Projects 2025/2026

(last revision September 2025)

Prof. Dag W. Breiby

All the projects outlined here can be tailored to 15 – 60 ECTS.

The suggested projects are closely linked to on-going research projects in the X-ray Physics Group, ensuring that the MSc students will be part of an active and stimulating research environment with PhD students, postdocs and international collaboration.

Note: We further offer a range of other projects not described here – united by experimental physics, advanced microscopy techniques and computer modelling including artificial intelligence.

We are looking for candidates who –

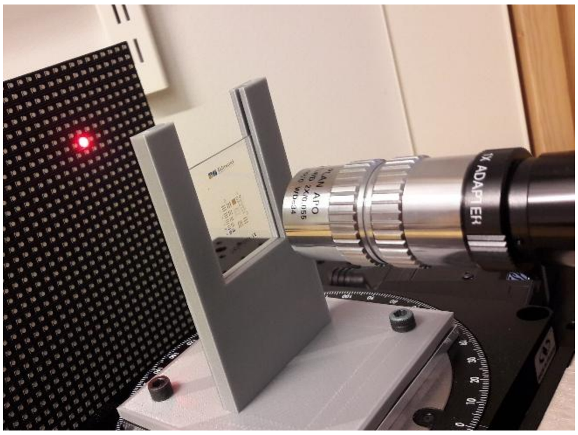
- *enjoy experimental work and/or advanced data analysis*
- *appreciate applied physics challenges with a direct coupling to environmental, industrial and societal challenges*
- *enjoy challenging theoretical models, often via numerical simulations*
- *enjoy computer programming*

Dag W. Breiby (dag.breiby@ntnu.no)
PhD in physics from NTNU, 2003.
Permanent scientific staff member at Dept. of Physics NTNU since 2007. Professor since 2013.

Teaching: TFY4165 Thermal Physics, TFY4195 Optics, TFY4220 Solid State Physics, TFY4255 Materials Physics, MEA4000 Measurement and Characterization (at USN), TFY4115/4125 General Physics.

Expertise: Physics of self-organized nano- and mesoscale structures, porous and functional materials, computational imaging, X-ray diffraction and microscopy.

Fourier-ptychographic microscopy
- a computer does half the imaging job!



The FP microscope at NTNU.

Fourier ptychography [Zheng 2013] is a microscopy technique where the traditional sample illumination has been replaced by a 2D array of partially **coherent** LEDs, see picture. From each single LED, used one at a time, the light enters the sample with a unique incidence direction. By making one exposure for each LED sequentially, one gets a set of images that can be used to reconstruct both the amplitude and the **quantitative phase** of the imaged object, with a **resolution** well beyond the Rayleigh diffraction limit imposed by the hardware. High-resolution phase-contrast gigapixel images with a wide field-of-view huge can be obtained with computational methods.

During the last years, several master and Ph.D. students have developed our Fourier ptychographic microscope, see image above. Now, we are keen to further improve the setup and to collect interesting data!

In this project you will:

- Review & understand the physics of Fourier ptychography.
- Several specific projects are available, including:
  - The mathematics of analytical images, including Hilbert transforms
  - Model the sample using *Deep Learning* ("implicit neural representation")
  - Use GPU programming for image reconstruction
  - Do quantitative polarization-sensitive microscopy for strain mapping
  - Perform 3D imaging of dynamics in *foams, bubbles and droplets.*
  - Quantitative imaging of *fractures in car windscreens* in collaboration with the Dept. of Structural Engineering and European car industry

These projects require good programming skills and an interest in optics.

Co-supervision: The project will be carried out in close collaboration with Prof. M. Nadeem Akram at the University of South-Eastern Norway, located between Horten and Tønsberg.

References:
Zheng et al, Nature Photonics, 2013:
http://www.nature.com/nphoton/journal/v7/n9/full/nphoton.2013.187.html

Phase contrast microscopy of droplet nucleation

The scattering of electromagnetic radiation by particles has played an important role in the history of physics, with highlights including Descartes' understanding of the rainbow 400 years ago, Rayleigh scattering by small particles, and Mié's exact solution to the scattering of plane waves by spheres.

In this project, we will study light scattering from liquid droplets on transparent functionalized substrates – relating directly to wetting, environmental physics, and CO_2 storage.

Ultimately, the project aims at measuring the condensation properties of CO_2 under conditions of high temperature and pressure - a challenge of high scientific interest and "green" industrial relevance.

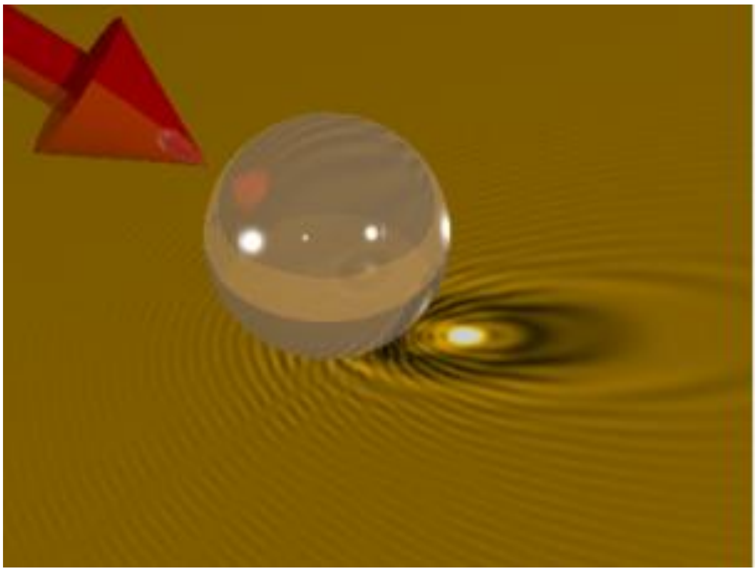


Figure 1. Modelling the light scattering from a translucent sphere.

Project tasks:

1. Study the relevant models for light scattering.
2. Study the thermodynamics of liquid wetting and droplet nucleation from gas phase.
3. Implement an efficient computer program for calculating the near- and far-field (static) light scattering from droplets.
4. Develop a climate chamber (aided by our engineer!) for droplet nucleation. Starting with water, we would like to proceed to CO_2 condensation under high p and T.
5. Work on the inverse problem of parameterizing in 3D the exact droplet shape based on microscopy data, using numerical optimization techniques, including deep learning.

Co-supervision:
The project will be carried out in collaboration with Dr. Basab Chattopadhyay.

X-ray phase-contrast microscopy

Phase contrast in X-ray images was first described by Einstein. The phase of the electromagnetic field changes upon traversing through materials, as described by the refractive index. This phase-change signal is exploited for imaging materials, in particular biological and other soft organic materials, which often gives a low signal-to-noise ratio for standard absorption-based imaging. We have recently purchased a state-of-the-art X-ray source ("***NanoTube***" from Excillum) that we will use for phase-contrast microscopy.

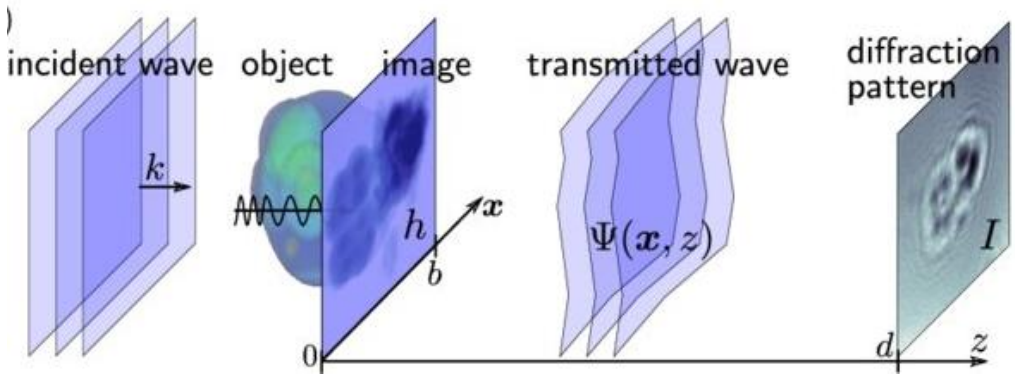


Figure 1. Modeling the transmission and scattering of X-rays through an object. Note how the object introduces ripples in the incoming wavefield, encoding information about the sample structure.
[Image Ref.: Maretzke & Hohage, SIAM Journal on Applied Mathematics 77 (2016)]

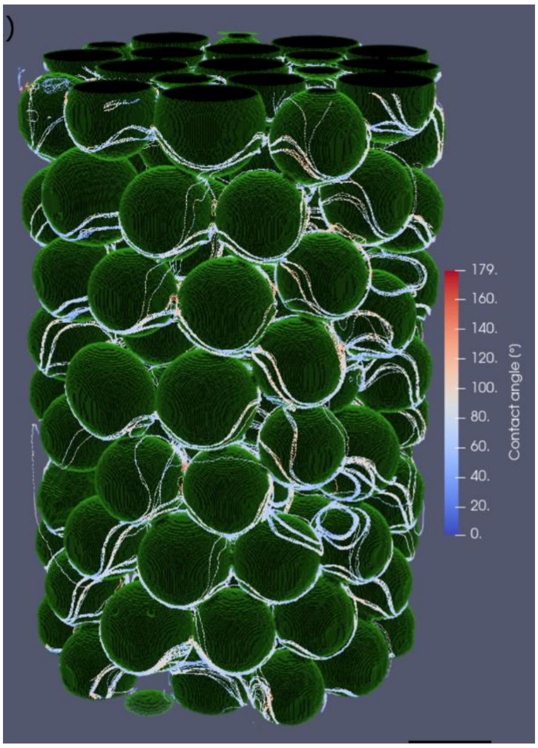
Project tasks:

- *Implement phase contrast X-ray imaging in 2D!*
- Verify that the phase-contrast imaging quantitatively matches theoretical predictions.
- Extend to 3D tomographic reconstructions. Rat brains from the Kavli centre are a particularly relevant sample!

Co-supervision: The project will be done in collaboration with Dr. Basab Chattopadhyay and Prof. Ragnvald Mathiesen.

4-D Computed Tomography ("4D-CT") with Equinor

Supervisor at NTNU: Dag W. Breiby (X-ray Physics Group, Dept. of Physics)
Supervisor at Equinor: Anders Kristoffersen (Equinor)



We offer exciting projects on porous media physics. Liquid flow in porous materials is interesting, complicated and important to society, the environment and industry. Computed tomography (CT) is a well-known experimental technique that gives 3D images of the interior of materials. If the object changes with time, the data will thus be 4-dimensional, hence "4D-CT". There are technical and scientific challenges associated with the 4D-CT measurements. Modelling of the large data sets (often several terabytes of data) is challenging. The current method of choice for analysing the data is Machine Learning.

Examples of specific problems that can be addressed with time-resolved CT are the melting of permafrost, mixing of pollutants in the soil, and medicine uptake in the brain. The project is particularly motivated by CO_2 storage in abandoned oil reservoirs, so-called CCS, which is a prioritized industry in Norway. The project will be carried out in collaboration with Equinor, Norway's leading energy company and a highly attractive workplace for graduates.

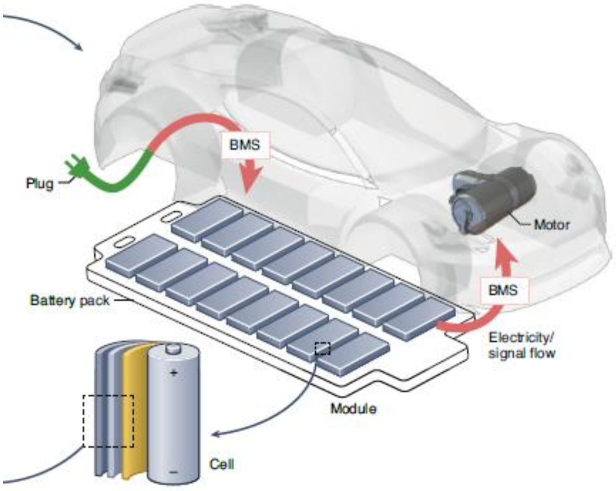
The candidate should ideally have a strong background in physics, but also candidates trained in related topics like nanotechnology, chemistry & thermodynamics, computer programming, mathematics, machine learning and artificial intelligence (AI) are welcome.

CT is a technique that is steadily gaining ground in new scientific fields, and the advanced analysis methods that will be used in this project are of high and generic interest. At the same time, the project is of course academically oriented and will be an excellent career step also for further university studies.

In this project you will:

- Learn the physics of CT
- Use CT to obtain **4D movies** of liquids in porous materials
- Use and develop Deep Learning for data analysis and modelling

Internal dynamics in Li-ion batteries during discharging



Lithium-ion batteries have been a game-changer giving rapid technological developments towards a *green*, mobile, and electric modern society.

In this project we will combine X-ray computed tomography (CT) with fibre optical measurements and IR inspection to study the degradation mechanisms taking place as batteries age. CT gives 4D images (3D + *time*) of the developments inside the batteries, while fibre optical sensors can be used to measure parameters like temperature and pH inside the batteries. IR cameras can be used to monitor the temperature distribution on the outer surface of the battery. Properly taken together, these data can be used to get a detailed view of the complex thermodynamical processes taking place inside the battery.

We note that several Norwegian companies, including SINTEF, are strongly involved in developing improved battery technologies. In this project, we will study how Li-ion batteries can be triggered to self-heal from the early onset of degradation.

In this project you will:
- Learn the physics of Li-ion batteries, CT and fibre optical sensing.
- Use CT to study the interior of batteries during operation
- Perform fibre optical measurements.
- Use Machine Learning to analyse and interpret the CT data.
-

Co-supervision: The project will be carried out in close collaboration with Dr. Basab Chattopadhyay and with the battery expert Prof. Steve Boles from the Dept. of Energy and Process Engineering.

References:

Huang et al, Nature Energy, 2020: https://www.nature.com/articles/s41560-020-0665-y