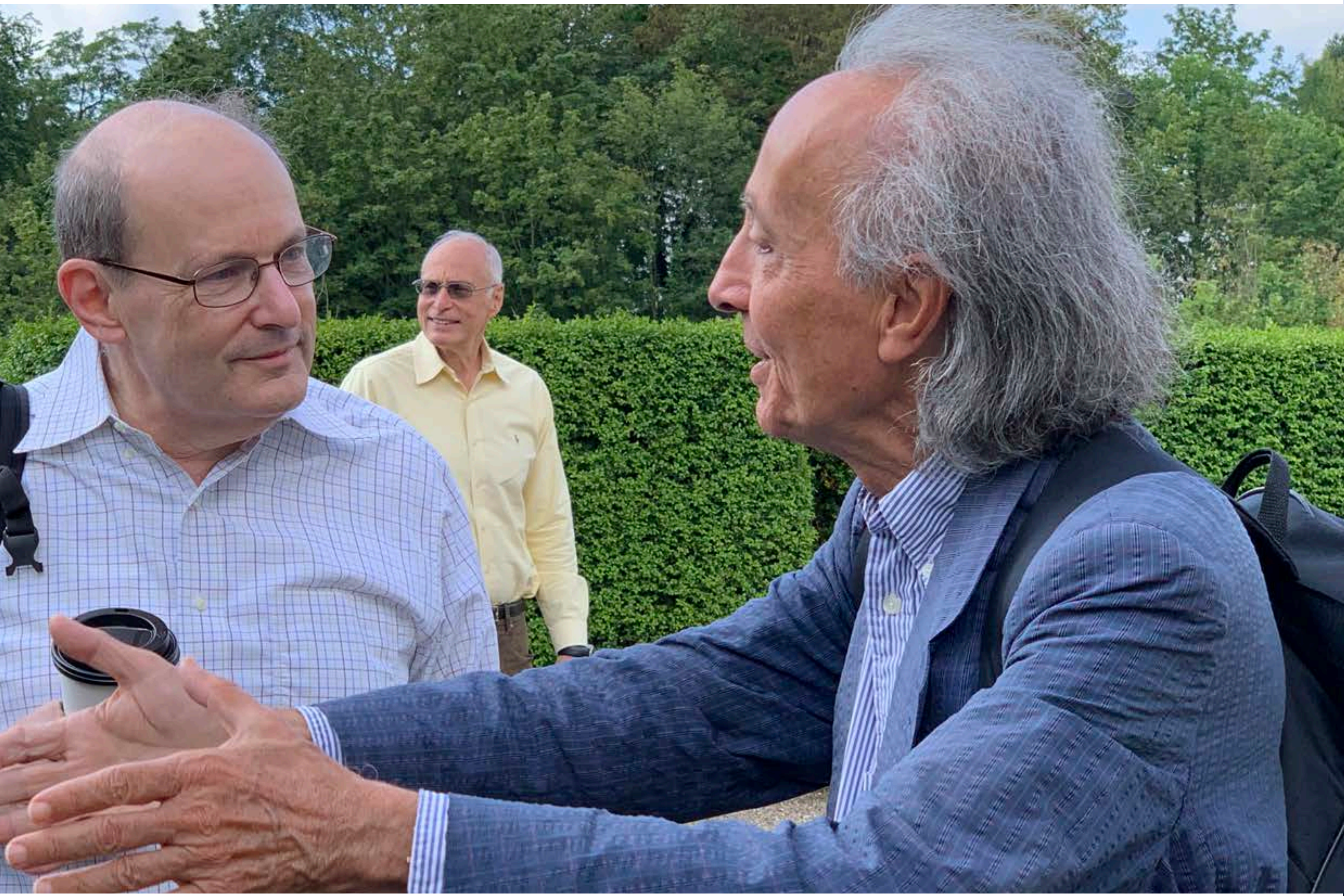
The Niels Bohr International Academy



Annual Report 2019

The Niels Bohr International Academy

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Cover: Professors Paul Steinhardt (Princeton), Adam Burrows (Princeton), and Thibault Damour (IHES)
Simons Program on Physics and Astrophysics in the Era of Gravitational Wave Detection, August 2019

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The Academy

NBIA Governance

International Advisory Board and Director's Council:

The Niels Bohr International Academy receives scientific advice from an International Advisory Board consisting of leading names in today's theoretical and mathematical physics as well as important advice and support from its Director's Council, which consists of prominent members of Danish society.

Current Members of the International Advisory Board:

- **Poul Henrik Damgaard**, Niels Bohr Institute (Director)
- **Andrew D. Jackson**, Niels Bohr Institute (Chairman)
- **Martin E. Pessah,** Niels Bohr Institute (Deputy Director)
- **David Gross**, KITP Santa Barbara
- **Charles Marcus**, Niels Bohr Institute
- **Itamar Procaccia**, Weizmann Institute
- **Barry Simon**, California Institute of Technology
- **Paul Steinhardt**, Princeton University
- **Frank Wilczek**, Massachusetts Institute of Technology

Current Members of the Director's Council:

- **Lars Kann-Rasmussen** (Chairman)
  Former CEO of the VELUX Group and Villum Foundation
- **Kirsten Smedegaard Andersen**
  Board member LD, Bodum, DanChurchAid, and other public and private organizations
- **Connie Hedegaard**
  Chair of the KR Foundation, former Minister and EU Commissioner
- **Niels Due Jensen**
  Former CEO of Grundfos and former Chairman of Poul Due Jensen Foundation
- **Per Magid** (Vice Chairman)
  Lawyer, Rovsing & Gammeljord
- **Bjørn Nørgaard**
  Prof. Royal Academy of fine Arts, Guest Prof. China National Academy of Arts
- **Michael K. Rasmussen**
  Former Vice President, Brand in VELUX Group, private consultant

The Niels Bohr International Academy

From the Director

When we look back upon the year 2019 it is striking that the Niels Bohr International Academy (NBIA) underwent a great renewal. This happened both in terms of new hires of young faculty (see below), and in terms of new research directions. Major institutional grants to the NBIA from the Aage & Johanne Louis-Hansen Foundation and the Novo Nordisk Foundation made this renewal possible. Based on the grant from the Novo Nordisk Foundation, the NBIA has now initiated what will become a massive move into physics related to life sciences. With the grant from the Aage & Johanne Louis-Hansen Foundation we have been able to select top candidates in new and exciting topics in astrophysics, particle physics and cosmology, and quantum condensed matter physics. Additional individual research grants to NBIA scientists have allowed us to move also into the theory behind the emission of gravitational waves during the inspiral of two massive compact objects such as black holes or neutron stars.

Four junior faculty members have joined us during the year. Michèle Levi comes to us from the Institute of Theoretical Physics at CEA Saclay in Paris. Michèle has pioneered computational efforts towards including spin effects in the dynamics of two black holes as the orbit each other, eventually merge into one single black hole, and emit the spectacular signal of gravitational waves. Johan Samsing comes to us from Princeton University where he was Einstein Fellow and Spitzer Fellow. A theoretical astrophysicist by training, Johan used his five-year stay at Princeton to move into the hot subject of how pairs of black holes form in different astrophysical environments, a field in which Johan is now a leading figure. Evert van Nieuwenburg joins us from Caltech where he had been a post-doc since 2017. Evert is pioneering the use of modern machine learning tools in theoretical condensed matter physics, using such tools to, for example, identify correctly phase boundaries without any input from theory and only based on either numerical or experimental data. Evert also does fascinating work on outreach, having created, for example, an app to play "quantum tic-tac-toe"! Amin Doostmohammadi comes to us from Oxford University, where he held a prestigious Royal 1851 Research Fellowship until the fall of 2019. Amin is spearheading the exciting new area of biological physics which goes under the name of active matter and which sets out to understand how motion at cellular level is driven and organized through collective effects.

The new research directions briefly outlined above illustrate well how the NBIA is able to change rapidly when new opportunities arise. The new hires should not overshadow the successes of scientists already present at the NBIA who also have demonstrated the ability to move into new research directions fast. Two prestigious scientific awards (the 2019 MERAC Prize and the 2019 Shakti P. Duggal Award) were presented to Irene Tamborra during 2019 and we were proud to see that Simons Visiting Professor Charles Bennett received the Micius Quantum Prize while here. Scientists at the NBIA also received individual grants and fellowships: Two Villum Young Investigator Grants, a Carlsberg Foundation Young Researcher Fellowship, a Sapere Aude Starting Grant, and a Marie Curie fellowship. All of these grants were obtained in fierce competition with other talented scientist across Denmark and Europe.

And as this report goes to press we learn that three NBIA scientists have been awarded Villum Young Investigator Grants. A wonderful way for the NBIA to start a new year!

Poul Henrik Damgaard
2019

NBIA International Advisory Board and Director's Council — Joint Meeting— August 2019

NBIA International Advisory Board and Director's Council — Joint Meeting— August 2019

From the Chairman of the Board

Since its inception in 2007, the goal of the NBIA has been to identify and recruit the best and brightest young researchers in theoretical physics. Exceptional ability and promise in any field of physics have been the sole criteria. This strategy was based on the belief that the most talented young scientists would enjoy working in the company of colleagues with expertise in other areas of physics. In our view it has been extremely successful. The result has been that the NBIA offers a heterogeneous and open intellectual environment distinct from the more inward atmosphere that characterizes the majority of the thematically focused research groups at the NBI. We are convinced that this approach has played an important role in the remarkable success of the NBIA. We are pleased to note the many recent intellectual achievements of our young people that are described in the bulk of this report, and we are particularly proud of the interdisciplinary collaborations that this open spirit has encouraged. This policy has also proved to be successful as measured by external financial support for the NBIA as a whole and by the truly extraordinary success of our younger colleagues in the competition for prestigious young investigator grants. This has been true from the beginning and, as described in Poul Henrik Damgaard's contribution to this Report, 2019 has certainly not been an exception! But this "silver lining" also has its cloud.

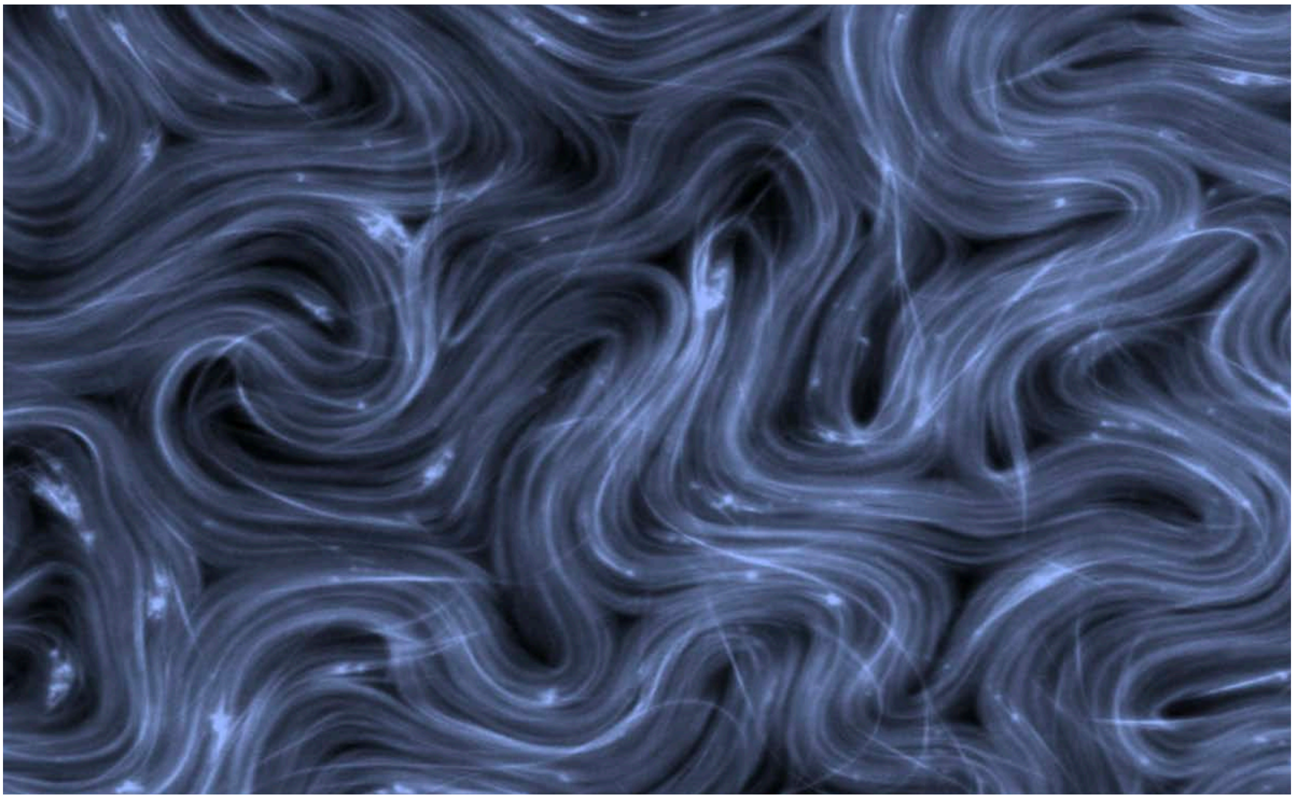
The financial value of young investigator awards has grown materially in recent years so that a total of 10 million Danish crowns over a 5–year period is no longer unusual. It is normal for theorists that the bulk of this money will be used to pay the salaries of new post-doctoral fellows working on the same project. Their selection is necessarily based on their perceived relevance to the funded project rather than on the broader criteria that the NBIA normally adopts. The result is an increased tendency to form precisely the kind of introspective subgroups that we would like to avoid. Since the realities of current funding patterns seem designed to reinforce present trends, it is important for the NBIA to find effective new ways to promote a more inclusive scientific atmosphere. These include the recently introduced series of NBIA colloquia and as well as the establishment of other less formal opportunities for the encouragement of interdisciplinary scientific discussion and collaboration.

A second concern can be dealt with more easily. In past years, a large grant to a younger scientist had a high probability of leading to a permanent NBI faculty appointment. Given the number of successful grant applications, this is clearly no longer the case. Thus, when assisting junior members of the NBIA in taking their next academic step, it is essential to be certain that they have a realistic understanding of what such awards can and cannot do in furthering their scientific careers. By helping its young people to realize their long-term goals, the NBIA will be able to continue to "do well by doing good" for many years to come.

Andrew Jackson
2019

Novo Nordisk Foundation Grant

The biggest institutional grant to the NBIA ever came from the Novo Nordisk Foundation in 2018. This grant of 35 MDKK aims at establishing up to five Novo Nordisk Foundation Assistant Professors, Novo Nordisk Foundation Associate Professors, or Novo Nordisk Foundation Full Professor at the NBIA. The new research directions should have potential for relevance within life science research. The time is indeed ripe for this expansion into areas in life sciences that are bordering physics, and it has for several years been the ambition of the NBIA to again establish a stronghold in theoretical biological physics (one of the first topics of research when the NBIA was founded in 2007). The large grant from the Novo Nordisk Foundation takes this to a much larger scale. It will massively support research at the NBIA that may potentially have large impact on the life sciences. For the NBIA new areas that naturally come to mind are (apart from biological physics and the more general area of biocomplexity): systems biology, computational biology, modern genetic studies and even close contact to laboratory work in the biological sciences. All of these are areas where physics-driven methods may provide new and groundbreaking results. In addition to making these new fixed-term hires the NBIA will provide the interdisciplinary atmosphere, the close contact with both theoretical physicists and mathematicians, and the steady flow of leading scientists that visit the NBIA every year. The first Novo Nordisk Foundation Assistant Professor (Amin Doostmohammadi, until 2019 Royal 1851 Research Fellow at the Rudolf Peierls Centre for Theoretical Physics at the University of Oxford) has already been selected and he started his NBIA appointment in the fall of 2019. In the spring of 2020 he will be joined for three months by Novo Nordisk Foundation Visiting Professor Julia Yeomans from Oxford University. More appointments will be made as we identify outstanding candidates in the coming years.



Louis-Hansen Foundation Grant

In 2018 the Aage & Johanne Louis-Hansen Foundation provided the NBIA with a crucial grant of 10 MDKK to hire Louis-Hansen Assistant Professors on 5-year fixed-term contracts at the NBIA. The grant is totally flexible and will allow the NBIA to seek the brightest young scientists in all areas of the physical sciences. This strategy is at the heart of the foundation of the NBIA and it opens up the opportunity to strike out in brand-new research directions that are not currently pursued, neither at the NBIA nor at the Niels Bohr Institute itself. The overarching principle when making these new appointments is to let the individual talent of applicants be the decisive criterion while simultaneously hoping for a renewal of research topics. Fortunately, these two strategic points of view often merge together, demonstrating that the best scientists move towards areas that are most promising. No one has better noses for this than young scientists who have had a PhD-education from some of the best universities in the world, followed by some post-doctoral years where they have been able to liberate themselves from their thesis topics and thus defined their own research directions. These are scientists who can drive the NBIA in the coming years and who we now invite to join us. The generous grant from the Louis-Hansen Foundation is a most important milestone in the short history of the NBIA and it is leaving its strong mark. Current Louis-Hansen Assistant/Associate Professors, working in as diverse topics as condensed matter physics, cosmology, and astrophysics, are Evert van Nieuwenburg, Subodh Patil, and Johan Samsing.

Husman Foundation Grant

A large donation from the Ernst & Vibeke Husman Foundation given to the NBIA in 2019 will allow us to attract top talent from around the world as Husman Foundation Visiting Scholars. Stays at the NBIA can last from less than a week for researchers invited to speak in our series of NBIA Colloquia and/or more specialized seminars, and up to four or six weeks for longer research visits and Husman Foundation Visiting Professorships. This program builds on and expands the internationalization that is at the core of NBIA's activities, and which is so important for keeping scientists at the NBIA abreast of new scientific developments. Thanks to this donation and through the use of some additional resources from individual research grants, the NBIA can now fulfill its dream of organizing a weekly NBIA Colloquium in which a broad range of new scientific areas is being exposed to all members of the Niels Bohr Institute on Friday afternoons. Husman Foundation Scholarships will be also awarded to collaboration partners of NBIA scientists in order to facilitate these scientific interactions.

ERNST & VIBEKE HUSMANS FOND

INTERACTIONS — EU-COFUND

Close interactions among scientist from a wide range of nations is one of the pillars defining the Niels Bohr International Academy. This is a tradition dating back to the original institute Niels Bohr created on the premises on Blegdamsvej almost a century ago. In 2019, with the valuable support of the European Commission through the COFUND program under the Marie Skłodowska-Curie Actions, the NBIA launched an unprecedented and ambitious Fellowship Program to enhance interactions among young scientist across theoretical physics and across Europe. The INTERACTIONS Fellowship Program will promote and ensure exposure of the fellows to other scientists within neighbouring areas. The programme also encourages interactions among scientists with different cultural backgrounds and from different scientific traditions. To this end, NBIA has teamed up, in a unique construction, with five of the strongest theoretical physics institutes in Europe who are partners of the INTERACTIONS programme:

• University of Cambridge	Department of Applied Maths & Theoretical Physics
• University of Oxford	Department of Theoretical Physics
• Max Planck	Institute for Astronomy, Heidelberg
• CERN	Theoretical Physics Department
• Saclay	Institut de Physique Theorique

These top institutions have been chosen for their excellence in research, for their existing strong ties to the NBIA, for their breadth in theoretical physics, and for their wide distribution both geographically and in terms of science culture. A formalized, structured and long-term collaboration with these partners is of immense importance for the development of the fellows and the overall success of the program, literally taking the concept behind INTERACTIONS to the top European level. It is a unique opportunity for fellows to be introduced to different research environments at the highest level, to build personal networks within Europe, and to intensify long-term collaborations between these institutions. This will increase network and research opportunities for the fellows, and at the same time bring our institutions much closer together at the European level. The INTERACTIONS programme links together the pinnacles of physics research across Europe, benefitting fellows, institutions and European research alike. The first call for the INTERACTIONS Program closed in November 2019 and the second call is expected to be open in October 2020. Relevant information can be found at http://nbia.nbi.ku.dk/interactions.

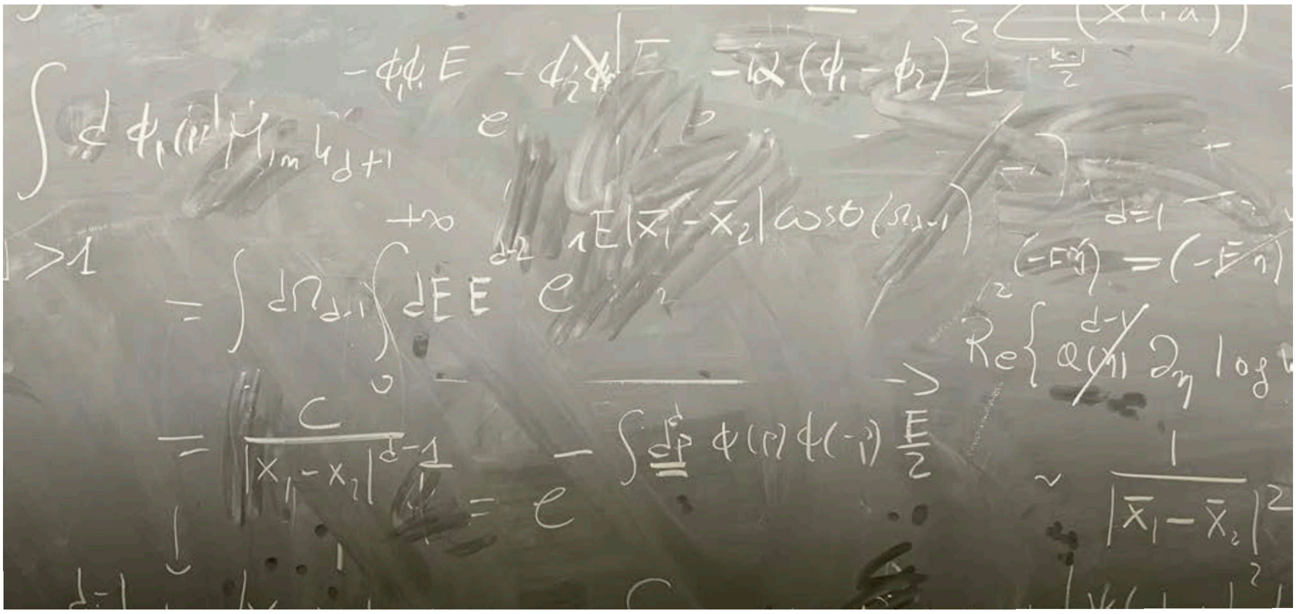
NBIA Research

Theoretical Particle Physics

A common theme of the theoretical particle physics group at the NBIA is the efficient evaluation of scattering amplitudes based on a variety of new developments that have essentially revolutionized the field over the past two decades. The scattering amplitudes are needed for the understanding of data from the Large Hadron Collider (LHC) at CERN, they are at the core of relativistic quantum field theory, and in there has been a surge in new methods for computing them. These methods transcends the original goals and point toward completely new ways of understanding perturbative quantum field theory. Amplitudes are computed in what is known as perturbation theory. One starts with a rough approximation ("tree level") and then gradually builds up a sum of new terms ("loops"). The most powerful methods for such computations have so far mostly focused on establishing compact expressions for the the integrands of such amplitudes. Work at the NBIA moved very strongly ahead on how to integrate these expressions. This work at the NBIA has interesting ramifications in mathematics and indeed proceeds hand in hand with new developments in pure mathematics. The NBIA group has been recently expanding greatly into this area and the number of publications, visitors, and seminars on this topic rose dramatically in 2019.

A completely new area of interest to the particle physics group at the NBIA has been the use of methods from theoretical particle physics to the evaluation of physical observables in general relativity, both at the classical level, and at the quantum level where gravity is treated in the sense of effective field theory. Work on quantum amplitudes suddenly finds new and unusual applications in the urgently needed analytical approximations to the scattering and bound state problem of two heavy and very compact objects (such as two black holes). The development has been long underway, but it received new momentum with an NBIA publication linking classical general relativity to scattering amplitudes in 2018, quickly followed up by papers from other groups elsewhere. The full computational power of the methods recently discovered in amplitude calculations made it possible to break completely new ground by American scientists who in 2019 managed to calculate the interactions between two black holes up to what is known as third order in the post-Minkowskian expansion of general relativity. Such calculations are urgently needed in order to be able to deduce physical observables from the spectacular observations of gravitational waves that began in 2015. Both effective field theory and new and efficient amplitude computations are needed in order to understand the subtle and small effects of higher order perturbation theory in classical gravity. The NBIA group has contributed to the foundational basis of these new developments by demonstrating the equivalence of two competing analytical methods, and by deriving a direct relationship between parameters of the effective potential governing the two-body interactions and the classical part of the amplitudes as computed in perturbation theory. The striking new relationship between classical general relativity and modern amplitude computations is a prime example of the surprising twists and turns in science, and the unexpected results that can come out of different subjects being investigated in the same scientific environment such as the NBIA.

Scattering amplitudes have also been most urgently needed for experiments based on the so-called Standard Model of particle physics, a gauge theory with gauge bosons, fermions, and a single scalar particle, the Higgs particle. Most prominent scattering processes relevant for the LHC are known up to third order in perturbation theory, corresponding to what is known in the field as two-loop order. Current efforts of the particle theory group consist in extending this in several directions. First, it is widely believed that what is today called the Standard Model of particle physics is only a small part of the full story, valid at the energies accessible today at the LHC. At higher energies new interactions are almost certain to emerge, hidden today by the large amount of energy required to see even small traces of them.



Part of the group at the NBIA is leading the effort to establish the most general framework for parametrizing the effects of interactions at higher energies. Known as Standard Model Effective Field Theory, it uses the sophisticated language of effective field theory to concisely pinpoint experimental consequences of the hidden interactions at higher energies, given the known particle content and symmetries of the Standard Model at the energies currently probed at the LHC. On the theoretical side there is no escape from the fact that the Standard Model of particle physics then becomes augmented by a large number of new interaction terms. But order-by-order, in an ordering dictated by available energy, the number of new terms is finite and they can be treated by the conventional tools of quantum field theory. Crucial to this program is the computation of the contribution of these new terms to the already established scattering amplitudes of the Standard Model alone. The group at the NBIA has been leading this program and continues to push it forward.

A major direction of research in the particle physics group at the NBIA concerns the efficient computation of scattering amplitudes in quantum field theories in bigger generality. The immediate impact of this program is the availability of new methods that allow other groups to compute scattering amplitudes in the Standard Model to yet higher order. Moreover, the general development in just these years shows that the original methods for such computations (based on so-called Feynman diagrams) have become completely replaced by modern techniques that have allowed computations up to complexities that just a few years ago were thought impossible. This concerns both the number of particles in the final states of the processes, and the order in perturbation theory for a given fixed number of particles in the final states. The latter problem, the computation of scattering amplitudes at what is known as high loop order is generically a daunting task. Much progress appears through first understanding the complexities in a theory similar to the Standard Model of particle physics, but with a large amount of a hypothetical symmetry known as supersymmetry. The group at the NBIA has been very actively pursuing this program of high loop order calculations. Many surprises have appeared already in the theory with large amount of supersymmetry, and will surely leave their marks also on high loop-order calculations in the Standard Model of particle physics, without supersymmetry.

A remarkable interplay between string theory and quantum field theory has led to the invention of an entirely new method for calculations of scattering amplitudes known as the Cachazo-He-Yuan (CHY) formalism. Recent developments in this direction at the NBIA have revealed a novel factorization property of such scattering amplitudes at tree level from what is known as a “double cover”. Work at the NBIA is currently exploring this new direction as well as the application of the CHY-formalism to the classical physics of scattering in gravity, hand in hand with the developments described above.

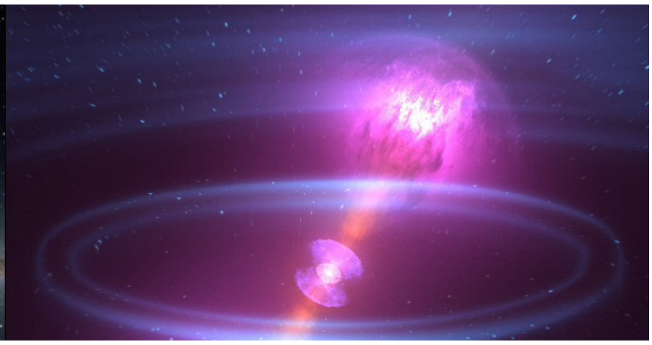
Astroparticle Physics & Cosmology

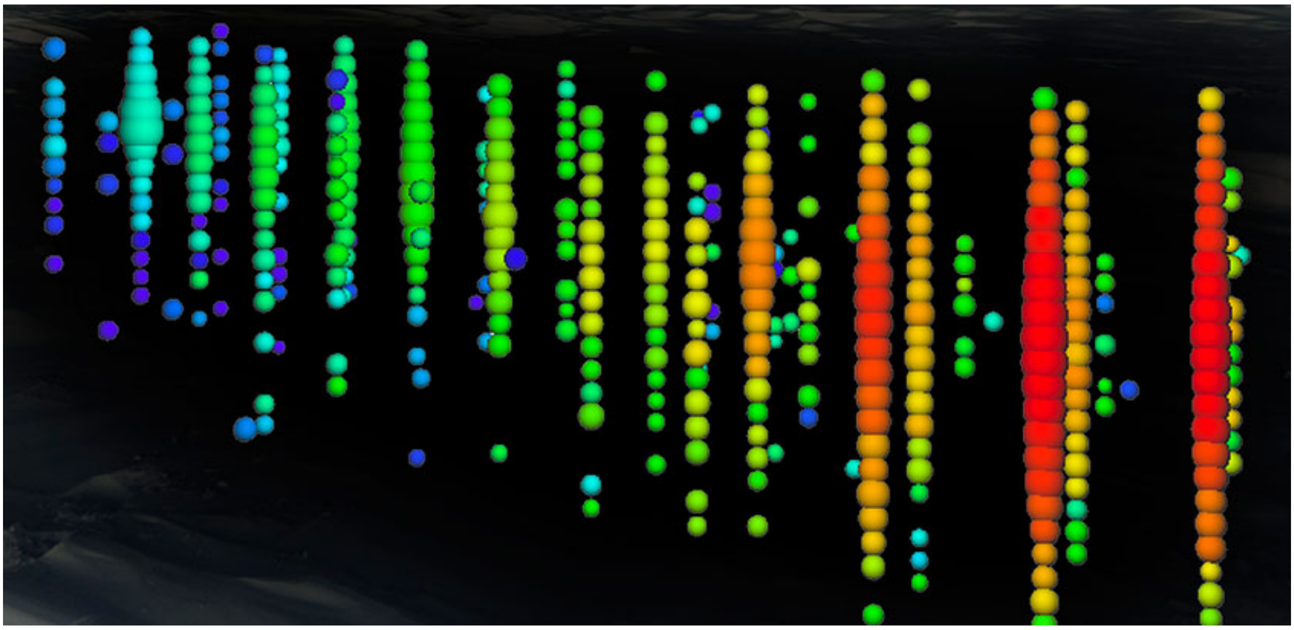
The research of the Astroparticle Physics Group lies at the rich interface between astrophysics, cosmology and fundamental physics. We are particularly interested in high-energy phenomena in our Universe that can be inferred from the observation of cosmic rays (energetic charged particles), gamma-rays (energetic photons) and neutrinos. The range of scientific questions that can be addressed with these energetic cosmic messengers is quite broad and covers various related aspects. A strong focus of our research lies on astrophysical neutrinos: their impact on stellar evolution, their potential to probe compact astrophysical environments (e.g. core-collapse supernovae), their fundamental properties inferred from interactions in dense environments and cosmic backgrounds, their direct probe of the origin of cosmic rays, and their observation in neutrino telescopes or experiments.

Presently, the most sensitive neutrino telescope in the TeV-PeV energy range is the IceCube observatory located at the South Pole. Our group maintains a strong collaboration with the experimental IceCube group, hosted by the Discovery Center. In 2013, IceCube made the first observation of high-energy (TeV-PeV) neutrino emission from extra-terrestrial sources. The origin of these neutrinos is presently unknown and one of the main scientific questions presently addressed in our research. For instance, last year our group studied implications of astrophysical neutrino flavours based on observations with IceCube and present uncertainties of neutrino mixing parameters. We developed a method that allows to translate standard neutrino flavour measurements into a posteriori flavour distributions at the source and therefore to probe initial neutrino production processes.

The IceCube neutrino experiment is in the process of receiving an intermediate upgrade and has plans for a large-scale expansion (IceCube-Gen2) in the next decade. To aid this process, our group played a leading role in two contributions to the “Decadal Survey on Astronomy and Astrophysics” (Astro2020) conducted by the US National Academies in 2019. The outcome of this survey influences the future allocation of US funding of large-scale astronomical instruments. The two submissions highlight the scientific potential of neutrino astronomy as a unique probe of astrophysics and fundamental physics.

An increasingly important aspect of our research are multi-messenger studies between high-energy neutrinos, gamma-rays and gravitational waves. A recent highlight in multi-messenger astronomy was the first observation of a binary neutron star merger in terms of photons (GRB 170817A) and gravitational waves (GW170817) on August 17, 2017. At that time, the IceCube collaboration was able to place upper limits on neutrino emission coincident with the short initial gamma-ray burst. The late-time afterglow of this object allows now to create detailed models of the initial jet structure. Based on these jet models, our group developed neutrino emission models for off-axis observers that provide new insight into IceCube’s limits.



Recent measurements of cosmic rays with state-of-the-art observatories have revealed hidden structures in cosmic ray spectra and arrival direction distributions. These data provide new possibilities to test the origin of cosmic rays and mechanisms of cosmic ray transport in Galactic and extragalactic environment with unprecedented precision. Our group is active in the analysis and interpretation of weak anisotropies in cosmic ray arrival directions at the level of 1 part in 1,000 or even 10,000. A highlight from 2019 is the first all-sky anisotropy reconstruction of Galactic cosmic rays from a combined analysis of IceCube and HAWC data. This analysis was based on a sophisticated reconstruction method developed by our group. Using the same reconstruction method, we were also able to reveal strong evidence of medium-scale anisotropies public data from the KASCADE-Grande experiment. The anisotropy is spatially coincident with the Cygnus region, that is also known for its unusually strong gamma-ray activity.

The Astroparticle Physics Group is also interested in the observational evidence of dark energy inferred from type Ia supernovae data. Considered as "standard candles" in cosmology, the observed flux allows to study the expansion of the local Universe by the comparison of luminosity distance to observed redshift. Our group has critically examined the observational data in light of a "bulk flow" in the local Universe which is faster and extends to much larger scales than is expected around a typical observer in standard cosmology. The cosmic acceleration deduced from supernovae data may thus be just an artefact of our being non-Copernican observers, rather than evidence for a dominant component of dark energy in the Universe.

Another line of research is the physics of the early Universe that can be studied by the primordial power spectrum (PPS) of curvature perturbations inferred from cosmic microwave background anisotropies or large-scale structure. The data suggest that the usually assumed power-law PPS has localised features. Our group showed that any given reconstruction of the PPS can be mapped on to functional parameters of an underlying effective theory. In this way, it is possible to identify simple representative inflationary models of the early Universe. Our group also derived analytic bounds on the shape of the PPS in the context of single-field inflation. These bounds have a particular relevance for models which generate relics due to an enhanced amplitude of the primordial scalar perturbations, such as primordial black holes. Furthermore, members of our group have been playing a leading role in the commission and proposal of the next generation of cosmic microwave background (CMB) observations, as part of the Astro2020 survey. CMB spectral distortions offers a hitherto untapped window into the thermal history of the early universe, as well as providing a window on small scale structure not accessible through other probes.

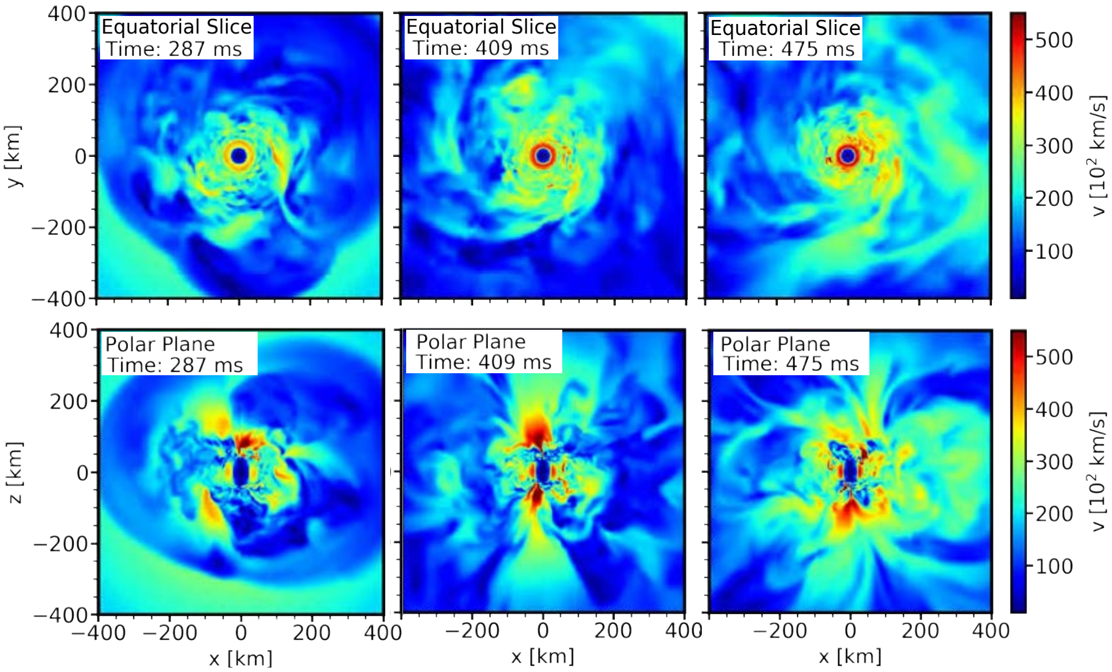
Neutrino Astrophysics

The Neutrino Astrophysics (AstroNu) group at NBIA aims at using the neutrino, a weakly interacting elementary particle, as messenger of poorly understood extreme astrophysical phenomena. Neutrinos are copiously produced in a number of astrophysical environments, ranging from the Sun to the most extreme transients and play a crucial role in powering those sources. The AstroNu group investigates how neutrinos affect the dynamics of these phenomena and explores what can be learned about standard and non-standard properties of neutrinos through astrophysical sources and from the Early Universe.

In 2019, the AstroNu group maintained strong ties with scientists at the Max Planck Institutes for Physics and Astrophysics through the Collaborative Research Center: Neutrinos and Dark Matter in Astro- and Particle Physics sponsored by the Deutsche Forschungsgemeinschaft. Thanks to the partnership between NBIA and the Academia Sinica in Taiwan, we continued to have active scientific collaborations with Dr. Wu (former postdoc of the AstroNu group, now affiliated member of our group). Two new PhD students, one new postdoc and two new Master students joined our group in 2019. Moreover, the AstroNu group hosted two exchange students, one from France and one from Mexico, and a number of international visitors.

In summer 2019, we successfully hosted the NBIA & LANL workshop: "Neutrino Quantum Kinetics in Dense Environments" in Copenhagen and co-organized the workshop SNEWS 2.0: Supernova neutrinos in the multi-messenger era in Canada as well as the PhD School "Advancing Theoretical Astrophysics" in Amsterdam. In addition, the AstroNu group members have been active in outreach activities, through lectures and by contributing to a number of articles for national and international newspapers on various topics in Particle Astrophysics.

A wide range of terrestrial and celestial sources produces neutrinos. Similarly to what is routinely done with photons, we built the Grand Unified Neutrino Spectrum and reviewed the neutrino emission from all possible sources across various energy bands.



Neutrinos have been studied since long time now, however, some of their properties, e.g. their possible interactions beyond the ones foreseen by the Standard Model, remain to be unraveled. The AstroNu group focused on modeling and constraining various scenarios of Non Standard Physics by employing astrophysical neutrinos. For example, we worked on understanding how the supernova evolution would be affected by sterile neutrinos with keV-mass (extra neutrino species currently considered good dark matter candidates). Our work has been the first step towards a self-consistent modeling of the sterile neutrino production and propagation in supernovae. Our research highlighted the major limitations of existing work on the topic and the dramatic relevance of a self-consistent modeling of the sterile neutrino production within the stellar core and its feedback on the stellar dynamics. Only a self-consistent modeling will place constraints on the existence of these particles.

Another research direction pursued in 2019 concerns the possibility of characterizing the properties of core-collapse supernovae through neutrinos. By employing three-dimensional hydrodynamical simulations of core-collapse supernovae, we pointed out that neutrinos can discriminate intrinsic properties of supernova rotation and carry detectable imprints of black hole forming stellar collapses. Given that neutrinos and gravitational waves are produced deep in the core of supernovae, for the first time, we employed neutrinos and gravitational waves to do supernova asteroseismology. The latter offers a unique window on the physics of the proto-neutron star, which is otherwise difficult to probe.

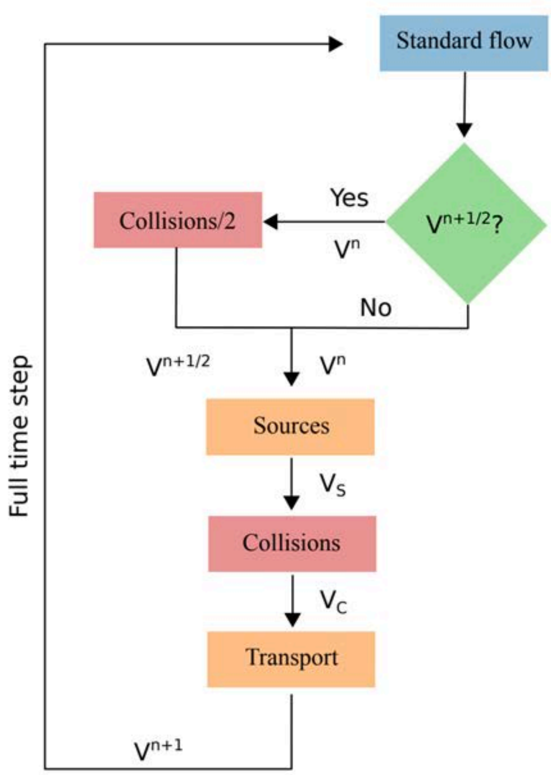
One of the most burning questions in particle astrophysics revolves around the role of neutrinos in compact astrophysical sources. In particular, compact binary mergers and core-collapse supernovae host a high density of neutrinos such that neutrino-neutrino interactions are not negligible. We focused on understanding under which conditions such interactions could lead to non-negligible flavor conversions. Notably, we developed the first multi-dimensional numerical modeling of the flavor evolution in compact astrophysical sources, moving beyond the limitations intrinsic to the analytical models adopted until now.

The AstroNu group also worked on exploiting the increasing amount of high energy neutrino events detected by the IceCube Neutrino Telescope to better understand the yet mysterious origin of these neutrinos, constrain the unitarity of the neutrino mixing, and the poorly known long-range interactions. We also provided an improved estimation of the neutrino-nucleon cross section at high energies. The origin of cosmic rays remains very mysterious. Upcoming radio-array neutrino facilities could help to finally unravel the origin of these particles as well as allow exploring the neutrino energy distribution at ultra high energies for the first time. The AstroNu group has been involved in defining the science goals of the next-generation neutrino experiment GRAND. For example, we showed that the detection of ultra-high-energy neutrinos in GRAND could constrain the yet unknown composition of cosmic rays as well as the redshift evolution of their sources.

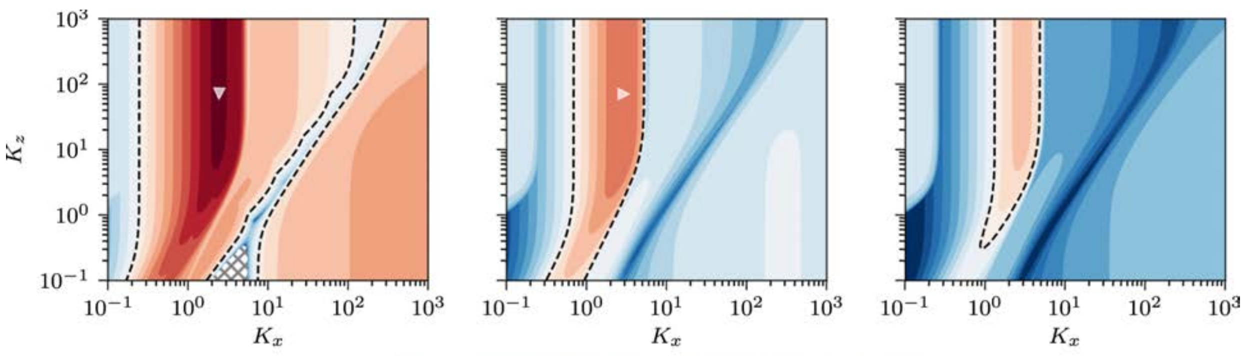
Theoretical Astrophysics

The Theoretical Astrophysics Group at the Niels Bohr International Academy strives for a comprehensive approach to astrophysics. Current research areas encompass protoplanetary disks and planet formation, black hole accretion disks, the physics of gravitational waves sources, and the intracluster medium in galaxy clusters. All of these problems are tackled with a very wide perspective, ranging from fundamental theoretical aspects to state-of-the-art simulations that make it possible to link theory with observations.

For thousands of years, humankind had only been aware of the handful of planets composing our Solar System. This changed dramatically over the last two decades with the discovery of several thousand planets around nearby stars. Most of these, so-called exoplanets, show remarkable differences when compared to the Solar System. We believe that processes leading to the formation of planets, combined with environmental effects associated with the protoplanetary disk in which they form, play a fundamental role in sculpting planets and planetary systems. Thus, in order to understand the wide diversity of planets we observe, and contextualize our own Solar System, it is critical to study and characterize such mechanisms self-consistently together with the dynamical evolution of the protoplanetary disk.



Our understanding of protoplanetary disks is undergoing a revolution driven by high-resolution observations. In order to unravel the processes driving the evolution of these disks it is critical to accurately model and solve numerically the self-consistent dynamics of gas and dust species. Several fundamental processes in protoplanetary disks in which dust dynamics plays an important role are usually investigated in the realm of monodisperse dust distributions. In order to overcome this simplification, we developed an asymptotically and unconditionally stable numerical method, which conserves momentum to machine precision, to account for the momentum transfer between multiple species. Aimed at studying dust dynamics, we implemented this numerical method in the publicly available code FARGO3D being developed by group members. Carrying out successfully a large number of tests, we showed that our scheme is suitable, and very robust, to study the self-consistent dynamics of several fluids. In particular, it can be used for solving the collisions between gas and dust in protoplanetary disks, with any degree of coupling. This framework opens up new opportunities for investigating a wide range of fundamental processes occurring in multi-species protoplanetary disks and planet formation including, for example, resonant drag instabilities and the structure and observational signatures of dusty protoplanetary disks harboring planets.



The streaming instability is thought to play a central role in the early stages of planet formation by enabling the efficient bypass of a number of barriers hindering the formation of planetesimals. In 2019, we presented the first study exploring the efficiency of the linear streaming instability when a particle-size distribution is considered. We found that, for a given dust-to-gas mass ratio, the multi-species streaming instability grows on timescales much longer than those expected when only one dust species is involved. In particular, distributions that contain close-to-order-unity dust-to-gas mass ratios lead to unstable modes that can grow on timescales comparable to, or larger than, those of secular instabilities. We anticipate that processes leading to particle segregation and/or concentration can create favorable conditions for the instability to grow fast. Our findings may have important implications for a large number of processes in protoplanetary disks that rely on the streaming instability as usually envisioned for a unique dust species. Our results suggest that the growth rates of other resonant-drag instabilities may also decrease considerably when multiple species are considered. This may have important implications for our understanding of how planetesimals form and evolve.

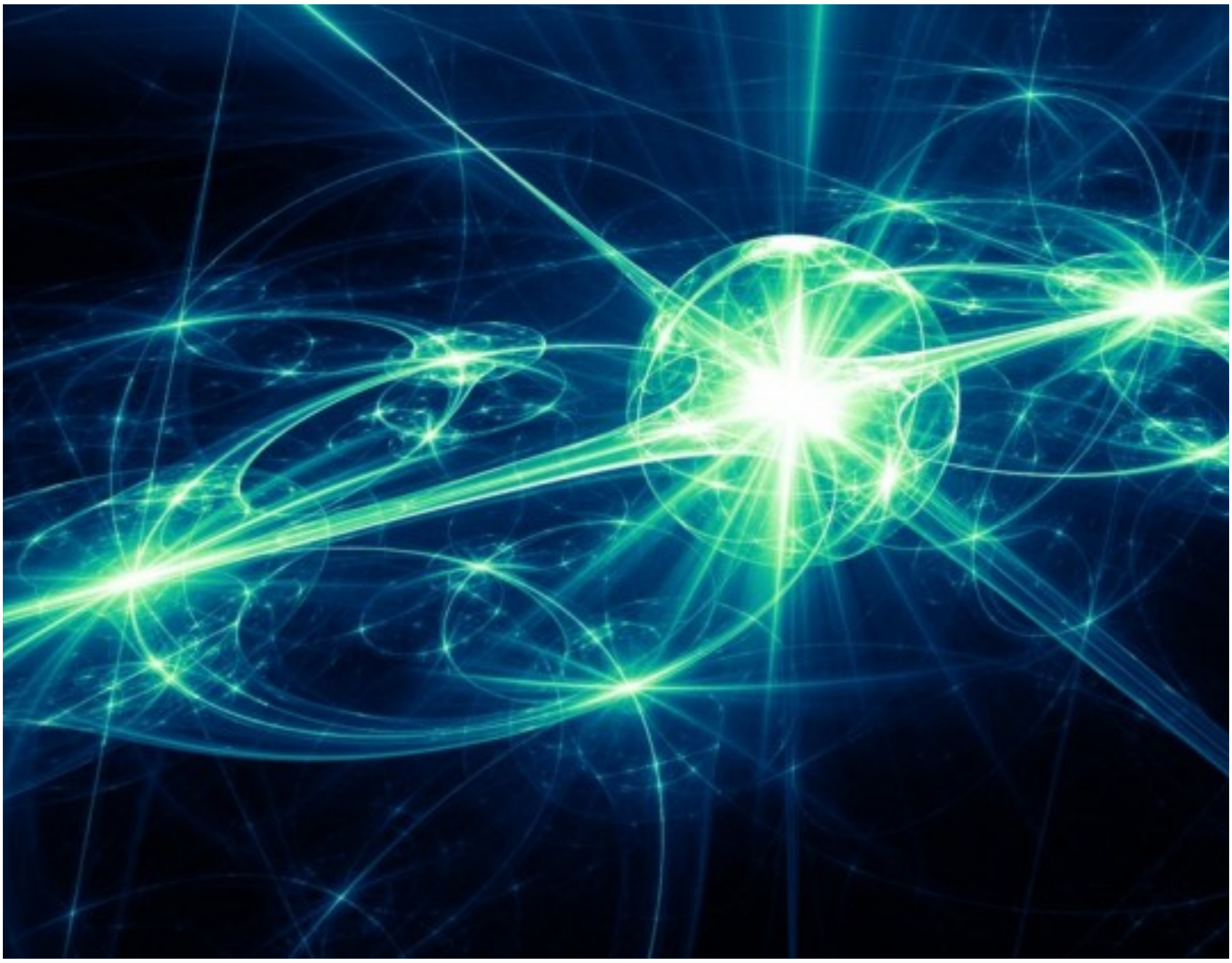
Understanding the connection between the large-scale disk features that result from the interaction between the forming planets and the disk is crucial not only for inferring the presence of planets but also for unraveling the crucial processes that shape planet formation. A planet embedded in a gaseous disk gives rise to a number of interesting physical processes. The most evident being spiral density waves that can transport angular momentum away from the planet, potentially altering its orbit. If the planet is massive enough, it can open up a gap in the disk. In the framework of the standard accretion disk model, the structure of the disk and gap result from the balance between the torques exerted by gravity, pressure, and viscosity. Due to the formidable complexity of this problem, a number of approximations have been invoked in order to model planetary gaps. Even though the spiral density waves that shape the gap structure are inherently non-axisymmetric, the vast majority of gap models assume axi-symmetry. The resulting one-dimensional models lead to gaps that are many orders of magnitude deeper than the original two-dimensional models, highlighting the shortcomings of current approaches. Our group is developing improved one-dimensional models of disks with planetary gaps that can accurately describe the most important disk properties as revealed by 2D hydrodynamical simulations.

This year, gravitational wave astrophysics has also opened as a new branch in the Theoretical Astrophysics Group. Gravitational waves were first observed in 2015 after decades of pioneering work, and we are therefore in a unique position to gain new insight into several fundamental questions, such as how black holes form in our Universe, and how matter behaves under the extreme conditions found in e.g. neutron stars. A few dozen of merging black-hole binaries have been observed to date, but how and where these systems form in our Universe are still major open questions. In the Theoretical Astrophysics group we are currently developing a new framework for describing how black hole binaries form and collide in very dense stellar systems, such as galactic nuclei and globular clusters. This work will lead to tight constraints on the origin of black hole mergers with the help of upcoming gravitational wave data.

Condensed Matter Physics

In the condensed matter theory group at NBIA we aim to discover new quantum dynamical phenomena and phases of matter. Our work covers a broad spectrum of topics, from solid state nano- and mesoscopic systems and quantum bits, to hybrid and bulk topological materials, cold atom systems, and more general aspects of quantum many-body dynamics. We maintain close ties with experimentalists at the Center for Quantum Devices and Microsoft Station Q Copenhagen, as well as other groups worldwide.

Topological phenomena are the subject of intense interest in the field due to their incredible robustness against perturbations. A prominent example of such behavior is the quantized Hall effect — when a two-dimensional electron system (as found in common semiconductor heterostructure devices, or graphene) is subjected to a strong magnetic field, the system's Hall conductance takes on a precisely quantized value, which is equal to an integer or simple rational fraction times a combination of fundamental constants (the electron charge and Planck's constant). What is so amazing about this phenomenon is that the quantization of this macroscopically measurable quantity is accurate to better than one part in one billion, independent of sample size and shape, as well as material composition, and survives in the presence of all of the "dirt" that inevitably permeates real-world solid state systems. Due to the exquisite precision of this effect, the quantized Hall conductance is now used as a measurement standard for the definition of resistance.



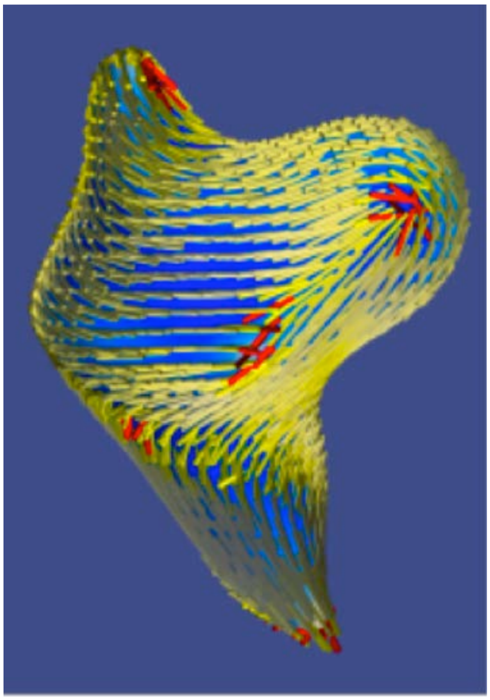
From a fundamental point of view, the robustness of the quantized Hall effect arises from a beautiful mathematical (topological) structure of the quantum mechanical wave function of the electrons in the system. This theoretical realization spurred a worldwide effort to seek out additional types of robust phenomena that could support a similar level of "topological protection." Such effects have, for example, even been proposed as forming the basis for an extremely powerful and fault-tolerant architecture for quantum computing. Seeking means to realize the quantum states necessary for building such a topological quantum computer comprises an important piece of our research in condensed matter theory at NBIA. Toward this end, in 2019 we have developed new paradigms for obtaining topological states and phenomena, both in thermodynamic equilibrium and in dynamical steady states of systems driven far from equilibrium. Our research is built on a combination of analytical work and numerical simulations that support our analysis and allow us to explore regimes beyond where analytical techniques can be applied.

One of the major aims of our research on quantum dynamics is to uncover new ways of dynamically engineering material properties through non-equilibrium driving. In particular, we are field leaders in the area of topological phenomena in periodically driven, or "Floquet" systems. Over the past 10-15 years, experimentalists have made great progress in developing new tools for probing and controlling the dynamics of solid state and cold atomic quantum many-body systems, e.g., using lasers and strong microwave fields. In this work we aim to bring together these new capabilities with modern theoretical notions of topological states, prethermalization, and many-body localization, to identify new routes for realizing and exploring topological phenomena out of equilibrium. The fruits of this work are two-fold: 1) time-periodic driving provides means to dynamically control the effective electronic structures of materials, potentially opening the opportunity to realize a variety of material properties on-demand, in a single system, and 2) by leaving the world of thermodynamic equilibrium (and the many constraints it imposes) behind, we find wholly new types of interesting and potentially useful robust quantum phenomena, which fundamentally can not occur in equilibrium. We have already uncovered a number of such phenomena, and continue to seek more, to study their properties, and to provide guidance to experimentalists to enable their realization in the lab. This work involves close collaborations with colleagues at Caltech, University of Geneva, Nanyang Technological University, Technion Institute of Technology, and the Weizmann Institute of Science. In 2019, our results on a novel form of non-equilibrium spontaneous symmetry breaking were featured on Phys.org, Nature Physics "News and Views," and in the Danish newspaper "Weekendavisen."

In addition to our research on developing robust platforms for eventual quantum computation, we are also deeply involved in present-day efforts in quantum simulation. A universal quantum computer is a single device comprised of quantum bits that can be manipulated to carry out arbitrary types of quantum computation tasks (analogous to a classical digital computer). In contrast, a quantum simulator is a specialized piece of well-controlled quantum hardware that is designed to emulate the behavior of a particular type of quantum system of interest. By carrying out and monitoring the quantum evolution under well-controlled conditions in the simulator, valuable insight can be gained about the nature of the original system of interest. In 2019, in collaboration with teams at Harvard and TU Delft, we participated in the theoretical analysis and experimental demonstration of the use of an array of solid state spin qubits as a quantum simulator to study the emergence of magnetism in interacting electronic systems. This work led to the first experimental demonstration of the so-called Nagaoka mechanism of ferromagnetism.

Soft Matter Physics & Active Matter

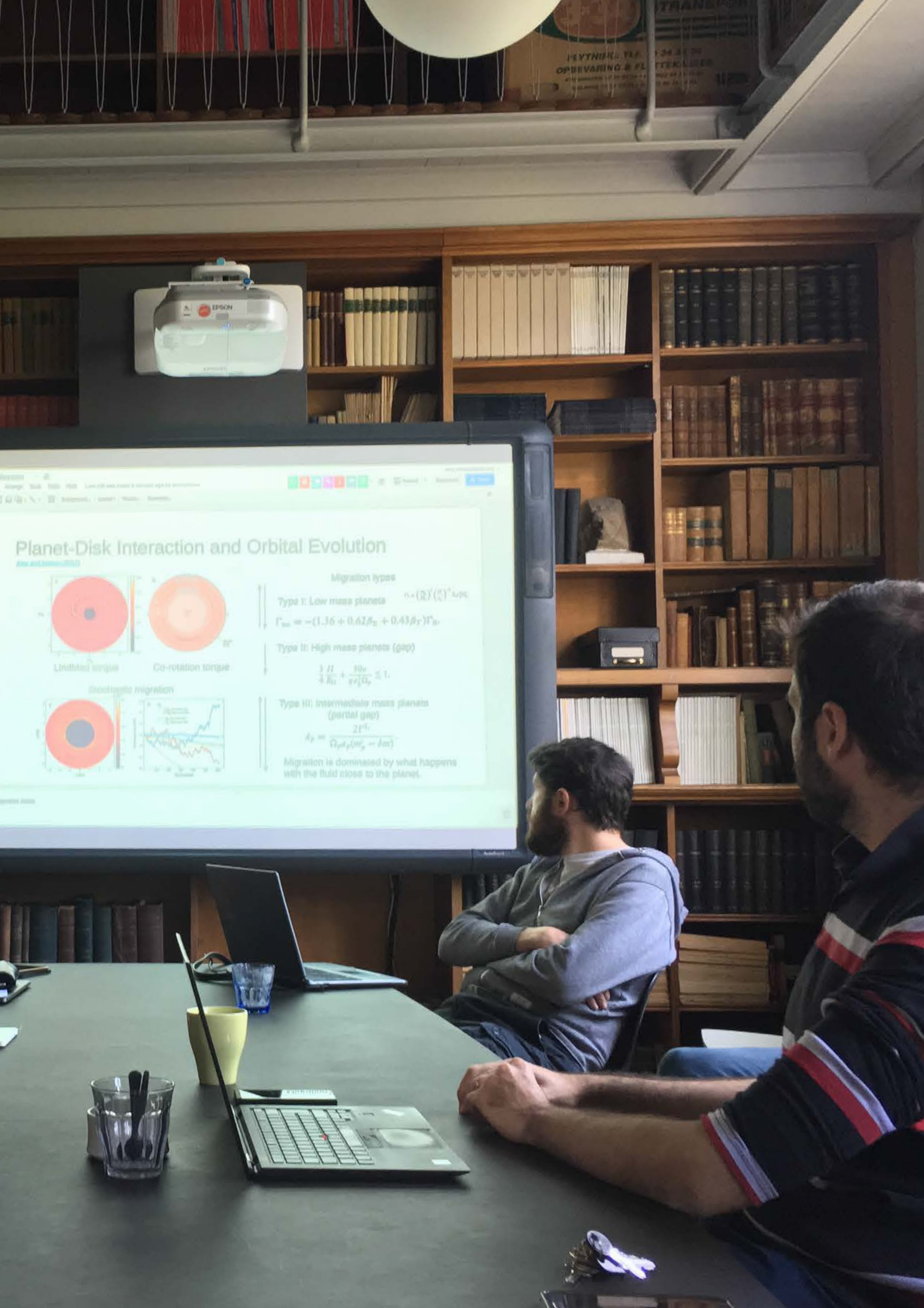
Soft matter physics lies at the heart of a quantitative understanding of many biological processes. From subcellular protein-driven flows to multicellular organ formation, biological matter continuously drives itself away from thermodynamic equilibrium using internal biochemical processes. In addition to their important biological roles, these intrinsically multiscale systems provide novel ideas for fundamental theories of non-equilibrium statistical physics and biomimetic inspiration for synthetic micro-machines capable of locomotion and self-organization. To tackle these diverse subjects, NBIA has recently launched an exciting new initiative to expand into soft matter physics and in particular the hot topic of active, self-organizing matter. Specifically, the research is focused on two fundamentally important areas in biophysics:



Bioinspired, Self-Organizing Active Matter: A material that organizes itself? Odd as this might sound, nature has found ways to make it happen: bacterial colonies, cellular tissues, and filaments inside living cells, all work as engines converting the chemical energy of their environment into motion, and are classified as “active materials”. The unifying feature of active materials is the continuous conversion of chemical energy to motion by individual particles, and the ability to create motion on scales that are significantly larger than the size of an individual. This swarm-like behavior is termed collective motion: simple building blocks organize into moving structures that are often complex and chaotic. Under the right conditions, active systems are capable of self-organization from chaotic flows into coherent flows: groups of active particles move together as a unit in a directed manner, forming a self-pumping fluid. However, the exact nature of these “right conditions” is currently the focus of intense study as many biological processes - including subcellular flows, formation of bacterial biofilms, morphogenesis, and collective tumor invasion – demonstrate active coherent flows. An outstanding question is how the activity of particles at the individual particle level is translated into self-sustained coherent flows. The key challenge is the gap between the scale of an individual particle and the scale of the collective motion. With an expertise in both discrete models and continuum theories, which enables us to explore the differing scales of the active matter, we are one of the pioneering groups to tackle this challenge. Specifically, our research has resulted in understanding: *i)* Under what physical conditions self-pumping coherent flows of active matter are established and *ii)* How can we design, control, and exploit coherent active flows as a novel transport mechanism for particles and fluids at micron scale. From the biological perspective, understanding the principles behind coherent active flows has enormous potential both for improved medical interventions and for targeted drug delivery. It offers fundamentally new capabilities to control the concentration of molecules in space and time. From the science point of view, studying these intrinsically multiscale systems provides novel ideas for fundamental theories of non-equilibrium statistical physics. From the technological perspective, understanding how self-pumping flows can be generated would prove to be a tremendous advance in the emerging field of microfluidics, where conventionally, external flows are imposed for mixing in micro-reactors, or for pumping flows at microscales.

Mechanostransduction: How do mechanics guide biochemical signaling? There is growing evidence that mechanical forces can activate biochemical signaling for tissue regeneration, stem cell differentiation, and morphogenesis. Importantly disruption of this effect by changes in the microenvironment leads to pathological responses including tissue fibrosis and cancer. The connection between mechanical forces and cell response is the process of mechanotransduction: mechanical forces activate biochemical signals by changing the concentration of mechanosensing proteins inside the cells. For example, putting cells under excessive tension localizes proteins that control cell division inside cell nuclei, leading to hyper-proliferation. Diffusion of chemical signals is too slow to be able to convey the mechanical information across the tissue. On the contrary, the force transmission between the cells provides a fast and long-range mechanism for propagation of mechanical cues over large spatial scales. Therefore, it is essential to understand the mechanism of mechanotransduction in the context of multicellular aggregates. The advent of new technologies for high-resolution microscopy and force measurement have made it possible to isolate the effect of mechanical forces from genetic and chemical factors. This gives us an unprecedented access to investigate fundamental questions on how mechanical forces at the tissue scale are able to affect biochemical signaling at a single cell level. Indeed, our early results show that the mechanical features of the tissue are key factors in activating cell division and cell death signals. At NBIA we combine multiscale modeling – discrete and continuum simulations of cell mechanics with in-house experiments to reveal the impact of mechanical forces from multicellular motion on signaling and the mechanical feedback from the activation of biochemical signaling. Our efforts are directly relevant to pattern formation during organ development, where tissue is normally under deformations and geometrical constraints. For instance, high aspect ratios are involved during various organ developments such as somite formation. Similarly, geometric constraints can be candidates for mechanically directing stem cell organization during early stages of development. We are also currently working on extending our results for designing biomaterial structures that foster tissue regeneration through focusing mechanical forces. Moreover, extreme mechanical forces emanating from abnormal physical constraints, for example inflammation or stiffening of the extracellular matrix can over-activate division signals, leading to unrestrained proliferation and metastasis. Similar undesirable activation of signals by mechanical forces is likely to be at play during hypertension and fibrosis. It is no longer hard to imagine that targeting mechanotransduction can be a future candidate for therapeutics of such diseases. Indeed, several new experiments have reported first results in this direction, and we are poised to capitalize on these advances.

Links with experiments are important in conducting these studies. We have launched exciting collaborations with international experimental groups in France (University Paris Diderot) and Japan (Osaka University), as well as with the Danish Stem Cell Center to profile NBIA as one of the leading institutions in these rapidly growing areas of research.


EPSON
Planet-Disk Interaction and Orbital Evolution
Migration types
Type I: Low mass planets
Lindblad torque
Co-rotation torque
Type II: High mass planets (gap)
Type III: Intermediate mass planets
(partial gap)
Migration is dominated by what happens
with the fluid close to the planet.

NBIA Staff

Faculty

Niels Emil J. Bjerrum-Bohr completed his Ph.D. in Copenhagen in 2004. He was postdoc in Swansea 2004 - 2006, concentrating his research on amplitudes for gauge theories and quantum gravity. He was a Member at the Institute for Advanced Study in Princeton 2006-09. Emil was appointed Knud Højgaard Assistant Professor at the NBIA in 2010, at the same time being awarded a Steno grant from the Danish Science Research Council. He was appointed Associate Professor in 2016. He is currently a Lundbeck Foundation Junior Group Leader and Associate Professor at the NBIA. Emil's current research focuses on amplitudes in Yang-Mills theory and quantum gravity.

Matthias Christandl is a Professor at the Department of Mathematical Sciences in Copenhagen. His research is in the area of Quantum Information Theory. It is his aim to improve our under-standing of the ultimate limits of computation and communication given by quantum theory. Concrete research results include a proposal for a perfect quantum wire and a new method for the detection of entanglement. Matthias received his PhD from the University of Cambridge in 2006. He then became a Thomas Nevile Research Fellow at Magdalene College Cambridge. In 2008, he joined the faculty of the University of Munich and 2010-14 he was assistant professor at ETH Zurich. He moved to the University of Copenhagen in April 2014.

Jacob Bourjaily joined NBIA as Assistant Professor in 2014 and became Associate Professor in 2019. Jacob completed his Ph.D. at Princeton University in 2011, writing a thesis on scattering amplitudes in quantum field theory under the supervision of Nima Arkani-Hamed at the Institute for Advanced Study. Jacob continued this research while a Junior Fellow in the Harvard Society of Fellows at Harvard University 2011-2014 before taking up his current position at the NBIA. The primary focus of Jacob Bourjaily's research has been working toward an emerging reformulation of quantum field theory. He has contributed in numerous ways to the subject, including the discovery of a recursive description of scattering amplitudes to all orders of perturbation theory. For this work, Jacob was awarded a MOBILEX grant from the Danish Council for Independent Research.

Poul Henrik Damgaard did his undergraduate studies at the University of Copenhagen and then went to Cornell University, where he received his PhD in 1982. He has held postdoctoral positions at Nordita, CERN, and the Niels Bohr Institute, and has for a period of six years been Scientific Associate at the Theory Group of CERN. In 1995 he took up a position as Senior Lecturer at Uppsala University and that same year moved to the Niels Bohr Institute on a similar position. He has been Professor of Theoretical Physics since 2010, and Director of Niels Bohr International Academy since its beginning in 2007. His current research interests include modern techniques for amplitude computations, non-perturbative studies of supersymmetric theories on a space-time lattice, and constraints on so-called electroweak baryogenesis from the Large Hadron Collider (LHC).

Tobias Heinemann joined the NBIA as an Associate Professor after postdoctoral appointments at the IAS in Princeton, at the University of California at Berkeley and KITP, University of California, Santa Barbara. His research interests span a wide spectrum of problems in astrophysical fluid dynamics and magnetohydrodynamics.

Andrew Jackson is Professor and Board Chair at the NBIA. Born in New Jersey, he was educated at Princeton University and received his PhD in experimental nuclear physics. After almost three decades at the State University of New York at Stony Brook as professor of Theoretical Physics, Andrew joined the Niels Bohr Institute in 1996. He is a Fellow of the American Physical Society and the American Association for the Advancement of Science and is also a member of the Royal Danish Academy of Sciences and Letters. His current interests include the biophysics of the action potential, the study of cold atomic gases, and various topics in the history of science.

D. Jason Koskinen is an Associate Professor and local group leader for the IceCube Neutrino Observatory. From 2009-2013 he was a postdoc at the Pennsylvania State University, with a brief trip to the South Pole for IceCube calibration studies. His focus is on neutrino oscillations, further physics beyond the Standard Model, and detector extensions to IceCube to probe fundamental properties of particle physics. Jason's research on neutrino mixing and neutrino probes of the universe is graciously supported by a Villum Young Investigator award.

Charles Marcus was an undergraduate at Stanford University (1980-84). He received his Ph.D. at Harvard in 1990 and was an IBM postdoc at Harvard 1990-92. He was on the faculty in Physics at Stanford University from 1992-2000 and Harvard University from 2000 to 2011. In 2012, Marcus was appointed Villum Kann Rasmussen Professor at the Niels Bohr Institute and serves as the director of the Center for Quantum Devices, a Center of Excellence of the Danish National Research Foundation, and director of Microsoft StationQ – Copenhagen. He is an affiliate of the Niels Bohr International Academy. Marcus' research interests involves fabrication and low-temperature measurement of quantum coherent electronics in semiconductors and superconductors, including nanowires, quantum dots, quantum Hall systems, and Josephson devices. Current activities include the realization of spin qubits for quantum information processing and topological quantum information schemes based Majorana modes in nanowires and 5/2 fractional quantum Hall systems.

Ben Mottelson received a Bachelor's degree from Purdue University in 1947, and a Ph.D. in nuclear physics from Harvard University in 1950. He moved to Institute for Theoretical Physics (later the Niels Bohr Institute) in Copenhagen on the Sheldon Traveling Fellowship from Harvard, and remained in Denmark. In 1953 he was appointed staff member in CERN's Theoretical Study Group, which was based in Copenhagen, a position he held until he became professor at the newly formed Nordic Institute for Theoretical Physics (Nordita) in 1957. In 1971 he became a naturalized Danish citizen. He received the Nobel prize in 1975.

Pavel Naselsky did his undergraduate studies at the Southern Federal University of Russia and received his PhD in 1979 at Tartu University. In 1989 he got Doctor Habilitation at Moscow State University, Russia, working with theoretical astrophysics group of Zeldovich. In 2000 Pavel Naselsky took up a position as Associate Professor at the Theoretical Astrophysics Center (Copenhagen, Denmark) and at 2003 he was appointed as Lecturer at the Niels Bohr Institute. He has been Professor of Theoretical Physics since 2015, and group leader of the Theoretical Particle Physics and Cosmology group at the Niels Bohr Institute. His current research interests include modern cosmology, theory of the primordial black holes formation, physics of dark energy and dark matter, physics of the CMB etc. Since 2000 Pavel Naselsky has been working on the Planck project.

Christopher Pethick is Professor at NBIA. He did his undergraduate and graduate studies at Oxford, and received his D. Phil degree in 1965. After a period as a postdoc at the University of Illinois, he joined the teaching faculty there, becoming full professor in 1973. In that year he also became a professor at Nordita. In 2008 he received the Lars Onsager Prize of the American Physical Society for his work on quantum liquids and cold atomic gases, and in 2011 the Society's Hans Bethe Prize for his work in nuclear physics and astrophysics. His research focuses on condensed matter in the laboratory and in the cosmos. Current interests include neutron stars (especially the properties of their outer layers), and ultracold atomic gases.

Martin Pessah obtained his first degree in Astronomy in 2000 from the University of La Plata, Argentina. He received his PhD in Theoretical Astrophysics from the University of Arizona in 2007. He was a Member at the Institute for Advanced Study in Princeton 2007-10. In 2010, Martin moved to Copenhagen as a Knud Højgaard Assistant Professor at the NBIA. In 2012, he started to build a new group in Theoretical Astrophysics after receiving grants from the Villum Foundation and the European Research Council. He became Associate Professor in 2013 and Professor MSO in 2015 and is now leading an active, young group working at the forefront of theoretical and computational astrophysics. His research interests span a broad range of subjects in plasma astrophysics, astrophysical fluid dynamics and magnetohydrodynamics, including fundamental aspects of accretion physics in young stars and and black holes, the interstellar medium, and galaxy clusters.

Enrico Ramirez-Ruiz has been Niels Bohr Professor at the DARK Center since 2016. He was educated at Cambridge University in England and was a long-term member at the Institute for Advanced Study in Princeton. Enrico Ramirez-Ruiz is currently Professor and Chair of the Department of Astronomy and Astrophysics at the University of California, Santa Cruz. He is also the Head of Theoretical Astrophysics at the Santa Cruz Institute for Particle Physics. His research seeks to address some of the pressing open questions surrounding the most violent phenomena in the Universe such as how stars explode as supernovae and the origin of Gamma-Ray Bursts; how stars end their lives and be-come compact objects such as white dwarfs, neutron stars, and black holes; how black holes grow in mass by ripping apart orbiting stars and swallowing the stellar debris; and what happens when two compact objects merge by emitting gravitational waves.

Mark Rudner is an Associate Professor at the NBIA. Mark received his PhD in Condensed Matter Theory from MIT in 2008. After his PhD, Mark spent three years as a postdoc at Harvard. In 2012 Mark landed in Copenhagen to take charge of the Condensed Matter Theory group at the NBIA. Currently Mark's group is enjoying the generous support of the Villum Foundation through the Young Investigator Award Program. He and his group is further supported by an ERC Starting Grant from the EU. Mark's research spans a broad range of topics in quantum dynamics and many-body physics. Current topics of interest include coherence and control in solid state qubits, nonlinear dynamics of many-body spin systems, topology and dynamics in strongly driven systems, and semiclassical dynamics of electrons in topological materials. The condensed matter theory group at NBIA maintains strong links with the Center for Quantum Devices, with a healthy interplay between theory and experiment.

Jan Philip Solovej did his undergraduate studies in Copenhagen and his Phd in mathematics at Princeton University in 1989. He was then a postdoc at University of Michigan, University of Toronto, and IAS Princeton before taking up an assistant professorship at Princeton University 1991-1995. In 1995 he became a research professor at Aarhus University and in 1997 he became a full professor at the mathematics department of the University of Copenhagen. He works in mathematical physics and in particular quantum physics. His current research interests include systems such as atoms, molecules, and gases of fermions, and bosons. His research addresses issues such as stability of matter, superconductivity and -fluidity, and quantum information theory. He currently leads the Centre for the Mathematics of Quantum Theory (QMATH) in the Department for Mathematical Sciences.

Irene Tamborra is Knud Højgaard Associate Professor at the NBIA since 2016. Irene completed her Ph.D. at the University of Bari in 2011. Irene has held research appointments at the Max Planck for Physics in Munich, as Alexander von Humboldt Fellow, and at GRAPPA Center of Excellence of the University of Amsterdam. Irene's research activity is in the area of theoretical particle astrophysics. Irene is interested in exploring the role of weakly interacting particles, such as active and sterile neutrinos, in astro-physical environments. She also aims at unveiling what can be learnt from the observation of neutrinos from the most extreme but yet mysterious astrophysical transients occurring in our Universe, such as core-collapse supernovae, neutron star mergers and gamma-ray bursts. Irene leads the AstroNu group at NBIA with focus on these subjects.

Michael Trott is leading the particle physics phenomenology group and is an Associate Professor at the NBIA. Michael completed his Ph.D. at the University of Toronto in 2005 and later held research appointments at UC San Diego (2005-2008), Perimeter Institute (2008-2011) and CERN (2011-2014) before joining NBIA in the fall of 2014. Michael has broad and continuing research interests in the areas of Higgs physics, Beyond the Standard Model physics, collider phenomenology, Flavour physics and Neutrinos, as well as precision Standard Model calculations and even Cosmology. In pursuing research projects into all of these areas, the common unifying tool used is Effective Field Theory. Michael was awarded a Villum Young Investigator award in 2015.


CARLSBERG FOUNDATION

Simons Program: Physics and Astrophysics in the Era of Gravitational Wave Detection — Carlsberg Residence

Junior Faculty

Markus Ahlers received his Ph.D. in Theoretical Particle Physics from the University of Hamburg (DESY) in 2007. He has been a Postdoc in Oxford and Stony Brook before becoming a John Bahcall Fellow for Neutrino Astronomy at the University of Wisconsin-Madison. He joined NBIA in 2017 as an Assistant Professor. Markus research focus is centered on astroparticle physics. He studies the origin and transport of cosmic rays, the associated emission in gamma rays and neutrinos as well as beyond-the-SM probes by cosmic messengers. He has been a member of the IceCube Collaboration since 2007.

Paolo Benincasa joined NBIA as Assistant Professor in November 2017. After completing his PhD at the University of Western Ontario and Perimeter Institute in Canada in 2008, where he developed the first studies on the hydrodynamics of non-conformal strongly-coupled plasmas using holography as well as on the perturbative structure of scattering amplitudes, he held postdoctoral position at the University of Durham, Santiago de Compostela as Juan de la Cierva fellow and at the Instituto de Física Teórica in Madrid as well as a visiting researcher position at Perimeter Institute in 2017. Paolo's current research focuses in reformulating quantum field theory directly in terms of observables and the application of this idea to cosmology.

Michele Burrello joined the NBIA as Assistant Prof. in 2016. He received his PhD in statistical physics from SISSA (Trieste) in 2011 and then he worked as a postdoc in Leiden University (2011-13) and in the Max Planck Institute for Quantum Optics (2013-16). His main research focus is the study of topological phases of matter, their engineering and the possibility they offer for quantum computation. He works on different quantum many-body systems, ranging from ultracold atoms to topological superconductors and he is interested in the common theoretical framework underlying these diverse systems.

Amin Doostmohammadi is a Novo Nordisk Foundation Assistant Professor at the NBIA. He also has a cross-appointment as Specially Appointed Assistant Professor at Bioengineering in Osaka University, Japan. Amin received his PhD from University of Notre Dame, followed by a postdoc in Oxford University and held a prestigious Royal 1851 Research Fellowship at Oxford before joining NBIA. Amin is leading the Active Intelligent Matter research group that works at the interface between physics and biology, modeling active materials as diverse as bacterial colonies, molecular motors and cellular tissues. In particular, their recent finding of the correlation between topological defects in tissues and the sites for cell death is a page-turner for the field of tissue biology, challenging the consensus, and brings physics of liquid crystals into studying diverse biological problems. Currently the research at Amin's group enjoys generous support from Novo Nordisk Foundation and DFF-ERC grant.

Villum Young Investigator Award Ceremony — The Black Diamond

Michèle Levi completed her PhD on the Effective Field Theory approach in General Relativity at the Hebrew University, followed by research appointments at the Lagrange Institute of Paris of Sorbonne University, and at the Institute of Theoretical Physics of CEA Saclay. She has been working on application of concepts and methods from Quantum Field Theory to gravitational wave measurements, and more generally on uncovering relations between gauge and gravity theories.

Cristian Vergu graduated from Ecole Normale Superieure (Paris, France) and obtained his PhD in Theoretical Physics from Paris VI University and IPhT Saclay. He held postdoctoral positions at Brown University, USA, ETH Zürich, Switzerland and King's College London, UK. He is interested in twistor theory, AdS/CFT, integrability and scattering amplitudes in N=4 super-Yang-Mills theory.

Subodh Patil joined the NBIA in the fall of 2016 as an Assistant Professor after post-doctoral stints at the University of Geneva (2015-16), CERN (2012-2015, as Marie Curie Intra-European Fellow from 2012-14), CPHT Ecole Polytechnique (2009-12), and the Humboldt University of Berlin (2007-9), having obtained his Ph.D from McGill university in 2007. He works on broadly defined themes in early universe cosmology, gravity and related aspects of beyond the standard model and string phenomenology.

Albert Werner obtained his PhD at the Leibniz University of Hannover in 2013 on propagation properties of quantum walks. He then joined Jens Eisert's group at the FU Berlin for a postdoc working on disordered quantum many-body systems. Albert has joined QMath with a Feodor Lynen Fellowship (a Humboldt Foundation sponsorship). He works within Matthias Christandl's Quantum Information Theory group and with Michael J. Kastoryano at the NBIA.

Johan Samsing joined the NBIA as a Louis-Hansen Assistant Professor and Marie Curie Fellow in 2019. He received his PhD from the Niels Bohr Institute (DARK) in 2014, after which he moved to Princeton University, first as an Einstein Fellow and then as a Spitzer Fellow. He currently works on the astrophysical formation of gravitational wave sources, and the origin of black hole mergers.

Matthias Willhelm received his PhD from Humboldt University Berlin before joining NBIA in 2015. His research interests lie within the field of quantum field theory and high-energy theory, with a focus on gauge theories, the gauge-gravity duality and exact methods. He works on the number theory behind scattering amplitudes, on form factors and on thermodynamics as well as on the effects of introducing defects.

Postdoctoral Fellows

Ajit C. Balram's research interests are in the field of theoretical condensed matter with emphasis on the physics of the fractional quantum Hall effect and topological insulators.

Pablo Benítez-Llambay received his PhD in Astronomy from the Universidad Nacional de Córdoba, Argentina in December 2015 and joined the NBIA as a postdoc in the Theoretical Astrophysics group in July 2016. Pablo's research focuses on studying the processes that determine the large-scale dynamics of planetary embryos as they interact with the protoplanetary disk in which they form. In December 2016 Pablo obtained a Marie Curie Fellowship that is allowing him to explore the impact of more detailed physics on planet migration processes, with the potential to produce a leap forward in our understanding of how planetary orbits evolve. Pablo's goal is to improve current models for the formation of planetary systems.

Ilaria Brivio carried out undergraduate studies at the University of Padua and obtained her PhD in 2016 from the Universidad Autónoma de Madrid. Her research focuses on the use of Effective Field Theories to study the phenomenology of electroweak interactions and the properties of the Higgs boson. Her interests are broad and related to main open questions of particle physics, from the nature of Higgs boson to neutrinos, flavor and Dark Matter. A relevant component of her research is the development of new ideas and theoretical tools to improve the interpretation and understanding of experimental data.

Mauricio Bustamante received his PhD in 2014 from the University of Würzburg, while also working at DESY. He was a CCAPP Fellow at Ohio State University until 2017, before joining NBIA. He studies particle physics using high-energy astrophysical neutrinos and models high-energy astroparticle sources.

Carlos Cardona Giraldo's interest concerns scattering amplitudes in both flat and curved spaces. In particular the study of mathematical structures of the S-matrix, as well as its use in several aspects of Gauge/Gravity correspondence.

Tyler Corbett completed his PhD at Stony Brook University in 2015 and completed a postdoc at Melbourne University before joining NBIA. Tyler's research interests include the Standard Model Effective Field Theory, collider phenomenology, and models explaining the Baryon asymmetry of the Universe.

Yoann Genolini received his PhD in theoretical physics at LAPTh (Annecy, France) in 2017. He later became a postdoctoral fellow at the Université Libre de Bruxelles. His research focuses on astroparticle physics, notably cosmic-ray transport and phenomenology. He is also interested in dark matter phenomenology and its indirect probe by astrophysical observables, especially those related to compact objects.

Humberto Gomez Zuniga got his Ph.D. at the IFT in Sao Paulo. His research focuses on computing scattering amplitudes in string theory using the pure spinor formalism. Currently, he is working on developing methods, uses and extensions of the so-called Ambitwistor string. Particularly, the study of underlying mathematical structures encoded in the scattering equations as well as developed techniques to make analytic computations.

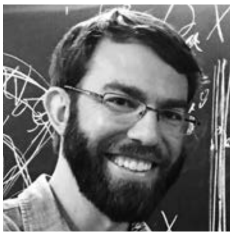
Rasmus Lundkvist received his PhD in Astronomy from Aarhus University in September 2015. Afterwards, he held an Alexander von Humboldt fellowship at Max-Planck-Institut für Kernphysik in Heidelberg before coming to NBIA. His research focuses on neutrino oscillations in the early Universe and in supernova explosions, but he is also interested in related topics such as dark matter and high energy neutrinos.

Ervand Kandelaki completed his PhD at Ruhr-University Bochum before joining the NBIA in 2015. Ervand's research interests include various areas of condensed matter physics. Currently, his focus lies in non-equilibrium quantum physics, especially with regard to the impact of interactions on many-body effects and topological properties. He is aiming at understanding gapped phases in periodically driven systems going beyond the one-particle picture and looking for genuine many-body phenomena.

George Mamatsashvili received PhD in 2011 from the University of Edinburgh, UK, in Astrophysics. He joined NBIA as Marie Curie Fellow in July 2018 after postdoctoral positions at Turin Astrophysical Observatory, Italy, and Helmholtz Center Dresden, Germany, with a Humboldt Fellowship. George's research focuses on dynamics and evolution of astrophysical disks and shear flows. At NBIA, he works on magnetorotational turbulence in disks, applying new tools to study its dynamics in Fourier space.

Natascha Leijnse holds a PhD in Biophysics from the University of Copenhagen which she obtained after finishing her MSc in Physics from RWTH Aachen University in Germany. After a postdoc in Alexander Dunn's group at the Department of Chemical Engineering at Stanford University, she returned to the Niels Bohr Institute for another postdoc. Natascha is interested in studying cellular dynamics using a combination of single cell manipulation and advanced imaging techniques.

David McGady completed his PhD at Princeton University before coming to the Niels Bohr Institute in 2015. David's research interests are spread across high energy physics and quantum field theory. Currently, he is actively focused on analytic structures in scattering processes in quantum field theories, and in elucidating both the fundamental cause of, and the consequences derived from, a recently discovered symmetry of partition functions under reflection of temperatures.



Andrew McLeod received his PhD from Stanford University in 2017. His research focuses on developing novel formulations of scattering amplitudes in quantum field theory. Currently, he is investigating the analytic, geometric, and infrared properties of gauge theory.

Frederik Nathan received his PhD from University of Copenhagen in 2018. His research focuses on novel driving-induced phenomena in quantum systems, including new topological phases, time-translation symmetry breaking, and energy pumping mechanisms. A second direction of research aims at developing an efficient and intuitive description of open and noisy quantum systems that may be applied to driven many-body quantum systems.

Yavor Novev joined the NBI after a brief postdoc with Julia Yeomans in the Oxford Physics Department. He also obtained his doctorate in Physical & Theoretical Chemistry at Oxford and prior to that did his Master's and Bachelor's degrees at the University of Sofia in Bulgaria. Yavor uses computational and analytical methods to study soft matter systems such as polymeric aggregates and thin liquid films.

Mohamed Rameez received his PhD from the University of Geneva in 2016, working on Dark Matter indirect detection and point source searches with the IceCube detector. He is now seeking a better understanding of Cosmology and local universe anisotropies.

Ximena Ramos works on planetary systems dynamics. In particular, she studies planet migration and its relation with the final configurations observed in exoplanetary systems, and the resulting disk-structure. She uses N-body and hydrodynamical simulations combined with analytical calculations.

Shashank Shalgar received his Ph.D. from Northwestern University in 2013. He later became a postdoctoral fellow at the University of New Mexico and Los Alamos National Laboratory. His research is focused on neutrino physics in extreme astrophysical environments and the early Universe. He is especially interested in the non-linear evolution of the neutrino flavor that occurs in these astrophysical environments.

Jim Talbert received his PhD from Oxford in 2016 and held a DESY Fellowship between 2016-2019. His work applies effective field theory techniques to various topics in particle phenomenology. He has contributed precision calculations for particle colliders and neutrino observatories, and has also explored deeper problems in particle physics, e.g. the origins of flavor, CP violation, and new fundamental symmetries.

Matt von Hippel received his PhD from Stony Brook. Before joining NBIA, he was a postdoctoral fellow at the Perimeter Institute. He develops new techniques for calculating scattering amplitudes in quantum field theory. He is well known for polylogarithmic bootstrap methods.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PhD Students

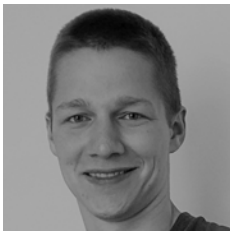
Andrea Cristofoli obtained his Master degree in Theoretical physics with Laude at the University of Padova. During his studies he also spent brief research periods at SISSA (International School for Advanced Studies) and at the Département de Physique Théorique of Geneva specializing in General Relativity. Currently, founded by a Marie Curie Grant, he is working at the Niels Bohr Institute with Emil Bjerrum-Bohr at the connections between Perturbative Quantum Gravity and classical General Relativity.

Andreas Helset received his MSc degree at the Norwegian University of Science and Technology in 2017. He is currently working on his PhD project titled "Scattering Amplitudes and the Standard Model Effective Field Theory" under the supervision of Profs. N. Emil J. Bjerrum-Bohr and Michael Trott. The project lies at the intersection of the fields of modern methods for scattering amplitudes and effective field theories.

Raffael Gawatz's research focuses on nonequilibrium dynamics of quantum many-body systems. In his studies he employs both exact diagonalization/evolution-type numerical simulations, and approximate schemes based on the efficient representation of quantum many-body states using tensor networks. Using these methods, he is exploring how new universal, topological phenomena can emerge in the (quasi) steady states of periodically-driven systems.

Leonardo Krapp obtained his degree of Licenciado from Cordoba University in Argentina in 2015 and started his PhD working with Oliver Gressel at the NBIA in 2016. His research interest involves studying gas and dust dynamics in protoplanetary disks using the codes NIRVANA and FARGO3D. He is studying numerical algorithms to couple the Hall effect with ambipolar and Ohmic diffusions with the goal of performing non-ideal MHD simulations of protoplanetary disks including non-equilibrium ionization.

Kays Haddad received his MSc from McGill University in 2018, having worked on beyond-the-standard-model phenomenology. He joined the NBIA later in the same year. Working under the supervision of Poul Henrik Damgaard, his research focuses on using effective field theories and modern scattering amplitude techniques to describe classical gravitational scattering.



Alexander T. Kristensson obtained his MSc degree in theoretical physics from the University of Copenhagen and recently started his PhD in the research group of theoretical high-energy physics at the NBI. His research focuses on understanding the strange behavior of the smallest components of all matter, the quarks, via the maximally supersymmetric Yang-Mills theory.

Meera Machado received her MSc at the University of Sao Paulo, with her thesis "Event-by-event Hydrodynamics for LHC". She currently works with Poul Henrik Damgaard and Ante Bilandzic on her PhD project "The Little Bang of High-Energy Heavy-Ion Collisions", whose aim is to analyse the anisotropic flow of heavy-ion collisions by using statistical tools employed in the analysis the Cosmic Microwave Background.

Yueting Pan is a PhD student in Beijing Normal University. She is currently working on her PhD project "Interacting ultracold hard-core bosons on the ladder model under a magnetic field" at the Niels Bohr Institute, under the supervision of Michele Burrello. The project is based on the bosonization method of a 1D model and the renormalization group.

Ida E. Nielsen received her MSc from the University of Copenhagen in 2019 with a thesis on exotic modes in hybrid quantum systems. In October 2019 she started her PhD with Prof. Michele Burrello. Her project focuses on the scattering theory of devices hosting multiple Majorana or parafermionic zero-energy modes, with potential applications for the realization of novel platforms to perform error-protected quantum computation.

Tetyana Pitik is a PhD student working in the Astro-Nu group under the supervision of Irene Tamborra. She obtained her MSc degree in Theoretical Physics from University of Perugia (Italy) with a thesis on force free electrodynamics approach to magnetospheres of extremal Kerr black holes. Tetyana's research activity at NBIA focuses mainly on developing a new, self-consistent estimation of particle acceleration in astrophysical transients to compare with observations.

Ian Padilla-Gay started a position as PhD student at NBIA under the supervision of Irene Tamborra after obtaining his MSc degree from Lund University (Sweden). Since then, he has been working on numerical simulations to understand the flavor evolution of neutrinos in compact astrophysical objects such as neutron star binaries.

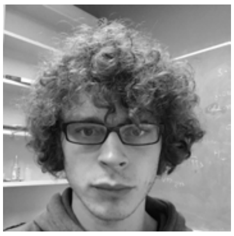
David D. Ribers received his Master's Degree at the Niels Bohr institute with his thesis "Lattice String Theory and Quantum Fields on a World-Line". In October 2019 he began his PhD at the NBIA under the supervision of Markus Ahlers. His project aims to clarify the origin of the cosmic neutrino flux through studies of candidate neutrino sources in the context of cosmic- and gamma-ray observations.

Anna Suliga obtained her master's degree working with the Neutrino Astrophysics group at the Niels Bohr International Academy, under the supervision of Prof. Irene Tamborra. The title of the thesis was "Diffuse supernova neutrino background". Anna continues to work with the Neutrino Astrophysics group, as a Ph.D. fellow since September of 2018. She is currently working on determining the role of neutrinos in the supernovae.

Laurie Walk obtained her masters at the Theoretical High Energy Physics group at Lund University. Her project focussed on model building in Grand Unification Theory. In October of 2017, she began her Ph.D in the Astroparticle Physics group at NBIA. She is currently working on identifying neutrino properties from 3D core-collapse supernova simulation.

Anagha Vasudevan received her MSc in 2017 from RWTH Aachen. She is currently working on phenomenological studies in the standard model effective field theory and the intersection between effective field theories and modern methods in scattering amplitudes under Prof. Michael Trott and Prof. Emil Bjerrum-Bohr.

Philipp Weber obtained his MSc from Heidelberg in 2016 and later started his PhD at NBIA with Oliver Gressel. He is developing an advanced implementation of dust in protoplanetary disks for the FARGO3D and NIRVANA codes. This development will enable realistic studies of disk features such as planet opened gaps and vortices. Previously, often a static vertical profile had to be assumed, but our framework will allow the self-consistent study of the vertical disk structure of the coupled gas and dust.



Matthias Volk obtained his MSc degree from the University of Copenhagen with a project about one-point functions in a defect version of the AdS/CFT correspondence. With his supervisors Charlotte Kristjansen and Jacob Bourjaily he is now working on topics related to integrability and scattering amplitudes in conformal field theories.

MSc Students

Christoffer Andersen — Astrophysics

Taro Valentin Brown — Particle Physics

Gregory Gold — Cosmology

Daniel Lozano Gomez — Particle Physics

Lea Halser — Astroparticle Physics

Taus Munk Hansen — Astroparticle Physics

Gustav Uhre Jacobsen — Particle Physics

Solvej Knudsen — Theoretical Physics

Emil Kozuch — Particle Physics

Mads Kruse — Condensed Matter Theory

Rohan Kumar — Astroparticle Physics

Zheng Ma — Cosmology

Stylianos Apollonas Matsoukas — Condensed Matter Theory

Henrik Jessen Munk — Particle Physics

Jens Nyhegn — Condensed Matter Theory

Marie-Louise Riis — Astroparticle Physics

Charlotte Rosenstrøm — Astroparticle Physics

Salik Ahmad Sultan — Soft Matter Physics

Christian Dissing Schiøtt — Particle Physics

Johannes Sørensen — Particle Physics

Mariana Andrade Vieira — High Energy and Gravity Theory

Administrative Staff

Jane Elvekjær is NBIA administrative officer. She is responsible for the organization of schools and workshops, secretarial support, visa applications, and budget allocation. She has a Master of Law from Århus University.

Kaare Møller is the finance officer responsible for the grants received by researchers at the NBIA.

Johan Lausen is a student helper at NBIA. He helps with NBIA colloquia, workshops, and day to day practical tasks. He is doing his MSc at NBI.

Maria T. Søgaard is a student helper at NBIA. She helps with workshops, NBIA colloquia, RejsUd and travel reimbursements. She is doing her MSc in Nanoscience at UCPH.

Adjunct & Associates

Oliver Gressel joined NBIA as an Assistant Prof. in 2013. He received his Ph.D from Potsdam University in 2009, and was a postdoc at the University of London 2009–2011. In 2012, he held a Nordic Fellowship at Nordita in Stockholm to work on mean-field magnetohydrodynamics and dynamo theory. He was awarded a MOBILEX grant in 2013 to study accretion disk turbulence. He received an ERC Starting Grant in 2014, which has allowed him to build his own research group at the NBIA. Oliver's current research is centered around astrophysical turbulence and magnetohydrodynamics, with special emphasis on dynamo theory. Applications included modelling the turbulent interstellar medium, the large-scale galactic dynamo, and magnetic turbulence in protoplanetary disks, including its influence on the formation of planets. In 2019, Oliver took up a position at the Leibniz-Institut für Astrophysik in Potsdam, Germany.

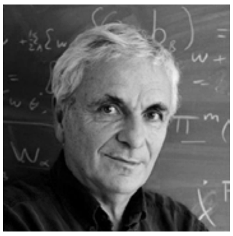
Subir Sarkar is Head of the Particle Theory Group at the University of Oxford. He was educated in India, obtaining Bachelors and Masters degrees in physics at the Indian Institute of Technology, Kharagpur. He did both experimental and theoretical work on cosmic rays at the Tata Institute of Fundamental Research, Bombay and was awarded a PhD in 1982. Subsequently he held positions at Oxford, SISSA, CERN and Rutherford Laboratory and worked for a year in science education & outreach in Bhopal. He returned to Oxford in 1990 where he was appointed Lecturer in 1998 and Professor in 2006. Subir's interests are at the interface between fundamental physics, astrophysics and cosmology and he participates in the IceCube experiment at the South Pole. In 2017 he was awarded the IUPAP-TIFR Homi Bhabha medal and prize. Subir Sarkar has been Niels Bohr Professor at NBIA from 2013 to 2018. During his time in Copenhagen he initiated the Astroparticle Physics Group with the support of the Danish National Research Foundation.

Jørgen Rasmussen is Associate Professor of Mathematics at the University of Queensland. He has made seminal contributions to conformal field theories, integrable systems, and in general the mathematical methods needed to solve and understand systems in statistical mechanics. He is a frequent visitor to the NBIA.

Meng Ru Wu is an Assistant Research Fellow in the Institute of Physics, Academia Sinica and a joint fellow in the Institute of Astronomy and Astrophysics, Academia Sinica, both in Taipei, Taiwan. He works on theoretical particle- and nuclear- astrophysics with particular focus on neutrinos, core-collapse supernovae, neutron star mergers, and the formation of elements in the Universe.

Visiting Professors

Jens O. Andersen studies QCD under extreme conditions. He has calculated the thermodynamic properties of the quark-gluon plasma us-ing advanced resummation techniques in hard-thermal-loop perturbation theory, and pion condensation using chiral per-turbation theory for two and three flavors.



Michael Green from Cambridge University and Queen Mary London is one of the founding fathers of superstring theory. His discoveries have been behind what became as the superstring revolution in the 1980's and he has since been at the forefront of developments in string theory and related field theory, such as modern amplitude computations.

Charles Bennett is Simons Visiting Professor this fall. He is a Senior Research Scientist at IBM. He co-discovered the concept of quantum cryptography and is one of the founding fathers of modern quantum information theory.

Si-Hui Tan is a Research Scientist at the Singapore University of Technology and Design. Her research interests lie in quantum information science, which is at the intersection of quantum mechanics and information theory.

Visitors

The NBIA maintains a vigorous visitor program, which attracted more than 60 scientists during 2019. These visitors actively engage in daily activities at the NBIA and the Niels Bohr Institute.

F. Teng	Uppsala	18.12.19	20.12.19
M. Perry	Cambridge	16.12.19	19.12.19
S. Nagy	Nottingham	01.12.19	04.12.19
J-W. Kim	Seoul National Univ	25.11.19	29.11.19
L. Plante	Saclay	21.11.19	25.11.19
H. Frellesvig	Karlsruhe Inst. of Tech.	21.11.19	22.11.19
I. Arav	Perimeter	20.11.19	23.11.19
J. Broedel	Humboldt Univ. Berlin	18.11.19	20.11.19
M. Shibata	Max Planck	14.11.19	15.11.19
T. Bautista	Max Planck	13.11.19	14.11.19
T. Berlok	AIP	06.11.19	08.11.19
D. O'Connell	Edinburgh	23.10.19	27.10.19
H. Johansson	Uppsala	21.10.19	25.10.19
R. Rabadan	Columbia	26.09.19	28.09.19
P. Rodenkirch	Max Planck	16.09.19	27.09.19
M. Schillo	Uppsala	18.09.19	20.09.19
R. Monten	IPHT	09.09.19	11.09.19
Y. Novev	U. of Oxford	25.08.19	27.08.19
M. Mojahed	NTU Trondheim	12.08.19	15.08.19
P. Adhikari	Wellesley College	05.08.19	23.08.19
J. Smirnov	SDU, Odense	05.08.19	06.08.19
J. Touma	Am. Univ, of Beirut	02.08.19	14.08.19
J.O. Andersen	NTU Trondheim	01.08.19	31.12.19
C. Bennett	IBM Research	01.08.19	31.10.19
A. Lande	Groningen	17.07.19	04.08.19
K. Zapp	Lund U.	01.07.19	01.07.19
R. Snellings	U. of Utrecht	30.06.19	01.07.19
A. Mirizzi	U. of Bari	20.06.19	23.06.19
P. Sharma	IIS Bangalore	19.06.19	20.06.19
L. Diaz	U. Salamanca	18.06.19	22.06.19
N. Cuello	Católica de Chile	17.06.19	19.06.19

N. Tenorio	U. of Pittsburgh	17.06.19	19.06.19
C. Dullemond	Heidelberg	05.07.19	07.07.19
S. Zoia	Max Planck	05.06.19	07.06.19
M. Levi	Saclay	05.06.19	08.06.19
K. Macias Cardenas	UABC, Mexico	05.06.19	16.08.19
H. Elvang	U. Michigan	04.06.19	04.07.19
A. Lukas	U. Oxford	03.06.19	06.06.19
P. Hoyer	U. Helsinki	27.05.19	30.05.19
G. Baym	U. Illinois	25.05.19	03.07.19
K. Hersent	ENS, Paris	20.05.19	09.08.19
D. Galante	Amsterdam	13.05.19	15.05.19
D. Anninos	King's College	07.05.19	09.04.19
A. Parnachev	Trinity Dublin	13.04.19	18.04.19
L. Tancredi	U. Oxford	16.04.19	29.04.19
P. Banerjee	PSI	08.04.19	09.04.19
A. Lukas	U. Oxford	02.04.19	06.04.19
L. Mason	U. Oxford	22.03.19	28.03.19
M. Paulos	Ecole Normale	10.03.19	15.03.19
H. Johansson	Uppsala	11.03.19	15.03.19
N. Matthes	U. Bonn	10.03.19	14.03.19
A. Belin	CERN	05.03.19	09.03.19
C. Mafra	Southampton	20.02.19	21.02.19
E. Panzer	U. Oxford	18.02.19	21.02.19
K. Kampf	Charles U.	07.02.19	07.02.19
A. Ferrari	CERN	03.02.19	07.02.19
L. Magnea	Turin U.	30.01.19	20.02.19
A. Bissi	Uppsala	27.01.19	30.01.19
M. Hanada	Southampton	20.01.19	25.01.19
C. Schweigert	Hamburg U.	15.01.19	18.01.19
M. Levi	Saclay	07.01.19	09.01.19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NBIA Activities


CARLSBERG FOUNDATION

NBIA Simons Foundation Program

Based on a generous grant from the Simons Foundation in New York, NBIA has established a highly successful series of Simons Visiting Professorships and associated scientific programs built around these appointments. The program was launched in the fall of 2016 with first Simons Visiting Professor Viatcheslav "Slava" Mukhanov, Chair of Cosmology at the Arnold Sommerfeld Center for Theoretical Physics in Munich. It was in connection with that visiting professorship, and a high-profiled workshop in August 2016, that the NBIA also brought Stephen Hawking to Denmark, for only the second time in Hawking's life. In 2017 the program continued with Simons Visiting Professor Steve Simon from Oxford who stayed at the NBIA in the spring of 2017. The subject concerned new topics in condensed matter physics, and the program included both a series of visiting scientists and two highly successful meetings, one of them organized jointly with Center for Quantum Devices (QDev) at the Niels Bohr Institute. In the fall of 2017 member of NBIA's Scientific Advisory Board Itamar Procaccia Professor of Chemical Physics at the Weizmann Institute) was Simons vVisiting Professor, helping to organize two workshops. The first was von hot topics in the theory of turbulence, while the second focused on the physics of new materials and novel states of matter. The Simons Visiting Professors of the spring and fall of 2018 were Charles Bennett (IBM Fellow, IBM Research) and Oxford Professor Alex Schekochihin. Michael B. Green (Professor of Theoretical Physics at Cambridge University and Queen Mary University London) was Simons Visiting Professor during the spring of 2019 wit a program largely focusing on amplitude calculations in string theory and field theory. The Simons Visiting Professors for the fall/spring of 2019/20 are Charles Bennett (IBM Fellow, IBM Research) and Paul Steinhardt (Albert Einstein Professor of Science, Princeton University).

"*Simons Program on Quantum Information Theory*" — 01.08 / 01.10.2019

"*Simons Program on Physics and Astrophysics in the Era of Gravitational Wave Detection*" — 19.08 / 23.08.2019

"*Simons Program on Amplitudes in string theory and field theory*" — 18.03 / 22.03.2019

"*Simons Program on Large-N field theory, string theory and hadron*s" — 25.02 / 01.03.2019

NBIA Colloquia

NBIA Colloquia consist of broad talks aimed at scientist who are not necessarily experts on the subject matter. Topics are not limited to physics, but can cover any subject of interest to the wide spectrum of researchers and students at NBIA. In the past we have had talks on such varied topics as ancient DNA, the geological history of the Earth, the science of textile archeology, the theory of paintings from a science perspective, and many other fascinating topics. The NBIA Colloquia in 2019 are listed below.

Chris Sander (Harvard Medical School) — 18.12.2019
"Computational models of cell biology inspired by physics"

Melvyn Davies (Lund) — 29.11.2019
"The Astrophysics of Stellar Clusters"

Masaru Shibata (Max Planck and Kyoto) — 15.11.2019
"Neutron-star mergers and numerical relativity"

Charles H. Bennett (IBM Research) — 06.11.2019
"What Math and Physics can do help combat fake videos"

Andreas Albrecht (University of California-Davis) — 01.11.2019
"Origin of probabilities and their application to the multiverse"

Ole Mouritsen (University of Copenhagen) — 11.10.2019
"What is gastrophysics?"

Raul Rabadan (Columbia University) — 27.09.2019
"An Introduction to Cancer Genomics"

Jes Jørgensen (NBI) — 20.09.2019
"The complex chemistry of young stars"

Amin Doostmohammadi (NBIA) — 13.09.2019
"Active Self-organizing Matter"

Marianne Vestergaard (NBI) — 06.09.2019
"Supermassive black holes and their galaxies - or why astrophysicists are excited about the new EHT results and capabilities"

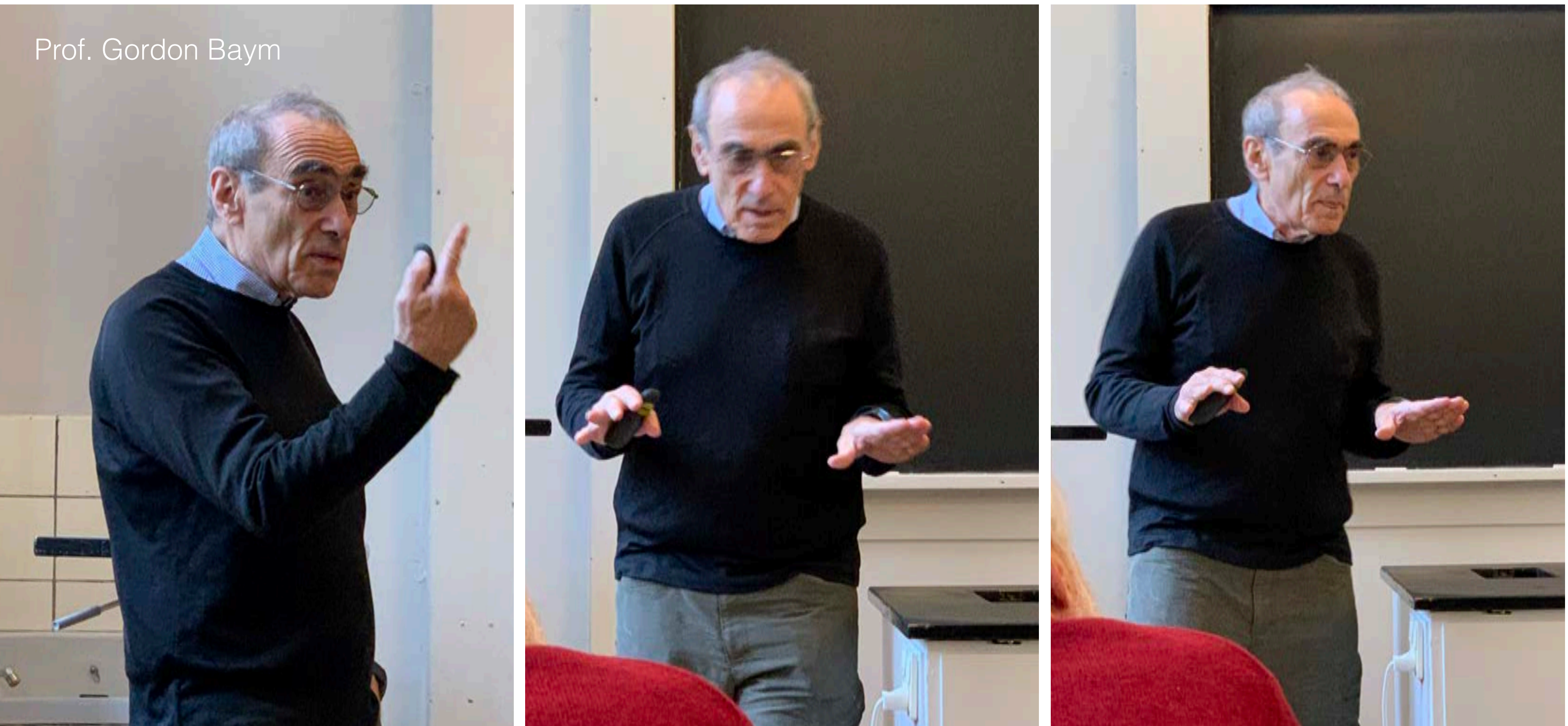
Paul Ho (ASIAA) — 23.08.2019
"First Direct Image of a Black Hole"

Nigel Goldenfeld (University of Illinois at Urbana-Champaign) — 16.08.2019
"Stochastic Turing patterns in the biosphere: from brains to biofilms"

Simons Program: Physics and Astrophysics in the Era of Gravitational Wave Detection — Carlsberg Residence


Prof. Eugene Polzik


Prof. Tine Jess


Prof. Gordon Baym

Angela Olinto (University of Chicago) — 09.08.2019
“Space Observatories of the Highest Energy Particles”

Cornelis Dullemond (University of Heidelberg) — 07.06.2019
“The Structure of Planet Formation”

Irene Tamborra (NBIA) — 14.06.2019
“The Ghostly Messengers of the High Energy Universe”

Rubina Raja (University of Aarhus) — 24.05.2019
“High Definition Archaeology and Historical Narratives. The Case of the Decapolis City of Gerasa”

Tine Jess (The State Serum Institute of Denmark) — 10.05.2019
“Big Data and Algorithms for Precision Medicine”

Jacob Bourjaily (NBIA) — 26.04.2019
“The Surprising Simplicity of Scattering Amplitudes”

Graham Farmelo (Churchill College, Cambridge) — 12.04.2019
“The Universe Speaks in Numbers”

Kresten Lindorff (Department of Biology, Copenhagen Biocenter, Univ. of Copenhagen) — 29.04.2019
“From protein folding to diagnosing genetic diseases using computational models”

Eugene Polzik (NBI) — 22.03.2019
“Measurements beyond the standard quantum limit”

Thomas Tauris (University of Aarhus) — 15.03.2019
“Neutron Stars, Black Holes and Gravitational Waves”

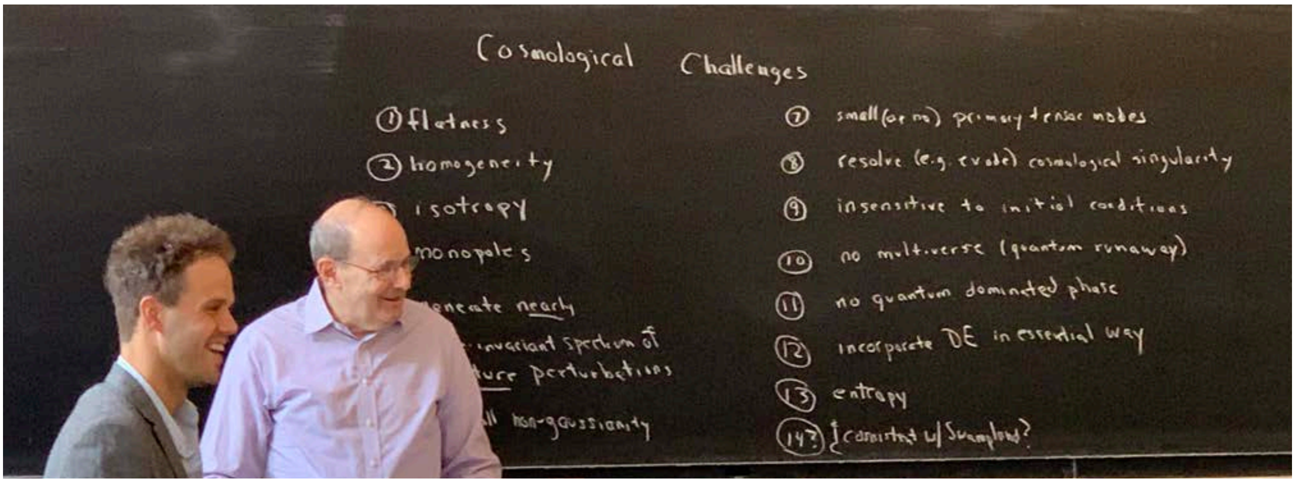
Tom Gilbert (University of Copenhagen) — 08.03.2019
“Does our understanding of how life works need tweaking?”

David J.T. Sumpter (Uppsala University) — 01.03.2019
“From fish schools to football teamwork”

Therese Graversen (Department of Mathematical Sciences, KU) — 22.02.2019
“Statistical sleuthing in criminal cases”

Sune Toft (NBI) — 08.02.2019
“Cosmic Dawn”

Kim Sneppen (NBI) — 01.02.2019
“Explaining Development of Biological Form as a Consequence of Cell Polarity”


Cosmological Challenges
① flatness
② homogeneity
isotropy
monopoles
non-gaussianity
⑦ small (or no) primary tensor modes
⑧ resolve (e.g. evade) cosmological singularity
⑨ insensitive to initial conditions
⑩ no multiverse (quantum runaway)
⑪ no quantum dominated phase
⑫ incorporate DE in essential way
⑬ entropy
⑭? {consistent w/ Swampland?


"Bumpy"
Neutron Star
$\varepsilon = \frac{I_{xx} - I_{yy}}{I_{zz}}$
f_{gw}=1kHz
? Unknown.
s: 10^{-12} – 10^{-5}
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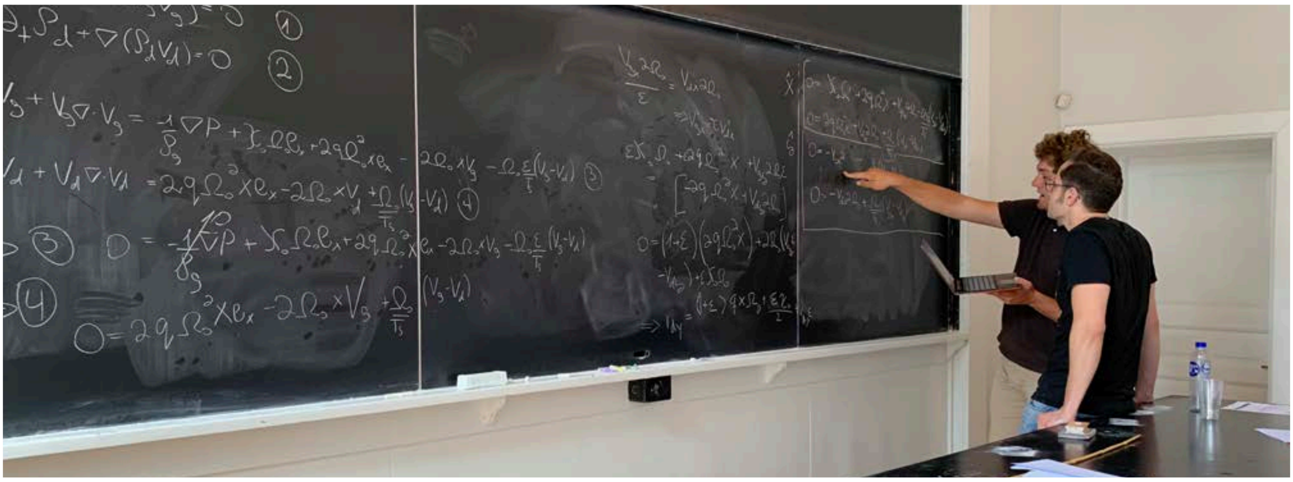
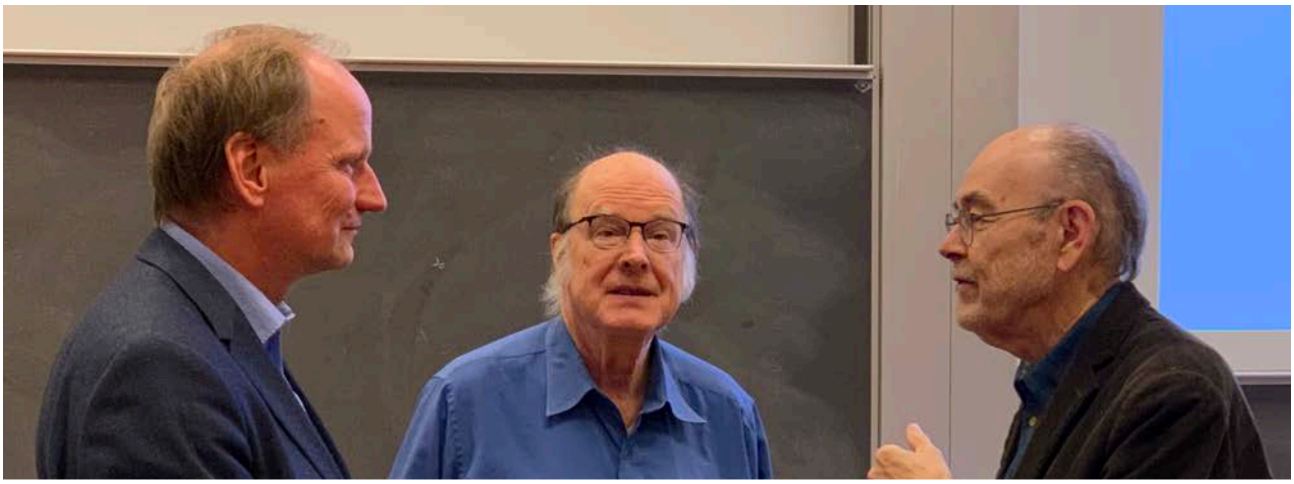
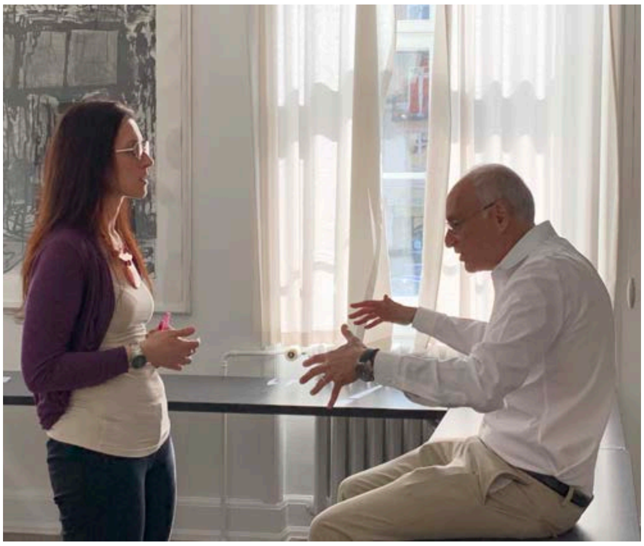


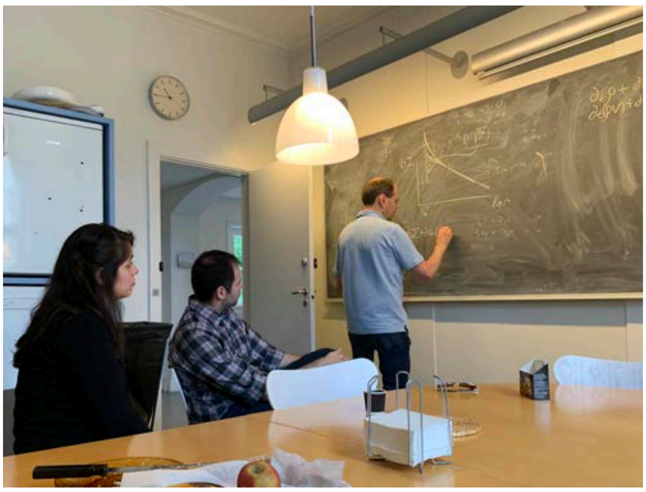


NBIA Seminars & Talks

Apart from the weekly series of NBIA Colloquia, members of the NBIA organize or co-organize numerous more specialized seminars and lectures. Members of the particle theory group at the NBIA co-organize up to two specialized seminars every week, held by visitors to the group. In condensed matter physics there is a flurry of activity and seminars organized through the QDev Center of Excellence, to which NBIA's condensed matter physics group belongs. In astrophysics the talks co-hosted by members of the NBIA are often held together with the Center for Star and Planet Formation. Astroparticle physics talks are customarily held on Mondays, often partially overlapping in topics with both astrophysics and particle physics. On any given week, it will be rare to find a day in which not at least one scientific event is being organized or co-organized by NBIA members. Topics range from gravitational waves emitted from black holes merging to the intricate mathematical structures behind quantum field theory amplitudes at high orders in perturbation theory.

A special opportunity for attracting scientific visitors and thus creating a flow of seminar and colloquium speakers is the NBIA programs for Visiting Professors, which typically open up for the opportunity to focus on a particularly hot subject in an area of interest to the Visiting Professor. Starting in the fall of 2019 the group on biological physics at the NBIA is beginning its own program of talks and lectures, also in conjunction with the new Novo Nordisk Foundation Visiting Professor program.





NBIA Summer School on Protoplanetary Disks and Planet Formation — Summer 2019

NBIA Workshops & PhD Schools

Building on Niels Bohr's vision, NBIA members engage in several activities aimed at promoting and enhancing the traditions of internationalism, interdisciplinarity and excellence in physics. The NBIA is instrumental in running of the order of ten high-profile, international events every year to the benefit of the wider Institute community. The following events were organized by NBIA members during 2019:

"*Astrophysics Meeting for Ramses Users* " — 30.09 / 04.10.2019

"*NBIA-LANL workshop: Neutrino Quantum Kinetics in Dense Environments* " — 26.08 / 30.08.2019

"*NBIA Summer School on Protoplanetary Disks and Planet Formation* " — 05.08 / 09.08.2019

"*Advancing Theoretical Astrophysics* " — 15.07 / 29.07.2019

"*Zooming in on Star Formation* " — 10.06 / 14.06.2019

"*Nordic Winter School on Cosmology and Particle Physics 2019* " — 02.01 / 07.01.2019

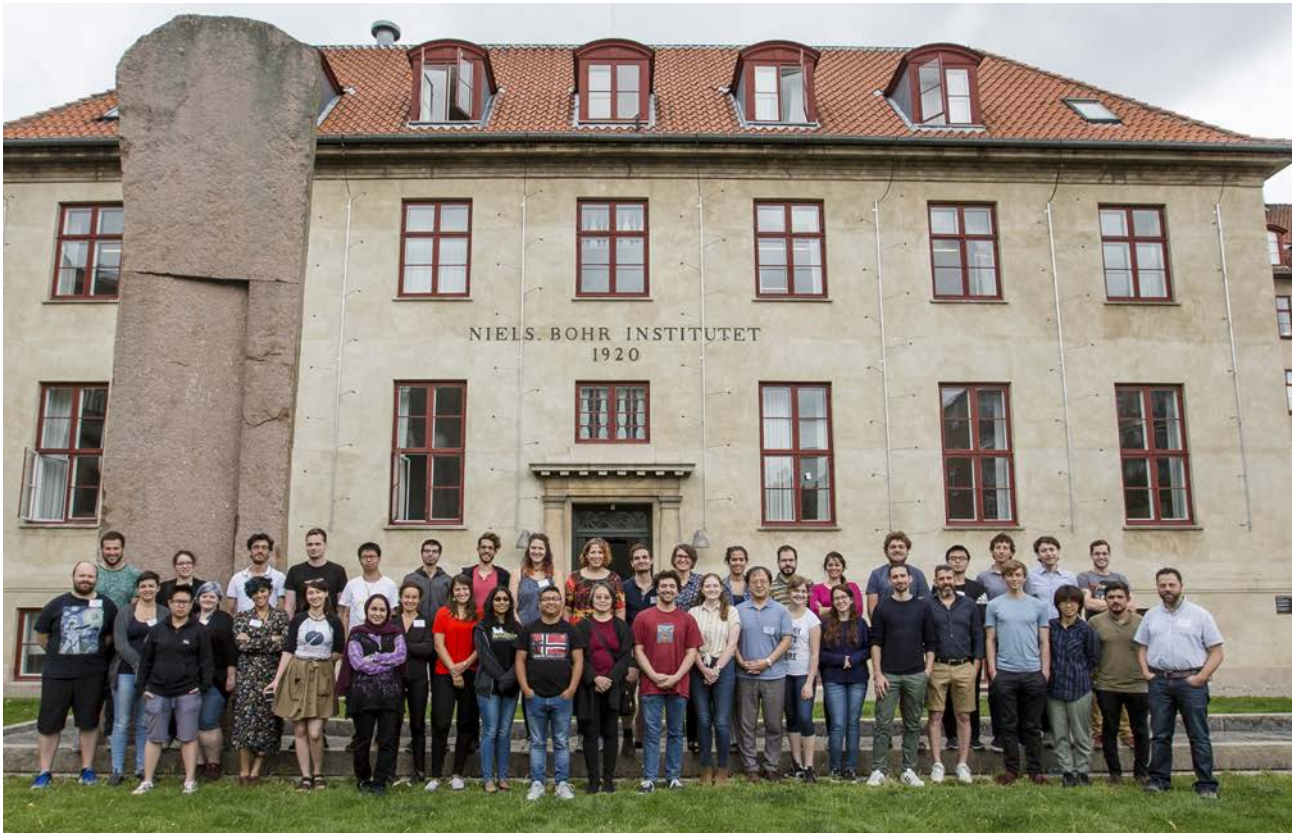

HLFX

Joint Activities with ASIAA

During the summer of 2019, scientists from NBIA, NBI, and the Center for Star and Planet Formation at the Natural History Museum of Denmark jointly organized in Copenhagen the "NBIA Summer School on Protoplanetary Disks and Planet Formation", together with the members of the Theoretical Institute for Advanced Research in Astrophysics (TIARA) in Academia Sinica Institute for Astronomy and Astrophysics (ASIAA) in Taipei, Taiwan.

The topics of the summer school ranged from observational properties of young stellar objects to the physics and chemistry of protoplanetary disks and from dust evolution and planetesimal formation to the formation of terrestrial and gas-giant planets. These themes are closely related to the broad interests and expertise present in all institutions involved and form the foundation for exchanges and efforts for collaboration and cooperation.

This was the second joint event after the successful PhD school "Origins of the Solar System" that took place in Taipei in 2018. These joint ventures between ASIAA, NBIA and the Center for Star and Planet Formation are based on mutual scientific interests in multidisciplinary studies involving cosmochemistry, theoretical astrophysics, and star and planet formation and are aimed at bringing closer together all scientists involved. The objective of these joint activities is to bring students with a wide range of interest together with top international researchers to participate in the exciting journey offered by the exploration of multidisciplinary studies.



Copenhagen International School — Astrophysics for 3rd Graders

NBIA Public Lectures & Outreach

In 2019 Simons Visiting Professor Charles Bennett delivered a special public NBIA lecture entitled "*The Boltzmann Brain Problem and Quantum Information Theory*" in the historic Auditorium A at Blegdamsvej. In addition, NBIA scientists continue contributing with enthusiasm to the series of public lectures that are becoming increasingly more popular.

Since 2011 the NBIA has organized an annual series of public lectures on physics in collaboration with the Danish Open University "Folkeuniversitetet". All lectures take place at the historic Auditorium A. The idea was from the start to let the public benefit from the presence of young and enthusiastic scientists at the NBIA, each of them speaking about a topic very close to their actual on-going research, but at a level appropriate for an audience with no background in science. By design, these lectures will then cover a wide range of topics in modern theoretical physics, giving a glimpse of the questions, ideas and approaches that are now at the scientific forefront. This formula turned out to be a success, and although the subjects covered are at the forefront of present-day research, the attendance is increasing.

Noticing that several of the attendees who signed up came back year after year, the NBIA has introduced a Friends of the NBIA circle of interested and supportive laymen who also receive the biannual Newsletter. As it develops and grows, the plan is to offer special opportunities for this group of people also beyond what they sign up for through the Open University. This year's lectures included:

Amin Doostmohammadi (Oxford/NBIA) — 03.10.2019
"Active Matter: the Engines of Life"

Sune Toft (NBI) — 10.10.2019
"Cosmic Dawn"

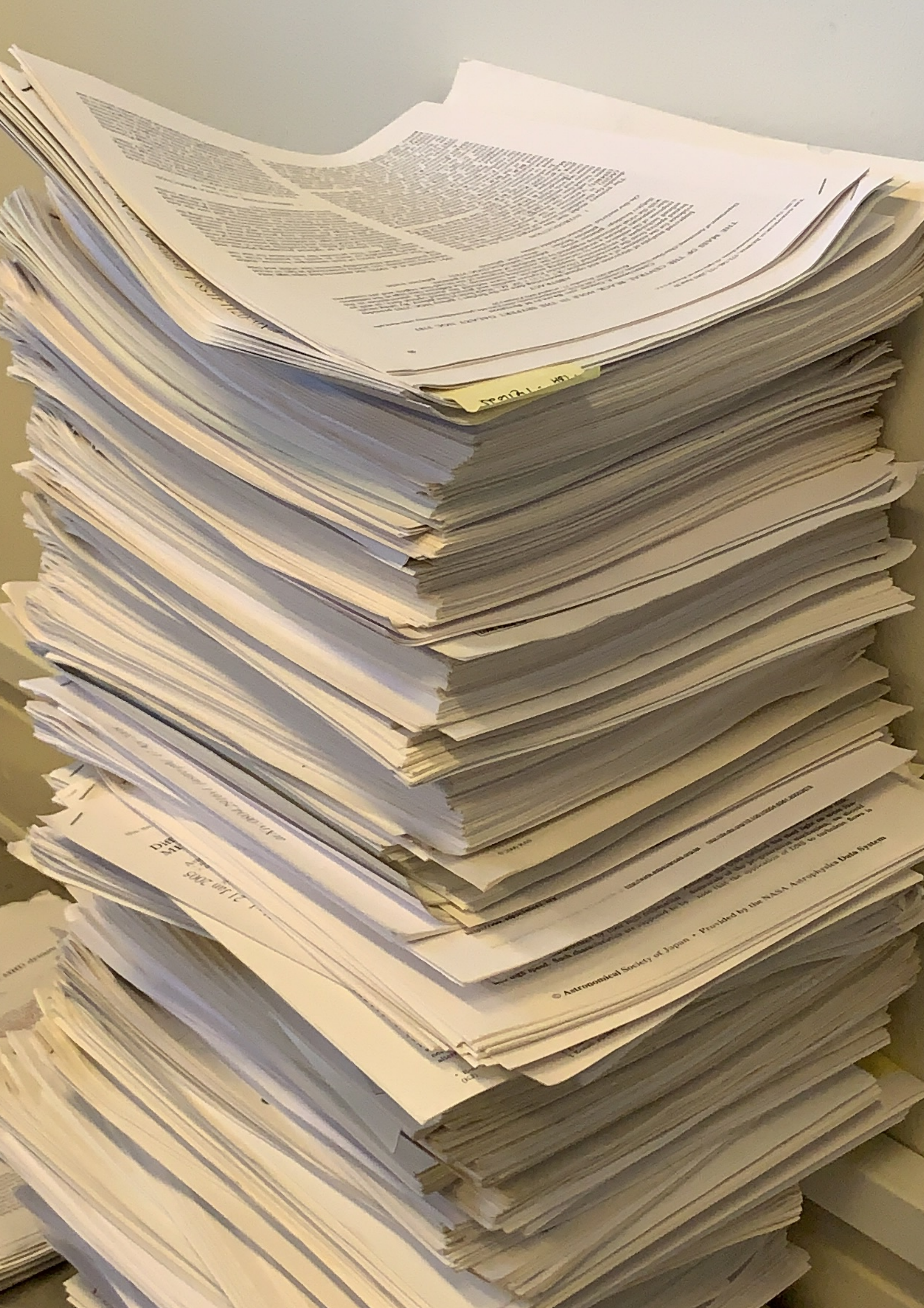
Pablo Benítez-Llambay (NBIA) — 17.10.2019
"The Birthplace of Planets"

Charles Bennett (IBM/NBIA) — 24.10.2019
"The Boltzmann Brain Problem and Quantum Information Theory"

Johan Samsing (Princeton/NBIA) — 31.10.2019
"Observing Black Holes and Gravitational Waves: A New Era in Astrophysics"

Outreach is not limited to this series of lectures. Scientists at the NBIA who speak Danish are often called upon for interviews in radio or TV, and some write in newspapers and Danish popular science journals on a regular basis. Likewise, popular talks are often given outside of the Copenhagen area, at public libraries or through local cultural organizations.

A most successful outreach activity for the youngest was initiated in 2019 by NBIA astrophysicists with the series "Astrophysics for 3rd Graders". An incipient tradition jointly organised with Copenhagen International School which caters to the most curious of all minds.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NBIA Publications

Refereed Papers

1. **The Spectral Evolution of AT 2018dyb and the Presence of Metal Lines in Tidal Disruption Events**
Leloudas, Giorgos, Dai, Lixin, Arcavi, Iair et al., 2019, ApJ, 887, 218 - ArXiv: 1903.03120

2. **GRB 180620A: Evidence for Late-time Energy Injection**
Becerra, R. L., De Colle, F., Watson, A. M. et al., 2019, ApJ, 887, 254 - ArXiv: 1910.09743

3. **Charge and spin textures of Ising quantum Hall ferromagnet domain walls**
Danon, Jeroen, Balram, Ajit C., Sánchez, Samuel et al., 2019, Phys. Rev. B, 100, 235406 - ArXiv: 1909.13249

4. **Current-Induced Gap Opening in Interacting Topological Insulator Surfaces**
Balram, Ajit C., Flensberg, Karsten, Paaske, Jens et al., 2019, Phys. Rev. Lett., 123, 246803 - ArXiv: 1901.08067

5. **Topology and Morphology of Self-Deforming Active Shells**
Metselaar, Luuk, Yeomans, Julia M., Doostmohammadi, Amin et al., 2019, Phys. Rev. Lett., 123, 208001 - ArXiv: 1909.04416

6. **Probing the Survival of Planetary Systems in Globular Clusters with Tidal Disruption Events**
Kremer, Kyle, D'Orazio, Daniel J., Samsing, Johan et al., 2019, ApJ, 885, 2 - ArXiv: 1908.06978

7. **Predicting the Observational Signature of Migrating Neptune-sized Planets in Low-viscosity Disks**
Weber, Philipp, Pérez, Sebastián, Benítez-Llambay, Pablo et al., 2019, ApJ, 884, 178 - ArXiv: 1909.01661

8. **X-Ray Fluorescence from Super-Eddington Accreting Black Holes**
Thomsen, Lars Lund, Lixin Dai, Jane, Ramirez-Ruiz, Enrico et al., 2019, ApJ, 884, L21 - ArXiv: 1907.11462

9. **Active matter invasion**
Kempf, Felix, Mueller, Romain, Frey, Erwin et al., 2019, Soft Matter, 15, 7538-7546 - ArXiv: 1908.00768

10. **Reconfigurable flows and defect landscape of confined active nematics**
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11. **Analytic computation of the secular effects of encounters on a binary: third-order perturbation, octupole, and post-Newtonian terms; steady-state distribution**
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Fragos, Tassos, Andrews, Jeff J., Ramirez-Ruiz, Enrico et al., 2019, ApJ, 883, L45 - ArXiv: 1907.12573

13. **The Evolution of Binaries in a Gaseous Medium: Three-dimensional Simulations of Binary Bondi-Hoyle-Lyttleton Accretion**
Antoni, Andrea, MacLeod, Morgan, Ramirez-Ruiz, Enrico et al., 2019, ApJ, 884, 22 - ArXiv: 1901.07572

14. **Ab initio exact diagonalization simulation of the Nagaoka transition in quantum dots**
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15. **Did GW170817 Harbor a Pulsar?**
Ramirez-Ruiz, Enrico, Andrews, Jeff J., Schrøder, Sophie L. et al., 2019, ApJ, 883, L6 - ArXiv: 1905.09179

16. **The Tidal Disruption of Sun-like Stars by Massive Black Holes**
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17. **Probing the black hole merger history in clusters using stellar tidal disruptions**
Samsing, Johan, Venumadhav, Tejaswi, Dai, Liang et al., 2019, Phys. Rev. D, 100, 043009 - ArXiv: 1901.02889

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31. **Asymptotically Stable Numerical Method for Multispecies Momentum Transfer: Gas and Multifluid Dust Test Suite and Implementation in FARGO3D**
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32. **How post-Newtonian dynamics shape the distribution of stationary binary black hole LISA sources in nearby globular clusters**
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Metselaar, Luuk, Doostmohammadi, Amin, Yeomans, Julia M. et al., 2019, J. Chem. Phys., 150, 064909 - ArXiv: 1812.04535

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Cummings, Jeffrey D., Kalirai, Jason S., Choi, Jieun et al., 2019, ApJ, 871, L18 - ArXiv: 1901.02904

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Mertsch, Philipp, Ahlers, Markus, 2019, JCAP, 048--048 - ArXiv: 1909.09052

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Byrnes, Christian T., Cole, Philippa S., Patil, Subodh P. et al., 2019, JCAP, 1906, 028 - ArXiv: 1811.11158

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