using explainable machine learning to understand precipitation patterns.

My thesis demonstrates the potential and limitations of explainable ML methods in climate science while highlighting gaps in our understanding of precipitation drivers in a changing climate. These findings suggest we need to dig deeper into explainable machine learning to use it for precipitation analysis.

Field of study:

Earth & Climate Physics

Supervisor:

Jens Hesselbjerg Christensen

Poster session: Enjoy the posters! / 13

Extending Prometheus: an Open Source Neutrino Detector Simulation Framework

Author: Jack Parkinson[1]

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Open source simulation frameworks are highly valuable in experimental particle physics, enabling collaborative data simulations shared among different research groups. This thesis extends Prometheus, an open source framework created to provide unified simulation capabilities for all active and proposed gigaton neutrino telescopes: IceCube at the South Pole, KM3NeT in the Mediterranean Sea, Baikal-GVD in Lake Baikal, TRIDENT in the South China Sea, and P-ONE in the Pacific Ocean. The work of this thesis improves upon the initial implementation of Prometheus and adds simulation capability to lower-energy neutrino events.

Specific contributions of this thesis include: implementation of low-energy neutrino event generation, implementation of multi-PMT (photomultiplier tube) optical modules, improvements on photon light yield from muons, and more. This modified Prometheus framework can generate simulated datasets to support machine learning algorithms for tasks such as neutrino energy and angle reconstruction, aiding in physics analysis of active and proposed gigaton neutrino telescopes.

Field of study:

Computational Physics

Supervisor:

Jason Koskinen

Poster session: Enjoy the posters! / 14

Neutrinos in collapsars

Author: Julien COMBEL[None]

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Collapsing massive stars are rich in neutrinos.
Neutrinos are elementary particles with exciting features. The goal is to predict their evolution when travelling through very dense matter and what flavor percentages we should get on Earth.

Field of study:

Quantum Physics

Supervisor:

Irène Tamborra

Poster session: Enjoy the posters! / 15

Probing the Ionization and Kinematics of AGN Broad-Line Regions: An Advanced Cloudy Photoionization Study

Author: Ivan Kanev[None]

Corresponding Author: isk@science.ku.dk

Active Galactic Nuclei (AGNs) are among the most luminous objects in the universe, powered by accretion onto supermassive black holes. The broad-line region (BLR), located within 5–30 light days of the black hole, produces strong emission lines that probe the ionization and kinematics of AGN gas. This project utilizes the Cloudy photoionization code to model BLR emission, incorporating new spectral energy distributions (SEDs) and additional ionic species beyond Hα, Hβ, C IV, and C III]. By varying the hydrogen density and ionizing photon flux, we explore how these parameters shape line intensities, equivalent widths, and the transmitted continuum. The results will help constrain BLR physical conditions in typical and atypical AGNs, providing new insights into AGN structure and evolution.

Field of study:

Astrophysics

Supervisor:

Marianne Vestergaard

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Construction of Fault Tolerant Interfaces for Topological Quantum Error Correcting Codes

Author: Max Emil K.S. Sondergaard[1]

[1] *University of Copenhagen*

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In this work we consider novel constructions for fault tolerant encoding and decoding interfaces in the context of channel codes that serve to protect quantum information being sent between a sender and receiver under the presence of general quantum noise. These encoding and decoding interfaces serve as the transitions between the physical quantum input output information of the system and the logical encoding of it in through a quantum error correcting code. We in particular consider low-overhead primarily measurement based encoding and decoding interfaces in the context of topological codes, specifically surface codes and color codes, due to their low weight generators, planar layout and respectable error correction performance. In the work we evaluate the performance of the interfaces under semi-realistic noise models through home-made stabilizer simulations and consider their theoretical error bounds. Comparisons with prior concatenation and code growing schemes are also to be made.

Field of study:

Quantum Physics

Supervisor:

Matthias Christandl, Ashutosh Goswami

Poster session: Enjoy the posters! / 17

Calibration of IceCube detectors

Author: Simon Ørgaard[1]

[1] *Copenhagen University, physics*

Corresponding Author: jxt726@alumni.ku.dk

This project aims to calibrate the Digital Optical Modules (DOMs) in the IceCube Neutrino Observatory using minimum ionizing muons. By analyzing simulated muon events in Monte Carlo data, we hope to determine the relative efficiency of which the DOMs have been simulated with. DOM efficiency is currently the third largest systematic uncertainty in IceCube, directly impacting event reconstruction and flux measurements. Reducing this uncertainty improves the accuracy of neutrino detection and enhances the detector's sensitivity. The results will contribute to more precise astrophysical neutrino measurements and support future IceCube upgrades.

Field of study:

Astrophysics

Supervisor:

Jason Koskinen

Poster session: Enjoy the posters! / 18

Probing Collective States of Ultracold Atoms via Cavity-Enhanced Interaction

Author: giulia campagna[None]

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In quantum information science, encoding information in atomic states and reading it through light is essential for building quantum networks. Enhancing light-matter interaction is crucial for improving the efficiency of such processes, and optical cavities have emerged as a powerful tool in this regard. This project experimentally investigates the feasibility of measuring a collective state of a lattice of ultracold cesium atoms using cavity-enhanced off-resonant dispersive interactions.

Field of study:

Quantum Physics

Supervisor:

Eugene Polzik

Poster session: Enjoy the posters! / 19

Sustaining galaxy gas turbulence by supernova feedback in dwarf galaxies

Author: Lauri Sassali[None]

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This master's thesis investigates the role of supernova (SN) feedback in driving turbulence within the interstellar medium (ISM) of galaxies, a key factor in galaxy evolution. While SN feedback is considered to be one of the primary drivers of ISM turbulence, its efficiency across star-forming galaxies remains uncertain. This study focuses on dwarf galaxies in the local Universe, aiming to determine the efficiency of SN energy input needed to sustain turbulence and how this varies with given galaxy properties. Given the low star formation rates and slow energy dissipation in dwarf galaxies, the research will provide crucial insights into SN-driven turbulence. The methodology involves hierarchical Bayesian modeling of archival observational data from the LITTLE THINGS survey and GALEX, comparing results with previous studies of spiral galaxies. The findings are expected to refine theoretical models and improve sub-grid simulations of SN feedback in galaxy evolution.

Field of study:

Astrophysics

Supervisor:

Cecilia Bacchini, Aku venhola

Poster session: Enjoy the posters! / 20

Ultra-high-energy neutrinos to look for super-heavy dark matter inside Earth

Author: Johannes Voss Jacobsen[None]

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As the Earth travels across the Milky Way, it passes through the galactic halo of dark matter particles. Occasionally a dark matter particle could interact with the contents of the earth, scattering it to a lower energy, which can lead to it becoming gravitationally trapped inside the Earth. If these dark matter particles are self-annihilating, or decay, one possible final state product will be neutrinos, which would lead to a flux of neutrinos at the surface of the earth, coming from dark matter, thus enabling indirect dark matter detection. The work focuses on the specific case of super-heavy dark matter in the mass range 1e7 GeV to 1e11 GeV, and explores the possibility of detecting ultra-high-energy neutrinos in the planned IceCube-Gen2 detector, in the hopes that data in the next 10–15 years can either discover or set new limits on dark matter.

Field of study:

Astrophysics

Supervisor:

Mauricio Bustamante

Poster session: Enjoy the posters! / 21

Angular reconstruction of high energy neutrinos in IceCube using machine learning

Author: Luc Voorend[None]

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The IceCube Neutrino Observatory, located at the South Pole, is a cutting-edge telescope designed to detect neutrinos, including high-energy (HE) cosmic neutrinos. Strong evidence links these HE neutrinos to astrophysical sources such as active galactic nuclei (AGNs), blazars, and tidal disruption events (TDEs). Current reconstruction algorithms achieve an angular resolution of approximately 0.5 degrees for HE neutrino events. To enhance the identification of HE neutrino sources, this work explores the use of machine learning to improve event reconstruction methods, aiming to refine angular resolution and bolster future astrophysical discoveries.

This presentation will provide an overview of the IceCube detector and its data, highlighting the potential of machine learning in neutrino physics while also addressing the challenges of applying these techniques to real-world data. A particular focus will be placed on the transformer architecture and its application to event reconstruction. The presentation will conclude with preliminary results and insights from ongoing work.

Field of study:

Physics of Complex Systems

Supervisor:

Troels Petersen

Poster session: Enjoy the posters! / 22

Photometric Tomography of the Intergalactic Medium at the Reionization Epoch

Author: Omar Ahmad Rashdan[1]

[1] *NBI*

Corresponding Author: frm511@alumni.ku.dk

The study of the intergalactic medium (IGM) and its interaction with light from distant galaxies provides crucial insights into the evolution of the universe. In this project, I will apply a technique called "photometric intergalactic medium (IGM) tomography" to reconstruct a map of the large-scale structure of the IGM in the early Universe using a publicly available photometric catalogue and data from the HSC and Subaru telescopes, and with the use of the COSMOS2020.

With this, I develop a spectral energy distribution (SED) fitting tool, using Markov Chain Monte Carlo (MCMC), to measure the IGM transmission along a sample of photometric background galaxies with Lyman α as a tracer of the IGM trasmission, which I will use to make a map of the IGM at the Epoch of Reionization (EoR).

This will firstly be done with a simple power-law to reconstruct the SED of the background galaxies, where the model will be characterized by two parameters, the UV magnitude, and the UV slope, to describe the SEDs of the galaxies. This model will then be improved upon with a more sophisticated SED model based on the BPASS (Binary Population and Spectral Synthesis) model, which accounts for contributions of binary stars and various stellar populations to the SED. This model will be characterized by parameters such as the star-formation rate, dust attenuation, metallicity, and cluster ages.

Field of study:

Astrophysics

Supervisor:

Koki Kakiichi

Presentations / 23

Modelling bursty star formation in high redshift galaxies

Author: Elie Cueto[1]

[1] *University of Copenhagen, Niels Bohr Institute*

Corresponding Author: vdm981@alumni.ku.dk

The James Webb Space Telescope (JWST) has uncovered an unexpectedly high abundance of ultraviolet-bright galaxies early in the Universe, at redshifts beyond 10. Various explanations have been proposed, including bursty star formation, a top-heavy initial mass function (IMF) or a higher star formation efficiency. However, to date we lack physical models or simulations that has explored the interplay of the underlying processes driving the luminosities of these UV_bright, early galaxies.

My project aims to bridge this gap by advancing our modelling of star formation in semi-analytic galaxy evolution models. To this end, I have built a model that uses the physical picture of stars forming in clouds, along with other galaxy evolution processes like supernova feedback, growth by accretion of gas and dark matter from the intergalactic medium, and metal enrichment from dying stars, to model bursty star formation in galaxies in the early Universe. In this model, molecular clouds form sequentially from the galaxy's available gas, and the stellar initial mass function and star formation efficiency depends on the cloud's properties in a way that accounts for stellar feedback mechanisms on the cloud. This allows us to self-consistently explore the interplay of various these various physical processes, and their effects on the luminosities of galaxies.

In this talk I will present my galaxy evolution model and how it simulates bursty star formation with molecular clouds. I will discuss how burstier star formation and a more top-heavy IMF affects the star forming behaviour and luminosities of galaxies, and how this may help explain the observed abundance of bright galaxies in the early Universe.

Field of study:

Astrophysics

Supervisor:

Anne Hutter

Poster session: Enjoy the posters! / 24

Schwarzschild Modelling of the barred galaxy NGC 3783

Author: Freja Amalie Nørby[1]

[1] *NBI Masters student at DARK*

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The Schwarzschild orbit-superposition method, developed for modeling galaxy dynamics, uses a combination of stellar orbits to represent the gravitational potential of a galaxy's center. This technique enables us to estimate the mass of the supermassive black hole (SMBH) residing in the galactic nucleus. Measuring the SMBH mass is crucial for understanding the growth and evolution of supermassive black holes and their role in galaxy formation. In this part of my thesis, I am working on using integral field unit (IFU) kinematics to construct a Schwarzschild model of NGC 3783's center and estimate the mass of its SMBH. NGC 3783 is a barred spiral galaxy, and the presence of this bar structure complicates the morphology and kinematics. Excluding bar structures from dynamical models can lead to biased SMBH mass estimates, and so we must adjust the Schwarzschild method to account for the bar, for which I will use the AGAMA: action-based galaxy modelling architecture developed by E. Vasiliev. This work is currently in progress.

Field of study:

Astrophysics

Supervisor:

Marianne Vestergaard

Poster session: Enjoy the posters! / 25

Effects of Dark Matter on Quasinormal Modes and Tails of Black Holes

Author: Qassim Hasan Ali Alnasheet[None]

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In 1915, Einstein formulated the general theory of relativity, which describes how massive objects bend and curve the fabric of spacetime. One of the main predictions of general relativity is the existence of black holes, which are dense regions of spacetime in which not even light can escape. Several detections and observations confirm the existence of black holes, including the trajectory of stars in the center of the Milky Way galaxy, the observation by the Event Horizon Telescope, and the direct detection of gravitational waves released from the merger of binary black holes. These gravitational wave detections were made possible through the simulations conducted in numerical

relativity. However, recently it has been discovered that 95 percent of the energy in the universe is dominated by dark energy and dark matter, and in my thesis, I study the possible effects dark matter can have on the emission of gravitational waves. These effects are explored by solving the Regge-Wheeler equation in a Schwarzschild background with a dark matter halo. The results show that the dominant effect occurs when the compactness of the halo is around $\mathcal{C} = 0.1$.

Field of study:

Astrophysics

Supervisor:

Vitor Cardoso

Poster session: Enjoy the posters! / 26

A multi-filter exploration of the galaxy size-wavelength relation

Author: Maya Merchant[None]

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The James Webb Space Telescope provides unprecedented access to galaxies at a broad range of redshifts observed in a variety of filters, which correspond to different wavelengths of observation. Due to the extraordinary volume of accessible and distinct filters, we are able to see how physical information drastically changes based on the differences in galaxy emission captured at different wavelengths. This introduces a free parameter, wavelength, to add to an analysis of the notable galaxy size-mass relation which describes the correlation between mass and structure of a galaxy over time and provides insight into the potential environmental effects driving mass evolution. The objective of this work is to further the understanding of galaxy evolution through expanding the size-wavelength relation to a generalized relationship for any redshift and at any wavelength of observation.

Field of study:

Astrophysics

Supervisor:

Georgios Magdis

Poster session: Enjoy the posters! / 27

Neutrino Flavour Classification on High-Energy IceCube Events Using a Transformer Model

Author: Cyan Yong Ho Jo[1]

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The IceCube Neutrino Observatory at the South Pole is designed to detect neutrinos originating from astrophysical sources such as Active Galactic Nuclei (AGN), supernovae (SN), and the Sun. The detector consists of 86 strings, each equipped with multiple Digital Optical Modules (DOMs) containing photomultiplier tubes (PMTs). These PMTs detect Cherenkov light produced by neutrino interactions in the ice.

The data from numerous detected events can be used to train neural network-based machine learning models such as Transformers or Graph Neural Networks. As different neutrino flavours exhibit distinct signal morphologies, geometric information plays a crucial role in providing context to the model. This project employs a Transformer, which is known for its effectiveness in analysing large-scale data, to investigate whether the model can identify patterns in simulated high-energy IceCube events.

However, Transformers are computationally demanding due to their self-attention mechanism, which scales quadratically with the input sequence length. To address this, this project adopts a data reduction approach to enhance computational efficiency.

Additionally, the dataset contains not only neutrinos but also other particles such as muons, which can mimic neutrino interactions. Therefore, data cleaning and proper event selection are essential steps in the workflow.

Field of study:

Computational Physics

Supervisor:

Troels Christian Petersen

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Gravitational waves lensing by the strong field of a black hole

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Effects of non-linear excitation on the propagation of light

Author: Deniz Adigüzel[None]

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Exploring nematic behaviour in systems with polar symmetry

Author: Niels de Graaf Sousa[None]

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Quantifying the Reduction in Carbon Footprint of Physics-Informed Machine Learning in the Pursuit of Greener Artificial Intelligence Practices

Author: Sophia Wilson[1]

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Construction of Fault Tolerant Interfaces for Topological Quantum Error Correcting Codes

Author: Max Emil K.S. Sondergaard[1]

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Neutron Star properties through Collider experiments

Author: Andreas Vitsos[1]

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Diatoms - A novel sea-ice proxy

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Modelling bursty star formation in high redshift galaxies

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