PHYSICS

The researchers are sorted into research areas. In physics we distinguish between Biological Physics, Cosmology og Particle Physics and Statistical and Physics. Researchers from chemistry also offer projects within physics.

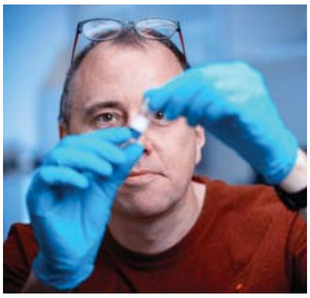
Biological Physics

Cosmology og Particle Physics

Statistical and Computational Physics

Supervisors from other research areas

You can find a description of these researchers in the designated catalogue.



Assoc. Prof. Adam Cohen Simonsen

Topics:
Experimental Physics, Soft Matter, Biophysics

SDU

Biointerfaces

A biointerface is the surface of a biological structure or the interface between a biological material and another medium. The physics of biointerfaces controls mechanisms of cellular processes and properties of many other soft materials such as foods or polymers. We are interested in the physics of soft materials using microscopy, image analysis and theory.

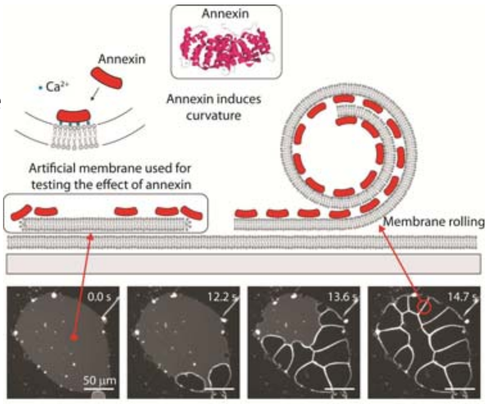
Our research is mainly focused on these 3 topics:

1. Biomembranes and model membranes
2. Gels of soft nanoparticles (e.g. cheese)
3. Wetting and capillary effects.

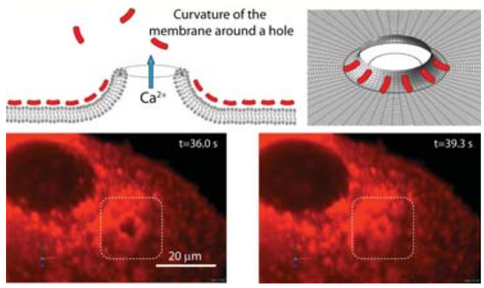
We use and develop advanced biophysical characterization techniques such as Atomic Force Microscopy (AFM), Fluorescence-based imaging tools, Imaging Ellipsometry and more.

Mechanism of membrane repair

Cells are repairing damage to their plasma membrane using the protein Annexin. We have shown that Annexin can induce curvature in artificial membranes.



A hole in a cell membrane will develop a neck-shaped structure due to Annexin binding. This is the first step of the repair process.

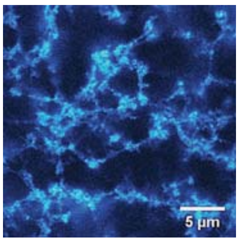


People: Martin Klenow, Christoffer Iversen

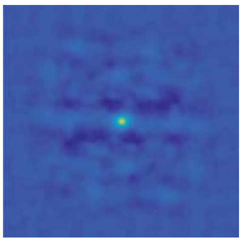
T.L. Boye et. al. Nature Communications 8, 1623 (2017)

Food Physics

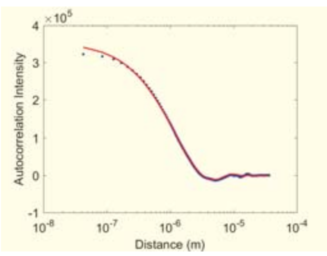
Confocal imaging of food materials can reveal details of their microstructure. Using custom image analysis algorithms, quantitative properties can be extracted for use in prediction and optimization.



Confocal STED image of cheese. Individual casein micelles are resolved.



Autocorrelation image of gel.

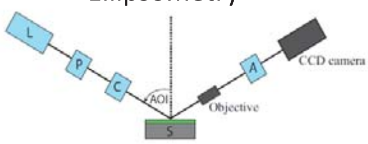


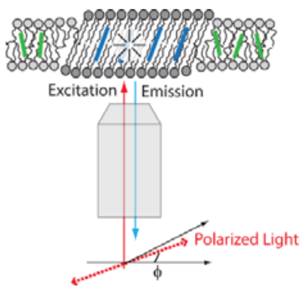
Radially averaged autocorrelation image of gel. From fitting we obtain the pore size of the gel and the size of protein particles.

People: Zachary Glover, Anne Louise Bisgaard

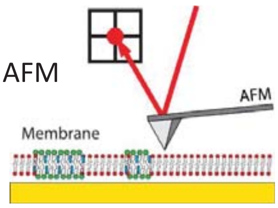
Techniques & Methods

Ellipsometry





AFM



Fluorescence Microscopy

Drop shape imaging

Image analysis

+ Programming
+ Theory

email: adam@memphys.sdu.dk

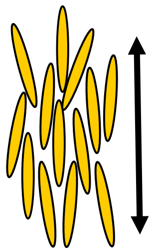
Associate Professor Francesca Serra

SDU

Topics: liquid crystals, cells, topological defects

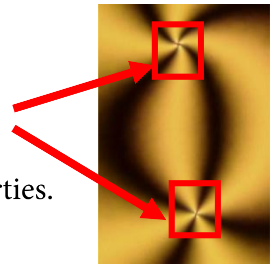
Liquid crystals - introduction

Liquid crystals are phases of matter intermediate between liquid and solid. They are made of rod-like molecules that spontaneously align with each other while maintaining their fluidity.



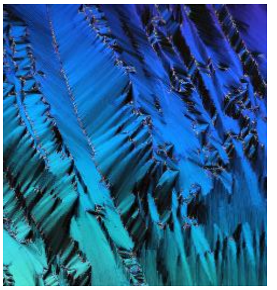
The order of the molecules in liquid crystals can be manipulated in many ways, for example with electric fields, which is why they are so important in TV displays.

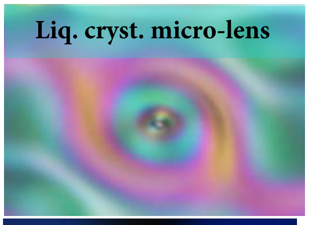
Under certain conditions, liquid crystals form small disordered regions called **topological defects**, which have unique optical properties.

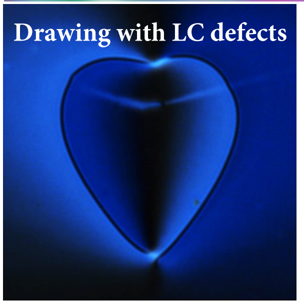


Optics and sensors

Liquid crystals are birefringent and they form beautiful patterns when viewed with polarized light microscopy.







Liquid crystal alignment is finely tunable by controlling its alignment near the surface. Topological defects can be highly controlled to create structures interesting for optics (such as micro-lenses) or used to "draw" arbitrary micro-patterns.

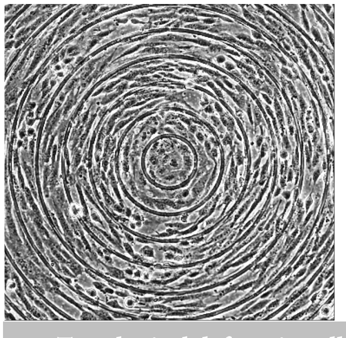
Specific projects:

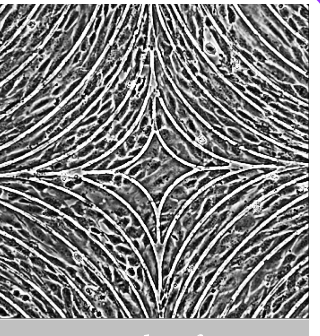
- Liquid crystal-based biosensor for amphiphiles
- Building a photo-alignment system for the control of surface alignment

Living cells as liquid crystals

Many types of living cells also align spontaneously, as liquid crystals do, and form topological defects. Cell alignment is important for cell-cell communication, cell migration and tissue mechanics. Cells also behave differently near defects, and this is important in tissue regulation.

Our goal is to control the type and location of the defects, by surface patterning, to observe how different cell types are affected by their presence and to use liquid crystal physics to interpret and understand the data.





Topological defects in cells on patterned surfaces

Specific projects:

- Study of effect of cell-substrate interaction on fibroblast alignment
- Study of the structure of the extracellular matrix in aligned monolayers of fibroblasts

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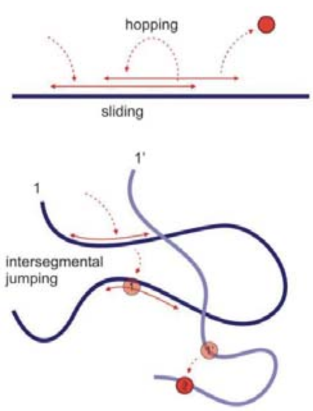
Associate Professor Michael Lomholt

Topics: Statistical physics, biophysics, soft matter, data analysis, stochastic processes

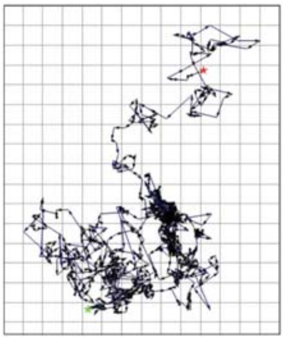
University of Southern Denmark

Random walks and dynamics of DNA-protein interactions



Random walks occur in many natural processes. For instance, a protein in a cell searching for a specific binding site on DNA. This gives rise to a complicated random walk that switches between movement in 3D around the cell with occasional binding to the DNA mocule. When bound to DNA the motion is then in 1D along the DNA.

Is diffusion in cells Brownian or anomalous?

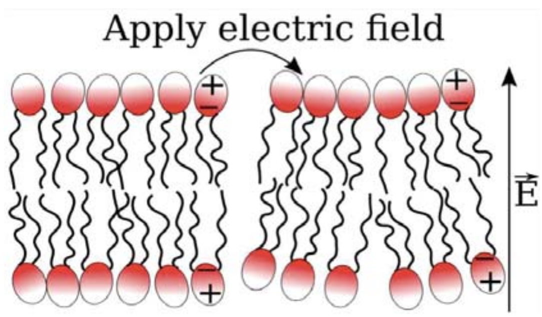


This is a question that can be tackled by Bayesian statistics. Bayesian statistics is a conceptually simple approach to statistics where ordinary probability theory is used to choose the theory that best describes the data. The evidence for a theoretical model is calculated as an integral:

$$Z_{\text{model}} = \int p(\text{data} \mid \text{parameters } \theta)\, p(\theta \mid \text{model})\, d\theta$$

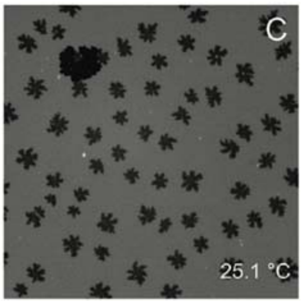
A limitation has so far been the computational complexities involved in calculating this integral. However, new Monte Carlo simulation techniques and greater computational power are allowing for this obstacle to be overcome.

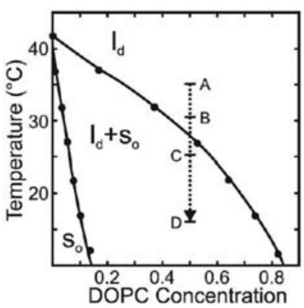
Membrane curvature and electric fields



A lipid membrane has electric dipoles situated at its interface with the surrounding water. When an electric field is applied across the membrane it will interact with these dipoles to create spontaneous curvature of the membrane. This effect can be studied in molecular dynamics simulations and with analytic models.

Dynamics of domain nucleations in lipid membranes





When a two-component lipid membrane is cooled below the freezing point of one of the lipids solid domains might form. It turns out that these domains are not distributed independently of each other, but interact through some mechanism. But what is this mechanism? A hypothesis is that the process is controlled by the tension in the membrane. Predictions from this hypothesis can be obtained through computer simulations or analytic theory.

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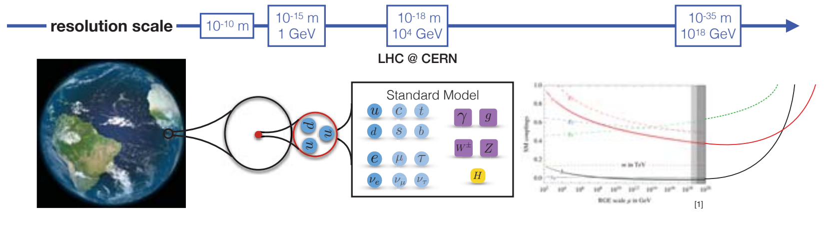
What are the fundamental building blocks of our universe?

Astrid Eichhorn

CP3-Origins, FKF, eichhorn@cp3.sdu.dk

SDU UNIVERSITY OF SOUTHERN DENMARK

Fundamental microscopic structure of matter - Going beyond the Standard Model

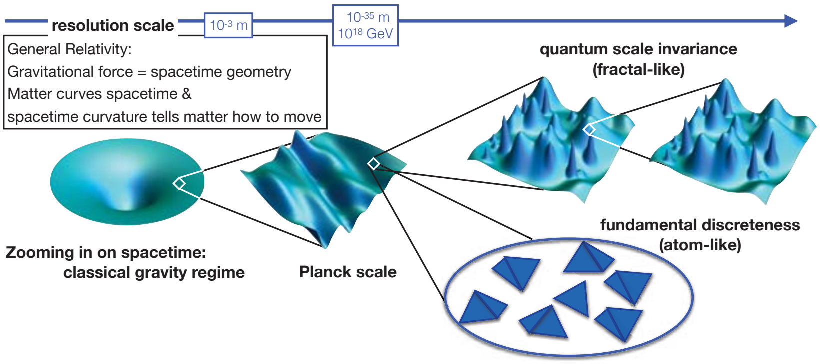


Zooming in on matter: atoms - protons - Standard Model (electrons, quarks, photons) - ????

Zooming in on matter:
Standard Model of particle physics:
singularities in interactions at very high energies
⇒ breakdown of description
⇒ something is missing

Hypothesis: Quanta of the gravitational field (gravitons) are missing

Fundamental microscopic structure of spacetime - Going beyond General Relativity



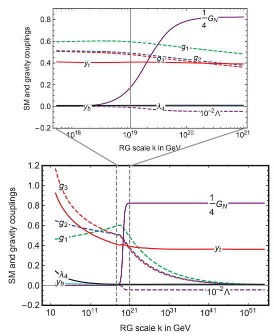
Zooming in on spacetime:
Quantum effects (Heisenberg uncertainty principle, interference effects) at tiny length scales/ high energies
→ is spacetime fundamentally "atomic"?
→ is spacetime microscopically scale-symmetric (like a fractal)?
Challenge: No experimental tests at 10^{19} GeV

Research strategy:

- develop theoretical models of fundamental quantum structure of spacetime and matter
- develop approaches within different paradigms in parallel
- test models by bridging the gap between microscopic scales of theoretical models & large scales with experimental access (mathematical tool: analogue of "inverse microscope")

Quantum gravity models: Highlights and perspectives

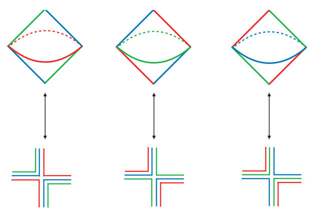
Asymptotic safety paradigm:
Towards a joint model of gravity & matter:



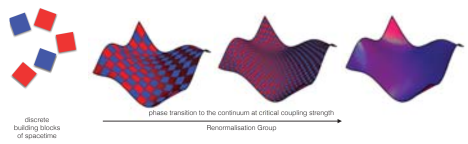
Gravity-matter interplay:
→ scale-symmetric quantum structure of spacetime
→ no divergences of matter interactions

Towards singularity-resolution in black holes & observable imprints in black-hole shadows: strength of gravity weakens at tiny distances

Discrete tensor models:
Encoding building blocks of spacetime in tensor model

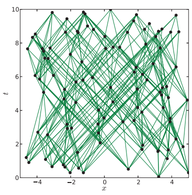


Coarse-graining techniques :

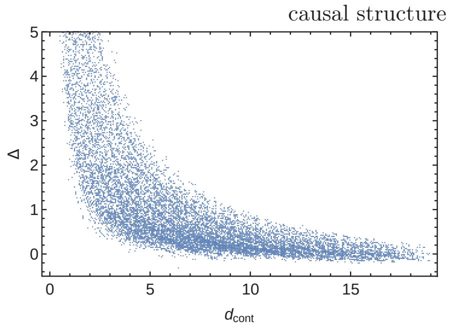


Towards a first phase diagram of 3 & 4 dimensional models

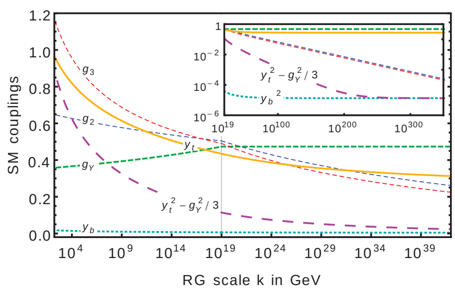
Causal set quantum gravity:
Emergence of spacetime from a causal network



- small scales: atomic spacetime becomes asymptotically silent
- $\Delta = 0$: measure of faithful reconstruction of spatial geometry from discrete causal structure



Observations decide! Zooming out



asymptotically safe matter-gravity model at high energies
→ zoom out to low energies to confront model with data

first hints (note: calculations require approximations!):

- fine-structure constant "retrodicted"
- masses of two heaviest elementary matter particles "retrodicted"
- dimensionality 4 could be "critical" dimension of the model

Associate Professor Mads T. Frandsen

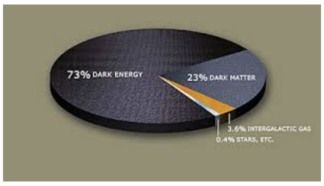
Topics: Particle and Astroparticle physics
The Origin of Mass, Higgs and Dark Matter

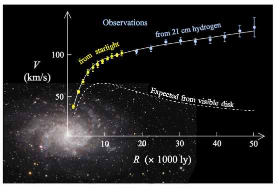
SDU

CP3 Origins

Dark Matter Astrophysics

Dark matter dominates the Universe on large scales. But even if a billion dark matter particles pass through you each second we don't know what it is.

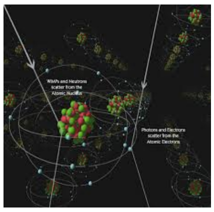


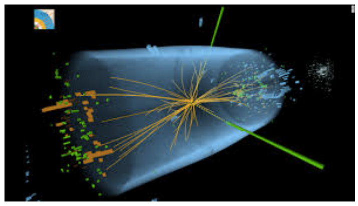


Using classical physics as in FY529 and FY504 you can study or do research on advanced applications to the astrophysics of DM

Dark Matter Particle Physics

Using quantum mechanics, you can study or do research on ways to detect and study Dark Matter particles in labs here on earth.

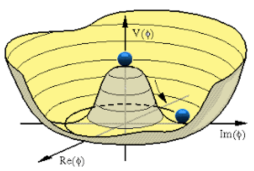




Using field theory and quantum field theory you can study and do research on the properties of Dark Matter as elementary particle and its origin

Origin of mass and the Higgs

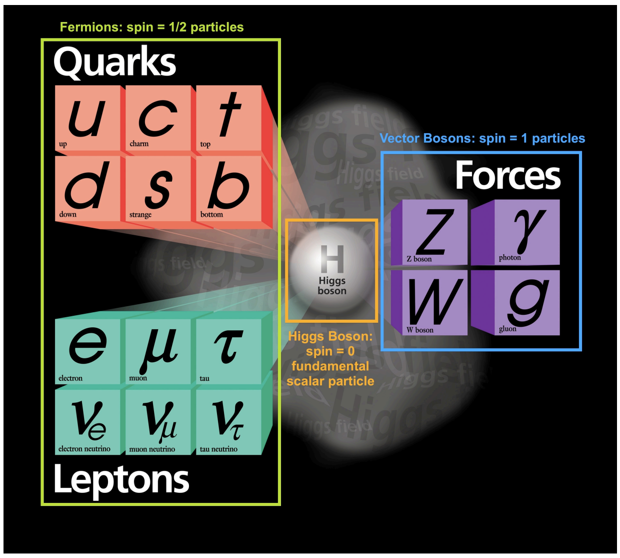
Matter and the elementary constituents have mass, it's a crucial property, but we still do not now how their masses arose. This is now being uncovered at the LHC experiment at CERN



In a bachelor thesis, using classical field theory, you can study, how the origin of mass is described in the SM of particle physics and why the Higgs is so special that we think other new particles might be waiting do be discovered.

See also poster by Heidi Rzehak from CP3-Origins

Beyond the Higgs boson



In a master thesis, using field theory and quantum field theory you can study extensions of the SM that solve the probles of the SM Higgs boson and maybe even solve the DM puzzle

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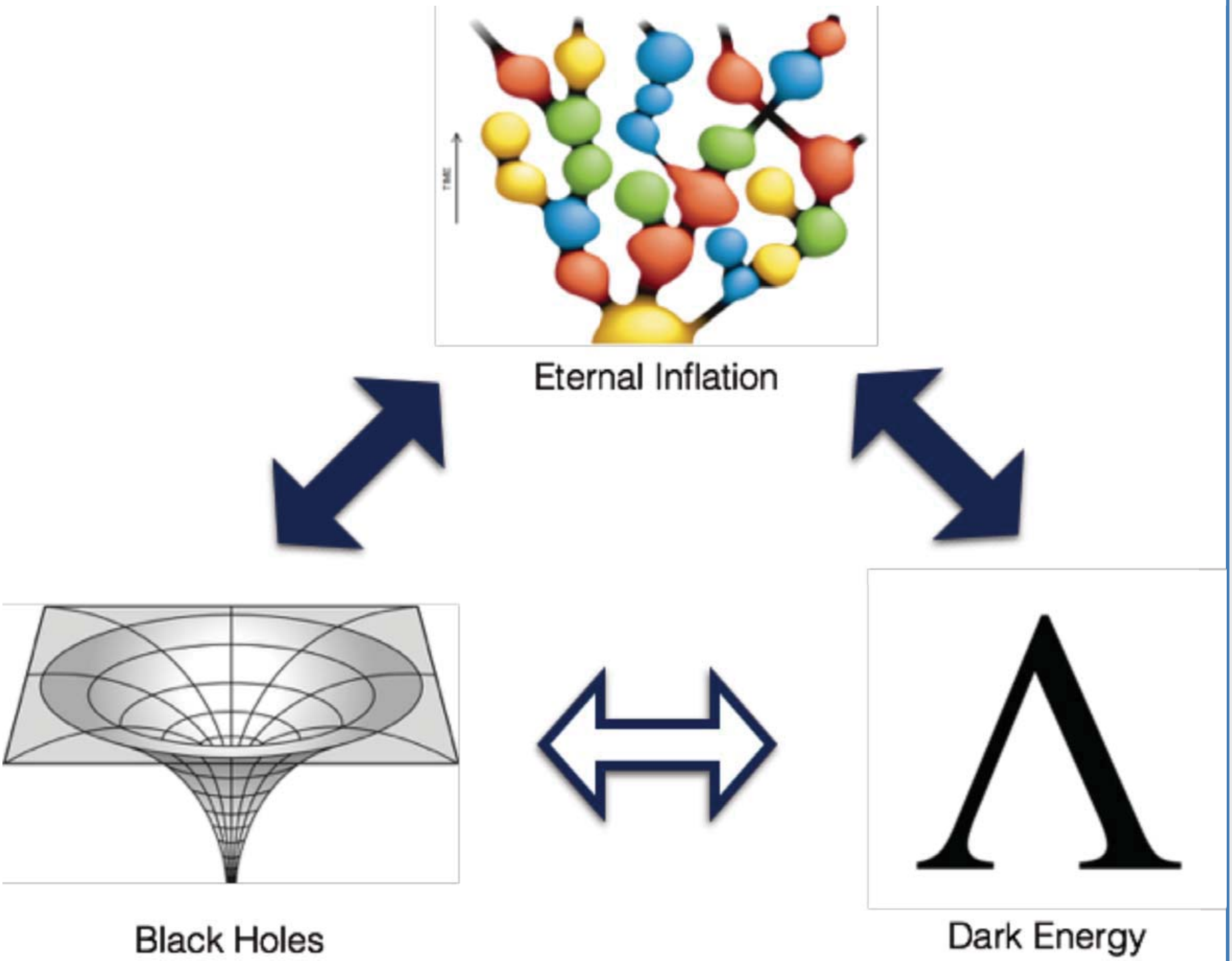
Professor Martin S. Sloth

Topics: Theoretical Cosmology

CP3 Origins
Cosmology & Particle Physics
SDU



web: http://universe-origins.dk

email: sloth@sdu.dk

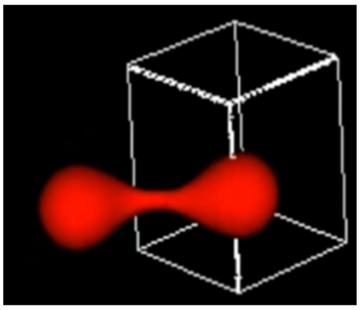
Assistant Professor Roman Gold

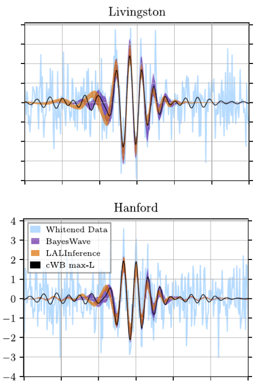
Topics: Black Holes in their natural habitat, Gravitational Waves

SDU

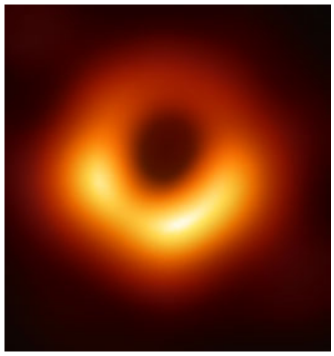
Simulating black hole collisions

In this part you can learn how to simulate colliding and merging black hole using numerical methods and how to compute gravitational waves from first principles. The resulting gravitational wave signals can then be compared to what Gravitational Wave detectors such as LIGO and VIRGO can measure. Depending on your interest the weight of the project could be more on the theoretical part or on data analysis.





Making Black Hole images and related analyses relevant for the Event Horizon Telescope

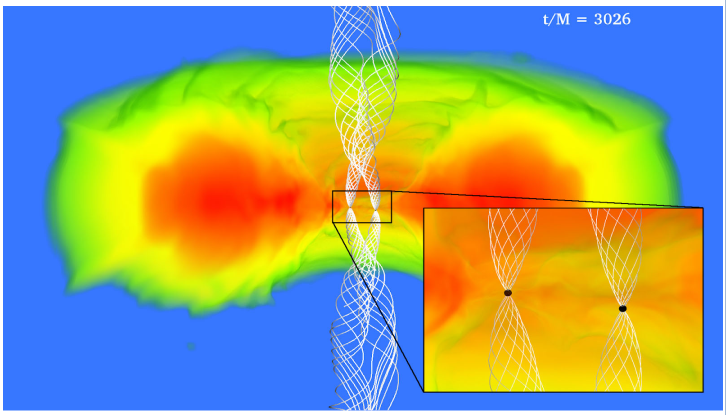


Actual data taken by the Event Horizon Telescope in 2017 produced the first-ever image of a black hole (right) which is also the highest resolution picture ever taken in the history astronomy. How the data has a lot more to offer than just the image.

Here you can learn about all the gory details around model fitting, physical modeling and image feature extraction and turn the Event Horizon Telescope data into scientific results. You can learn about powerful tools like the MCMC based Bayesian parameter estimation tool THEMIS or the observation tool eht-imaging and explore what we can learn from such data sets. There are so many possibilities including contributions to the next generation Event Horizon Telescope design phase that is currently ongoing.

Simulate the dynamic astrophysical environment of black holes

In this project you can learn how to simulate the astrophysical environment of a black hole and how it interacts with the black hole. The black hole consumes hot gas while powering spectacular jet outflows. You can simulate single black holes or a pair of black holes within a magnetized gaseous environment. Both types of simulations are rich in features and visualizing them is an important part of the analysis. You can also turn these into actual images that one could take from far away by employing ray-tracing and radiative transfer codes. There is a lot of physics here and computational skills are definitely helpful!



Designing cubesat or other satellite missions as radio antennas

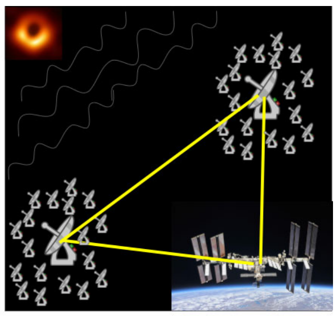
Putting Radio telescopes like those that are part of the Event Horizon Telescope into space offers tremendeous advantages but come with a variety of huge challenges. In this project you can contribute (in collaboration with TEC) to overcoming some of these challenges. We are investigating the role of nanosatellites/cubesats in space-based radio interferometry.
There are many sub-projects here which can be tailored to your specific interests. We are also in the process of building a simple and cheap array of Radio dishes on the ground.

SDU University of Southern Denmark CP3

EHT

Roman Gold

with:
Nicolai Iversen, Mads Toudal Frandsen, Rema Jamal Ahmid, Dom Pesce, Jose Gomez, Avery Broderick



PHAMILI Space -
Phased **H**ierarchical **A**rray for **Milli**meter **I**nterferometry
A cost effective space vlbi concept for black hole images and GR tests

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CP3

Fundamental physics in the laboratory and in space

Associate Professor Manuel Meyer

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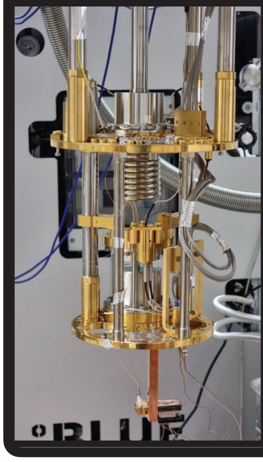
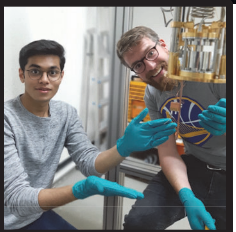
Projects: Particle and Astroparticle Physics, low-background low-temperature detectors, astrophysical data analysis

Search for fundamental particles in the laboratory

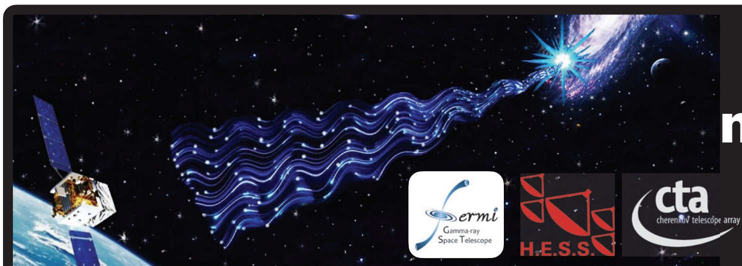


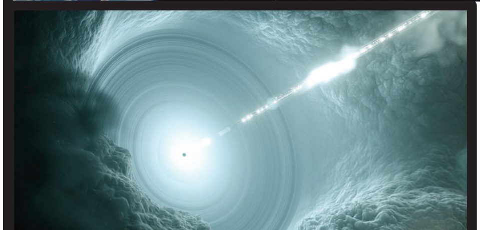


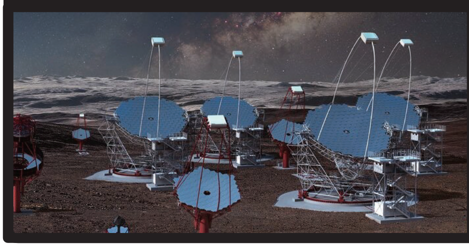
- Many theories particle physics predict existence of yet **undiscovered fundamental particles**
- These particles could explain nature of mysterious **dark matter**
- Our group is part of the **Any Light Particle Search II** experiment which is taking its first data at DESY in Hamburg, Germany

- The experiment searches axions and axion-like particles by trying to **shine light through walls**
- **Projects available** related to our **superconducting single photon detector**
- Projects can cover, e.g., **data analysis and machine learning, detector characterization, and improved background reduction**

Understanding the most energetic processes in the Universe







- We use observations of **distant galaxies** at **gamma-ray energies** (one millions times the energy of X-rays) with **telescopes and satellites** to…
  - … understand how particles such as **electrons are accelerated** to almost the speed of light **close to supermassive black holes**
  - … investigate what happens to gamma rays on their **journey through the intergalactic medium**
  - … search for **traces of yet undiscovered particles**
- **Projects available** to **analyze** telescope and satellite **data**
- Opportunity to **join** large **international collaborations**

Get in touch at **mey@sdu.dk** for and visit
https://axion-alp-dm.github.io/

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Associate Professor

Carsten Svaneborg

Soft-condensed matter, statistical physics, and computational physics.

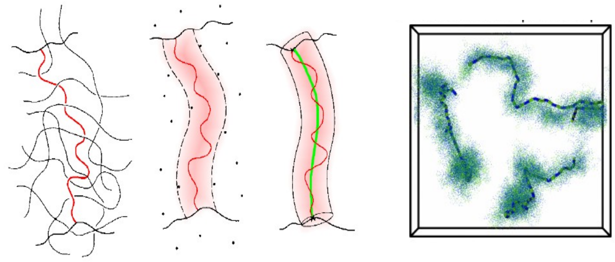
Research focus: How to achieve a more fundamental understanding of the physics of soft-matter, and use this to design new materials?

- **Study** how macroscopic material properties emerge from molecular structures and interactions.
- **Design** computationally effective models
- **Develop** analysis methods to obtain new knowledge
- **Improve** state-of-the art theories and experimental analysis methods.

From Molecules to Materials

Molecular structure

Microscopic structure of rubbers or gels

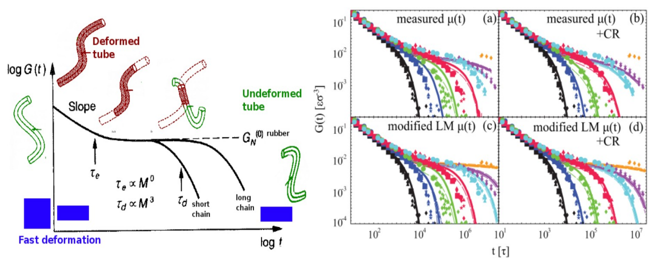


Tube due to confined thermal fluctuations. Green line tube axis.

Visualization

Material response to deformation

Macroscopic viscoelasticity of rubbers or gels



Picture: Doi Edwards "Theory of polymer dynamics" (1986)

J.-X. Hou, C. Svaneborg, R. Everaers, G.S. Grest. **Phys. Rev. Lett.** 2010. 750 core years of work!

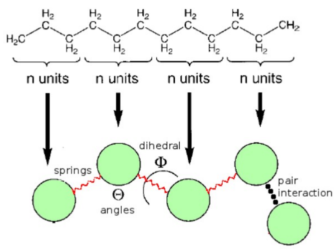
Soft-condensed matter

Key features:

- Many practical/technological applications
- Building material for all living organisms
- Emergent structures coupling physics from molecular up to macroscopic scales
- Entropic interactions dominate
- Complex response to external perturbations

Coarse-grained models

Coarse-graining



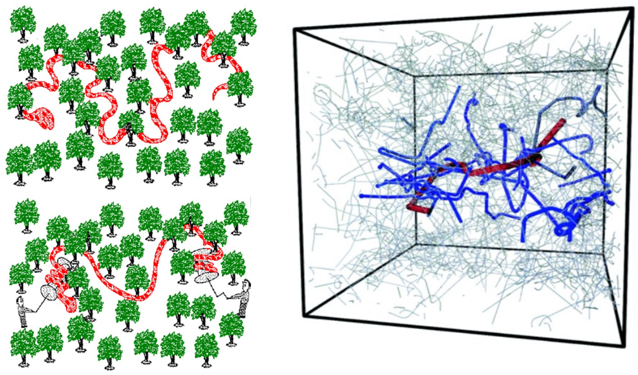
Langevin dynamics:

$$m\frac{\partial^2 \mathbf{R}}{\partial t^2} = \mathbf{F} - \Gamma \mathbf{V}(t) + \mathbf{F}_{stoc}$$

Coarse-grain models are
1) computationally more effective
2) describe physics more succinctly
3) provides fundamental understanding

Example: Analysis providing tube structure of polymer materials to predict viscoelasticity.

Topological analysis



First realization in a simulation: R. Everaers, S.K. Sukumaran, G.S. Grest, C. Svaneborg, A. Sivasubramanian, and K. Kremer, **Science** 303, 823-826 (2004)

Suggestions for projects:

- Polymer blend morphology (+Federica)
- Polymer drug delivery systems (+Federica)
- Diffusion in complex environments (+Federica)
- Aging in colloidal glasses. (+Paolo)
- Models for biological gels of stiff polymers
- Microscopic origin of friction phenomena
- Physics of living polymers
- Design new effective polymer models preserving topological entanglements
- Analysis techniques for X-ray / neutron small angle scattering
- Implement features in LAMMPS simulator

In many of the projects, you will run simulations on the Abacus2 cluster.

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