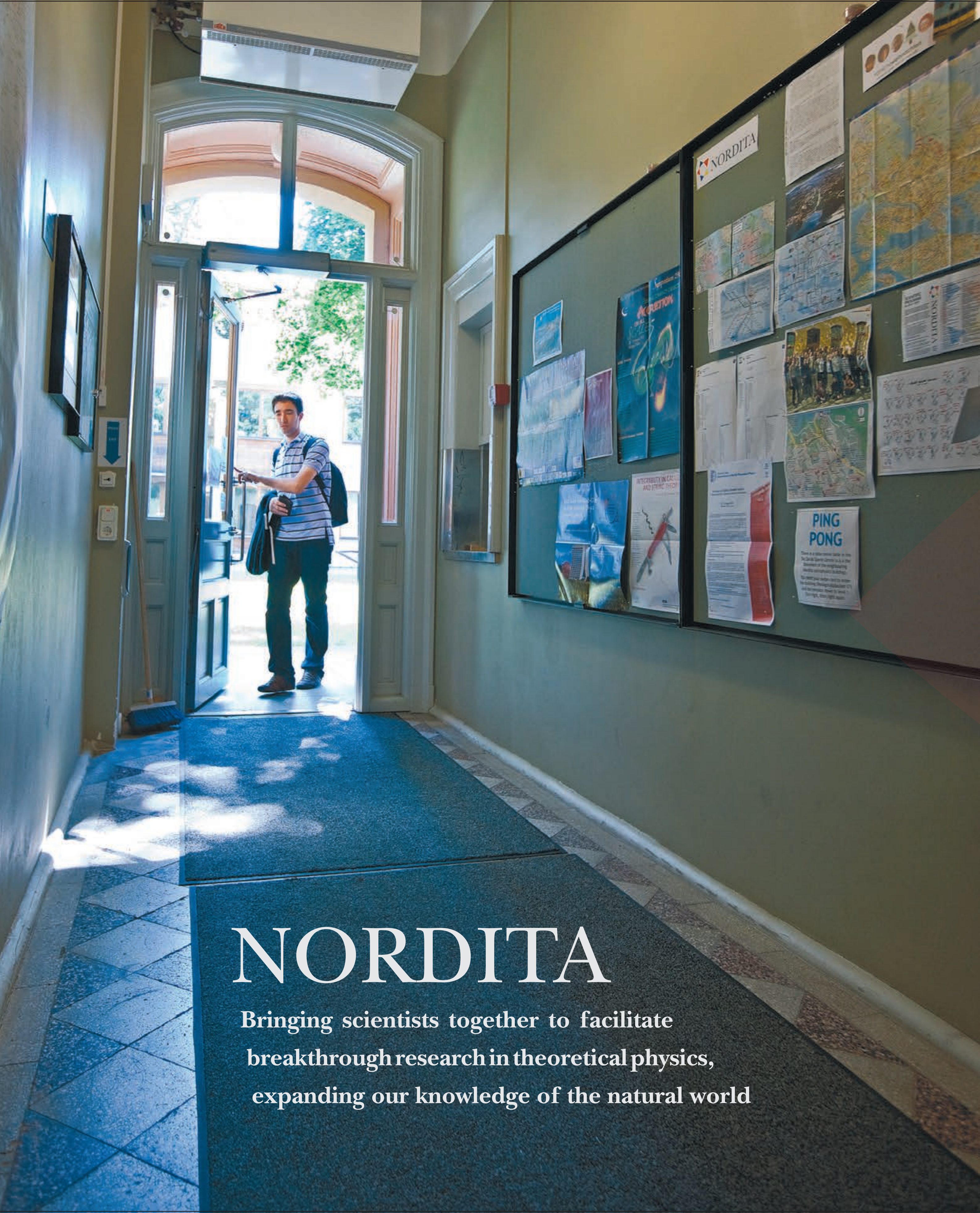
NORDITA

The Nordic Institute
for Theoretical Physics



NORDITA

Bringing scientists together to facilitate breakthrough research in theoretical physics, expanding our knowledge of the natural world

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A WORD FROM THE DIRECTOR

I am honored and excited to be Director of The Nordic Institute for Theoretical Physics (Nordita), one of the most prestigious international centers for theoretical physics in the world. Nordita was founded in Copenhagen in 1957, where its first Board was led by the renowned Danish physicist Niels Bohr, and has played an important role in Nordic physics ever since. Nordita has been home to Nobel Prize winning discoveries and an important training center for future research leaders. As part of a reorganization of Nordic cooperation, the Institute moved from Copenhagen to Stockholm in 2007, where it is jointly hosted by SU and KTH.

Our mission is to achieve scientific excellence through cutting edge research and to promote Nordic and international cooperation in theoretical physics. Our in-house academic staff consists of four permanent faculty members, roughly four assistant professors, and up to 20 postdoctoral fellows (Nordita Fellows). These scientists are engaged in research on many fronts ranging from traditional areas of theoretical physics to novel interdisciplinary and related areas. We are proud of the large number of current faculty members in Nordic physics departments and elsewhere who were previously trained as Nordita fellows.

Nordita is also well known for the numerous scientific one-month programs, shorter conferences, and schools for graduate students that are organized every year. We welcome a large number of visitors from around the world. We plan to expand our outreach activities; it is part of our mission to educate and inspire members of the public, and to encourage young people to join us as scientists. Theoretical physics is essential both for satisfying our innate human curiosity and drive to understand our world, and also as a building block for discoveries that benefit society.

We have produced this booklet to introduce the reader to our Institute, touching on Nordita's history, introducing the current academic physicists, describing some of the ongoing research, explaining the organization, and encouraging physicists everywhere to participate as organizers or members of our scientific programs. Most of all, we want to give the reader a view of the scientific life of the Institute, who we are, what we do, and to share the excitement we feel in working towards unraveling the mysteries of Nature.

Image credits: Alexis Brandeker

BACKGROUND

Theoretical physicists study nature at its most fundamental level. Breakthroughs in this area cannot be planned and are rarely anticipated. For every approach that is successful, many others lead nowhere, but the rare successes in theoretical physics have the potential to fundamentally change the way we think about ourselves and the world around us. These successes arm us with new knowledge to understand and harness natural resources and to develop innovative technology affecting all aspects of our lives.

The US National Science Foundation refers to this type of research, which is at the heart of Nordita's mission, as "transformative", while the European Research Council calls it "frontier research". Its defining quality is a high risk with a potential high payoff. It is the type of research needed to break existing scientific paradigms and make possible what was previously considered impossible.

For centuries, science was a pastime of the wealthy but with the spread of modern democracy, at the dawn of the 20th century, it was recognized that scientific research plays an essential role for innovation and economic growth.

Today, basic research and public education are among the most important investments that societies make for their future benefit. Due to the long time for such investments to bear fruit – often several decades – funding for basic research is usually channeled through national governments. With many government funding agencies facing budget pressures and a growing proportion of public funding being targeted towards predetermined strategic areas, alternative forms of support for basic research become increasingly important. This includes donations from individuals or private foundations, which can afford researchers the freedom to engage in particularly ambitious research that can greatly accelerate progress if successful.

Research and advanced education traditionally go hand in hand at universities, but independent institutes focused on research play a pivotal role for innovation. They offer scientists flexibility and sustained time for research. First rate research institutes are, however, difficult to create and maintain in countries with small populations. Niels Bohr, one of the founding fathers of quantum theory and winner of the Nobel Prize in Physics 1922, recognized the challenge and proposed that the Nordic countries – Denmark, Finland, Iceland, Norway, and Sweden – join forces to create an international research institute for theoretical physics.

The Nordic Institute for Theoretical Physics, Nordita (from Danish: Nordisk Institut for Teoretisk Atomfysik), was founded in 1957. The initial focus on atomic physics was broadened and adapted to the ever changing frontier of research. Presently, research at Nordita includes elementary particle physics, astrophysics and solar physics, condensed matter physics and biophysics, and touches on complex systems, network science, and neurobiology.

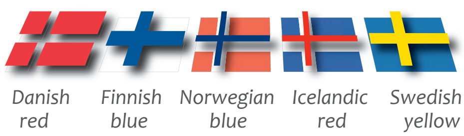
During the over 50 years since its establishment, Nordita has been of great importance for theoretical physics in the Nordic countries. It has strengthened ties between Nordic scientists, provided training for young physicists, and served as a conduit for international collaborations. During most of its history, Nordita was financed by and organized directly under the Nordic Council of Ministers (www.norden.org). It was located next to the Niels

NORDITA'S MISSION

- to pursue scientific excellence and promote cutting edge research,
- to foster and utilize existing Nordic strengths in theoretical physics,
- to kindle activity in new and emerging areas through international collaboration and strategic recruitment,
- to create Nordic "critical mass" in specialized areas by stimulating collaboration and coordination among Nordic researchers,
- to support graduate level physics education and research training.

The Nordita Logo

The five colors of the Nordita logo come from the national flags of the five Nordic countries.



Nordic Perspectives

Bohr Institute and closely integrated into the research environment in Copenhagen. Following policy changes at the Nordic Council of Ministers, Nordita was relocated in 2007 to Stockholm, Sweden, where it is jointly hosted by the KTH Royal Institute of Technology and Stockholm University. The new arrangement has resulted in a fruitful exchange with researchers at the local universities while at the same time maintaining the financial and intellectual independence of Nordita.

When Nordita moved to Stockholm in January 2007, a building on the campus of the AlbaNova University Centre was placed at its disposal. Being in a separate building bolsters the separate identity of Nordita and contributes to its independence. The Institute has, however, already outgrown its building and expanded into a neighboring house of a similar construction. Long-term housing plans at the host universities include substantial new construction in an area immediately to the north of the AlbaNova centre. Future housing for Nordita is included in those plans and is expected to be ready for use in 2018.

A BRIEF SCIENTIFIC HISTORY

The Nordita Board in 1958

In the first half of the 20th century, the work of Niels Bohr and his collaborators established Copenhagen as a world center for modern physics. Bohr encouraged contacts and collaborations with Nordic physicists, several of whom visited Copenhagen to take part in the international research going on there. These developments naturally led to discussions to establish a joint Nordic research center.

The 1950s saw a widespread political will for joint projects, both at the Nordic and at the European level; the war had demonstrated the importance of scientific preeminence and that of physics in particular. In 1952, the Western European nations decided to establish a large accelerator laboratory, the European Center for Nuclear Physics (CERN). Copenhagen figured prominently as a possible site for the new laboratory. Eventually Geneva was preferred but the theory group of the new laboratory was initially located in Copenhagen.

The AlbaNova University Center main building (front) and the two Nordita buildings (immediately behind the AlbaNova main building). Image credits: Pontus Walck.

When it was finally decided that the CERN theory group was to move from Copenhagen to Geneva, Torsten Gustafson, Niels Bohr and other prominent Nordic physicists took the initiative to establish a Nordic center for theoretical physics in Copenhagen. The idea was well received at the political level, notably by the Swedish Prime Minister Tage Erlander. Theoretical physics was an uncontroversial, relatively inexpensive area of collaboration and research, and the other Nordic countries stood to benefit from the eminent research group in Copenhagen.

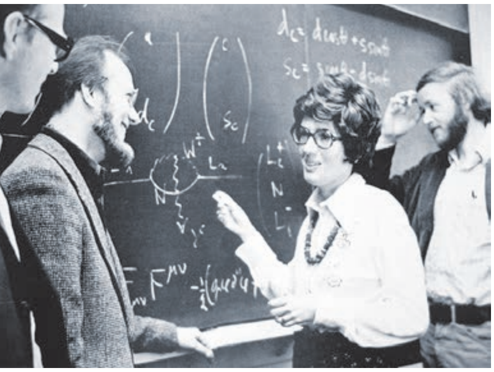
The former Nordita building in Copenhagen. Image credits: Axel Brandenburg.

Nordita opened on October 1st 1957. An important activity of the new Institute was the training of young Nordic researchers, as there was no organized doctoral education in physics in the Nordic countries at that time. In the 1960s, the Nordic countries considerably expanded their research and teaching in physics, with many new positions being established at the universities. A large fraction of the researchers who had been trained at Nordita were offered positions and the Institute has continued to train future leaders in theoretical physics. Out of 320 young researchers who worked at Nordita in Copenhagen between 1957 and 2006, at least 165 have secured permanent university positions. It is still early days for Nordita in Stockholm, but of 20 postdoctoral fellows at Nordita since 2007, 18 have moved on into other academic positions at the postdoctoral or junior faculty level. Today, Nordita alumni form an extensive contact group, which the Institute draws upon for maintaining and extending Nordic collaborations.

The Niels Bohr Institute, with the Nordita building to the left. Image credits: Christen Hansen.

Although Nordita originally derived its name from atomic physics, the Nordita faculty was quite diverse from the beginning. Christian Møller (1904-1980), Nordita's first Director, was known for his contributions to the theory of gravitation and quantum chemistry. Léon Rosenfeld (1904-1974) joined Nordita in 1958. He coined the term "lepton" and was among the first to work on quantum electrodynamics. Gunnar Källén (1926-1968) worked on elementary particle physics and the renormalization of quantum electrodynamics. Nuclear and atomic physics was represented in the early years by Stefan Rozental (1903-1994) and Ben Roy Mottelson. Mottelson would go on to win the 1975 Nobel Prize in Physics, together with Aage Bohr and Leo James Rainwater, for his groundbreaking work on the geometry of atomic nuclei. Aage Bohr became Director of Nordita in 1975. Gerald E. Brown accepted a Nordita professorship in 1960, bringing his research on many

Nordita East building, Stockholm



Cecilia Jarlskog discusses weak interactions with Matts Roos and Finn Ravndal, early 1980's.


Participants in the Nordita Master Class in Physics in June-August 1997.


Wolfram Weise in discussion with two students during the Dense Hadronic Matter meeting at Nordita in April 1997.

body problems and effective models for the atomic interaction, and later the theory of compact stars and the chiral bag model of the atomic nucleus.

James Hamilton arrived at Nordita in 1964 and soon established a research group in elementary particle physics, focusing in particular on the use of dispersion relations in the analysis of the strong interaction. At that time, particle physics was still widely considered a sub-field of nuclear physics and Hamilton's lectures provided invaluable guidance for young Nordic researchers interested in this emerging area of theoretical physics. In the years 1976-78, Hamilton published a series of papers calculating the effect of electromagnetic interactions on hadron scattering that became known as "the Nordita method."

Gösta Gustafson came to Copenhagen as a Nordita fellow in 1968 and worked with James Hamilton. He remained in close contact after returning to Lund in 1972 and the famous "Lund String Model" later emerged out of this interaction. This is a phenomenological model of hadronization in particle scattering that is still widely used, for instance in analyzing data from the Large Hadron Collider at CERN. As of today, it has been cited more than 2000 times, a striking documentation of its impact.

Holger Bech Nielsen was a Nordita fellow from 1967-1971. In the following years he produced a number of tremendously influential articles on highly energetic particle collisions. Nielsen is today regarded one of the fathers of String Theory. Nordita has remained a strong player in the field of String Theory with Paolo Di Vecchia, Lárus Thorlacius, and Konstantin Zarembo leading the high-energy theory group.

In the 1970's Nordita was instrumental in building up the field of astrophysics and cosmology in the Nordic countries through the training of young researchers and organizing workshops, and summer schools. It was an attractive subject for Nordita to introduce because of the numerous observational discoveries due to advances in instrumentation, and because astrophysics has broad contacts with other branches of physics that were already pursued at the Institute. This extension of research areas was aided by the flexibility Nordita had to make strategic recruitments and attract world class talent.

Astrophysical research at Nordita is still outstanding in its areas of specialization: the study of compact objects and high-density matter (neutron stars, black holes) led by Christopher Pethick, astrophysical magneto-hydrodynamics and plasma astrophysics led by Axel Brandenburg. This is a field that has greatly benefitted from the rapid increase in computational power

allowing more sophisticated simulation of physical systems. Pethick has advanced physics by his imaginative applications of many-body theory across several different areas, starting with helium liquids, continuing with neutron star dynamics and supernova collapse, and more recently the analysis of the rich physics of ultra-cold atomic condensates, where he and his colleagues are engaged in a continuing dialogue with leading experimentalists.

Nordita has a strong tradition in the field of condensed matter physics. Alan Luther and Christopher Pethick came to Nordita in the mid 1970's and had profound influence on the development of condensed matter physics in the Nordic countries. Alan Luther is known for his work on electron systems in one dimension. The techniques he invented are of prime importance in the study of nano wires, including those exhibiting topological phases of matter. The strong emphasis on condensed matter physics continues with the recent addition of Alexander Balatsky, a leading expert on the theory of strongly correlated electrons, to the Nordita senior faculty.

The discovery of chaos and self-organized criticality in complex systems was one of the most important developments in science in the second half of the 20th century. These concepts are tightly woven into the fabric of many fields of science, and we have only touched on the full scope of insights they can bring. John Hertz, who joined Nordita in 1981, is a pioneer in the theory of neural networks and author of one of the defining textbooks in the field. Kim Sneppen, who was a Nordita fellow from 1989 to 1991, and co-author of the well known Bak-Sneppen model of co-evolution of interacting species, is recognized for his work on self-organized criticality and nonlinear dynamics, extending into the field of biological networks. This field of research has a close interaction between theory and experiments on specific biological systems, such as bacteriophages (viruses infecting bacteria).

The scientific history of Nordita spans over 50 years and includes many other notable developments that are not described here. Over time, not only the content of fundamental research in theoretical physics has changed, but also its infrastructure and technology. The information age deeply affects how researchers gather and disseminate information and facilitates long-distance collaborations. Today seminars at Nordita are routinely recorded and uploaded to YouTube and software for computational astrophysics, developed at Nordita, is publicly available worldwide at Google Code. Extensive numerical simulations have become an indispensible part of Nordita research, and, in that, the Institute greatly benefits from ready access to world-class technological infrastructure in Sweden and the other Nordic countries.

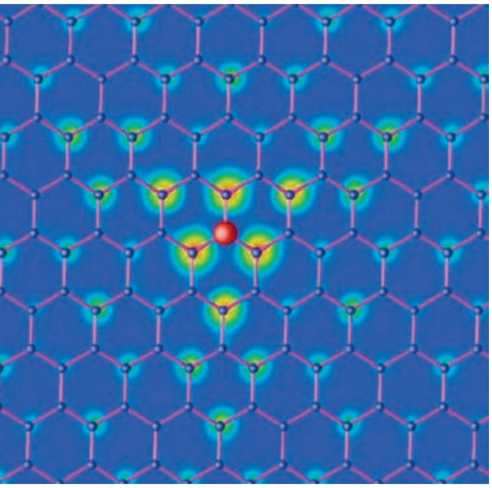
Nordita seminar in Copenhagen, March 2003

Lecture by Alexei Abrikosov at the conference on the Physics of the 2D Electron Gas, June 1995

Bengt Gustafsson, lecturer at the Master Class in Physics held at Nordita in July-August 1997, in conversation with Sven Åberg and Ricardo Broglia

RESEARCH AREAS

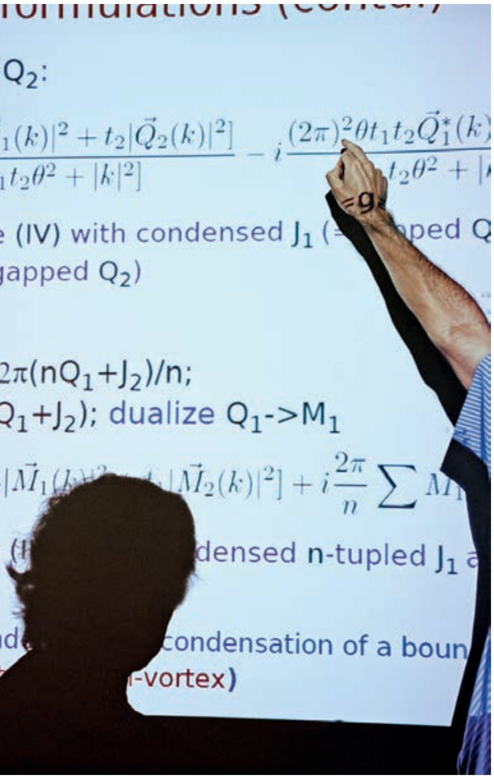
Condensed Matter Physics



Local electronic feature in graphene calculated theoretically by Balatsky et.al.

Condensed matter physics is one of the cornerstones of research at Nordita. In this area of research, rather than studying collisions between a few particles, one is interested instead in understanding the collective behavior of very many particles. Phase transitions, in which the properties of matter change abruptly, are of particular interest in condensed matter physics. A familiar example is the cooling of water below zero degrees Celsius at normal atmospheric pressure: Suddenly all the water molecules arrange in a regular pattern, forming ice. The study of phase transitions and other collective phenomena, and the properties of the resulting phases of matter, make up a large part of condensed matter physics.

A spectacular new phase of matter was discovered in 1911 by Kamerlingh Onnes. He and his team observed that when mercury is cooled down to very low temperature (4.2 K), it loses its electric resistance completely. Electric current flows without any dissipation and we say the metal becomes “superconducting”. It took until 1957 for a theoretical explanation of this effect to be put forward by Bardeen, Cooper and Schrieffer. According to their theory, the electrons which form the currents in metals interact with the vibrations in the atomic lattice. This results in an attraction between the electrons, which normally repel each other due to their charge, and allows them to form pairs, called “Cooper pairs” after their discoverer. The Cooper pairs move without resistance through the atomic lattice and form the superconducting state of matter.

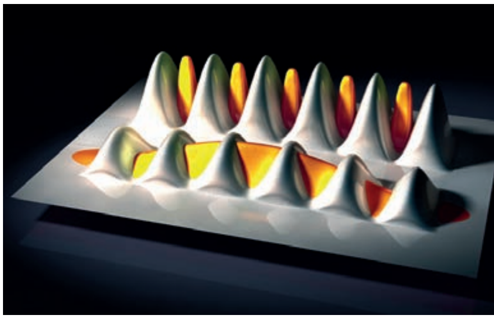


In 1986, Bednorz and Müller discovered a material which became superconducting at a much higher temperature than the materials discovered so far. This sparked the hope that one day superconductivity might become useful for applications in daily life. A big stumbling block, however, is that these high-temperature superconductors cannot be explained by the theory of Bardeen, Cooper and Schrieffer, and exactly how they function is one of the big open questions in condensed matter physics today. Alexander Balatsky, who has recently joined Nordita as Professor of Theoretical Condensed Matter Physics, leads a group of researchers working on understanding high-temperature superconductivity.

The invention of the transistor by Bardeen, Brattain and Shockley in 1947 is a good example of the immense practical relevance of condensed matter physics. The impact the transistor on our lives is hard to overestimate. Transistors are, quite literally, the building blocks of our information technology society. But transistors have limitations that will soon be reached. To keep the power of our computers growing at the rate it has done for decades (roughly doubling every 18 months), transistors have to be packed denser and denser, and therefore have to become smaller and smaller. This miniaturization will inevitably come to an end when we reach the atomic limit, the ultimate smallest size a transistor can have.

One way to overcome this limit was envisioned by Richard Feynman and others already in the early 1980’s. Feynman proposed harnessing the laws of quantum mechanics, which govern how matter behaves at small scales and low temperatures, to perform computations. One of the striking features of quantum mechanics is that particles can be in a superposition of different states. If one is able to store information in such superpositions and manipulate them, one can in principle use the laws of quantum mechanics to greatly speed up computations. The quest for such a "quantum computer" drives a massive research effort in condensed matter physics worldwide. If successful, quantum computers would have a dramatic potential to shape our future.

Various routes towards quantum computation have been proposed but we will focus on a particular one here. The idea, put forward by Kitaev in 1997, is to use "topological states of matter". These topological states of matter host particles with curious properties: Even if one fixes all the degrees of freedom of these particles that can be controlled, such as their position and velocity, then the state of these particles is still not completely fixed. Instead, there are different quantum states, which only differ in their global properties; knowing how these states look like locally is not enough to tell them apart. Kitaev proposed to use these topological states of matter to store quantum information because they are unaffected by local perturbations, which are always present and present major problems for most other proposals for quantum computation.



Physicists can observe quantum mechanical phase transitions using ultracold atoms (yellow) in optical lattices (white surface). For weak interactions the particles are spread out over the lattice in a superfluid state (front); a deep lattice potential is necessary to confine them into single lattices (back). Image credits: Elmar Haller, Innsbruck.

Of course, to be able to use topological states of matter for quantum computation, one needs access to such states! Recently, there has been tremendous progress in this field, both theoretically as well as experimentally. It was realized only a few years ago that topological states are more common than condensed matter physicists previously thought. The prototypical topological state was discovered by von Klitzing, Dorda and Pepper in 1980 and is responsible for the quantum Hall effect (Nobel Prize in Physics 1985). And during the last decade, it was realized that insulators and superconductors also come in topological variants, which might be utilized in quantum computation. Topological phases of matter are studied intensely at Nordita. Researchers at the Institute are trying to understand when such states form, what their properties are, and how then can be used.

High-temperature cuprate superconductors, graphene and topological insulators are examples for a special class of materials in which excitations have a linear energy-momentum relation. These so called "Dirac materials" are another focus area of research at the Institute. Striking similarities in the properties of these diverse compounds point to same key organizing principles that control their electronic, magnetic, optical properties. Understanding these key principles can allow us to design novel materials with desired functionalities.

Another field of study at Nordita, building on the work of Christopher Pethick, is the behavior of cold atomic gases which exhibit various interesting properties. A question currently under study is what happens to these systems if one tries to position the atoms in regular patterns, by means of so-called "optical lattices". Optical lattices are formed by shining laser light on the system from opposite directions, creating standing waves and forcing the atoms to arrange in regular patterns, much in the same way as in conventional solids. Theses atomic systems allow for unprecedented control of system parameters, and one can create and study model systems in the lab including models of high-temperature superconductors and topological phases of matter. Recent years have seen an exciting synergy emerge between the communities working on atomic gases and condensed matter physics.

Further reading:

- *Jonas Larson and Jani-Petri Martikainen, "Coupling internal atomic states in a two-component Bose-Einstein condensate via an optical lattice: Extended Mott-superfluid transitions," Phys. Rev. A 80, 033605 (2009); arXiv:0811.4147.*
- *Paata Kakashvili and Eddy Ardonne, "Integrability in anyonic quantum spin chains via a composite height model," Phys. Rev. B 85, 115116 (2012), arXiv:1110.0719.*
- *O. Wehling, A. V. Balatsky, et.al. , "Local electronic signatures of impurity states in graphene," Phys. Rev. B75, 125425 (2007).*

Elementary Particle and High-Energy Physics

Particle physics is the study of the most fundamental constituents of matter and the interactions among them. To get access to the short distances on which these fundamental constituents make themselves noticeable, enormous amounts of energy have to be released in an extremely small volume.

This field of high-energy particle physics has seen truly extraordinary progress in the last decades. A coherent and beautiful picture has crystallized out of the laws that govern the smallest constituents of Nature. It explains the origins of mass of all the matter around us and describes the nature of forces that keep the matter together. These are the very same laws that determine the history of the Universe as a whole since the very early moments of its existence. Recent results from the Large Hadron Collider at CERN in Geneva reinforce this picture of particle physics that is currently accepted as the "Standard Model" of fundamental interactions.

According to the Standard Model, the smallest constituents of matter are elementary particles without any geometric size and shape (such as electrons and photons), which form larger composite particles (such as protons and neutrons). Stuff around us, and we ourselves, are built from enormous numbers of these particles. In everyday life we normally only encounter situations in which a huge number of particles act in unison at fairly low energy. This collective behavior is the subject of condensed matter physics and quite different from the properties of individual particles at the very small scales that high energy physics is concerned with.

The laws of particle physics are quite unusual by measures of our everyday experience. Particles, for instance, can appear and disappear from "nothing" if they do so quickly enough, thanks to Heisenberg's uncertainty principle. An electron, if we could see it from nearby, would therefore look as if it was surrounded by a cloud of photons, and pairs of electrons and positrons, that continuously appear out of the vacuum and almost instantaneously disappear. Physicists call these vacuum fluctuations "virtual particles."

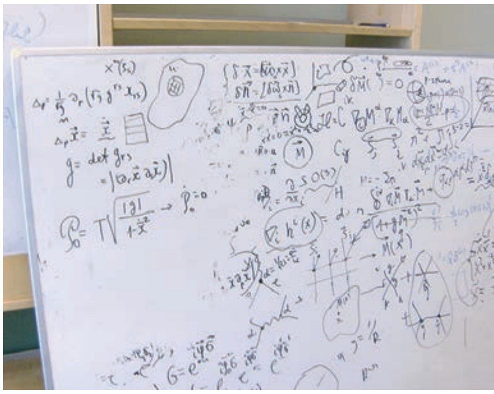
It is a remarkable but well confirmed fact that all the forces in Nature at the fundamental level arise from exchange of such virtual particles, and the Standard Model is built on this idea. For instance electrons repel each

other by constantly emitting and absorbing virtual photons. The virtual particles surrounding an electron only slightly change the electron's own properties. But these tiny changes can be predicted and calculated accurately, and agree extremely well with experimental measurements.

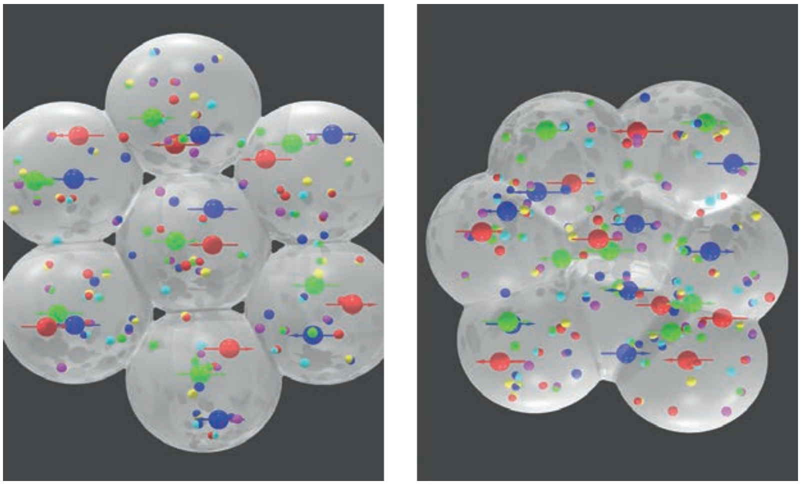
The story is much more difficult for the particles that make up atomic nuclei, protons and neutrons. Neutrons and protons are not elementary but composed of smaller constituents called quarks. The strong nuclear force that keeps protons and neutrons together arises due to the exchange of gluons between these quarks. The properties of quarks are dramatically changed by the cloud of virtual gluons that surrounds them: The forces between quarks are so strong that they remain permanently confined within protons and neutrons. The virtual gluon cloud carries energy and makes quarks about a hundred times heavier than they would have been otherwise. Since the mass of an atom is mostly the mass of protons and neutrons composing its nucleus, this virtual glue makes up more than 99% of our body weight!

The theory of quarks and gluons was discovered already in the early 70s and is called "quantum chromodynamics." Although much has been learned since then, the most fundamental questions remain unanswered, most notably the mechanism of quark confinement. Researchers at Nordita are working on many different aspects of quantum chromodynamics, in particular on the behavior of quarks and gluons under extreme conditions, such as in the interior of neutron stars or in the universe just fractions of a second after the Big Bang, when matter was extremely hot and dense. Under these extreme conditions, quarks are no longer combined in neutrons and protons; instead, together with gluons they form what is known as the "quark gluon plasma." Understanding the properties of the quark gluon plasma is among the big challenges of high energy physics.

In spite of its remarkable successes, the Standard Model is known to be incomplete. We know for example that the Standard Model describes only the visible matter, which only accounts for 4% of all matter in the universe. The rest is made of dark matter and dark energy. We know very little about the microscopic properties of these enigmatic substances. It presently seems likely that dark matter consists of so far undiscovered particles whose interactions with ordinary matter are so feeble that they have



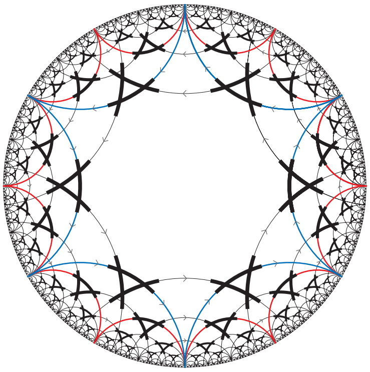
Whiteboards are important tools for theoretical physicists, for teaching, for discussing new ideas with your colleagues, and for getting that important overview of your own ideas that you wouldn't have on a piece of paper or computer screen. So at Nordita there are whiteboards everywhere.



Left: Normally, quarks and gluons are confined to form larger particles like neutrons and protons, collectively called "hadrons". Small colorful balls are gluons. Large colorful balls are quarks. The arrows indicate spin. Transparent grey bubbles indicate the elementary particles are bound to form (color-neutral) hadrons.

Right: At high temperature or density, quarks and gluons no longer form cleanly separated hadrons. Instead, they form what is known as the quark-gluon plasma. Image credits: Stefan Scherer, Heidelberg.

escaped detection until now. But that only begs the question what these undiscovered particles are.



Strange geometries sometimes turn out to be surprisingly useful for describing physical phenomena. This image represents the hyperbolic world on the "Poincaré disk".

Another difficulty of the Standard Model is the vast disparity of energy scales between various interactions. Roughly speaking, a natural order-of-magnitude estimate of the electron mass overshoots its experimentally known value by a factor of billions of billions. This is known as the "hierarchy problem." And the problem whose solution has been the most elusive is that the gravitational interaction is not part of the Standard Model because it is not known how to quantize it. Yet, such a theory of "quantum gravity" is necessary to understand the first moments of our universe and the structure of space and time itself.

To address these fundamental problems of current high-energy physics, many new ideas have been put forward; among the best developed ones are supersymmetry, extra dimensions, and string theory. Physicists at Nordita are actively participating in this research, in particular supersymmetry and string theory.

String theory asserts that elementary particles have an internal structure: Each particle is a string curled into a ring of a very small size. Different particles are just different vibrations of this string. These very simple assumptions have far-reaching consequences. Perhaps the most remarkable feature of string theory is its relationship to quantum gravity: In contrast to the Standard Model, string theory is capable of explaining all known particles and all types of interactions, including gravity. String theory has also proved to be mathematically very rich, and in the last decade has given rise to a whole new area of research, known as holographic duality. The basic idea of holographic duality is that theories of the type that are used in the Standard Model can be equivalently described in an entirely different, geometric way – the "holographic dual" – by using string theory in higher dimensional space-time.

Holographic duality has shed an entirely new light on the quark confinement problem and has deepened our understanding of the quark gluon plasma. Most recently, its applications have expanded to condensed matter physics and the understanding of quantum criticality and superconductivity.

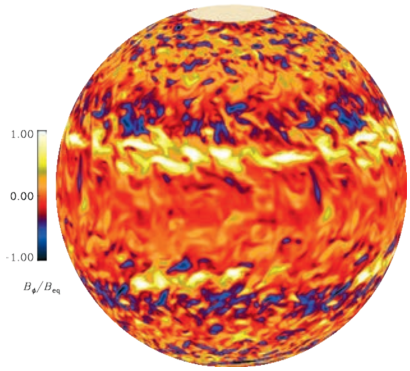
Further reading:

- *K. Zarembo and S. Zieme, "Fine Structure of String Spectrum in AdS(5)xS(5)," JETP Letters 95, 219 (2012), arXiv:1110.6146*
- *V. Keränen, E. Keski-Vakkuri and L. Thorlacius, "Thermalization and entanglement following a non-relativistic holographic quench" Phys. Rev. D 85, 026005 (2012), arXiv:1110.5035.*

Astrophysics and Astrobiology

Astrophysics deals with physical phenomena on enormously different length scales, ranging from the solar system to the furthest reaches on the Universe. Life on Earth would not be possible without the energy constantly supplied by our Sun's nuclear fusion, but understanding the physics of this hot ball of plasma, and that of other stars like our Sun, remains a challenge.

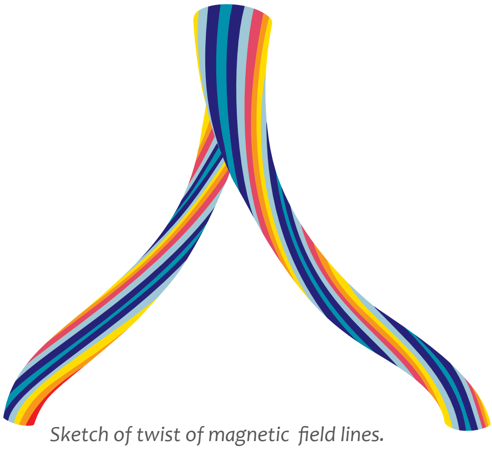
Sunspot activity and its consequences are particular highlights of astrophysics research at Nordita. Sunspots are surface manifestations of strong magnetic fields in the Sun. Their number varies cyclically with a period of about 11 years. Predicting the height of the next maximum is of significant commercial interest to space agencies, because the high ionospheric activity that comes along with sunspot activity increases friction on space crafts and shortens their life span. Estimating the height of the next maximum requires an accurate and self-consistent theory of the solar dynamo, which is the mechanism by which kinetic energy of the turbulence in the Sun is being converted into magnetic energy through a large-scale instability.



Visualization of the magnetic field from a solar dynamo simulation. Yellow shades indicate eastward direction and blue shades westward direction. The magnetic flux belts are responsible the production of sunspots in low latitudes. Adapted from Käpylä, Mantere, and Brandenburg (2012, Astrophys. J. Lett. 755, L22).

A particular focus of research at Nordita, lead by Axel Brandenburg, is supported by an Advanced Grant from the European Research Council (ERC) on Astrophysical Dynamos. The aim of this research is to understand the origin and manifestation of magnetic fields in astrophysical bodies. The numerical study of a gas, whose density increases strongly over many orders of magnitude from top to bottom due to gravity, has been central to this work. In the course of the investigation an instability was discovered, which leads to spontaneous magnetic field concentrations. This potential explanation for the origin of sunspots has sparked a lot of interest and inspired many follow-up works.

The research done at Nordita demonstrated the importance of the conservation of total magnetic twist. To build up a large-scale field with twist of one handedness, twist of opposite handedness has to be released at smaller scales. Moreover, further work has now shown that this can happen through so-called coronal mass ejections, which are intense outbursts on the solar surface (see image). Such events release energetic particles that hit the Earth, predominantly in the auroral belt in polar latitudes. They are also of



Sketch of twist of magnetic field lines. (The case shown is not the actual case relevant for sunspots.)

commercial interest, because they pose significant radiation hazard to flight crew and passengers on polar routes. Flights may have to be re-routed to lower latitudes during such outbursts, which is costly in terms of time and fuel.

A dynamo mechanism is also at work in the engines of quasars that convert the potential energy of inflowing material ultimately into visible light, as gas swirls deep into the gravitational well of its central supermassive black hole. Nordita staff were involved in the numerical demonstration of a feedback loop involving both the dynamo instability and the magneto-rotational instability at the same time. Dynamos also produce large-scale magnetic fields in spiral galaxies on scales exceeding 10,000 light years. Here, turbulence is driven by supernova explosions occurring randomly in the galaxy and pushing the interstellar gas around. Again, Nordita was involved in producing realistic simulations of such processes.

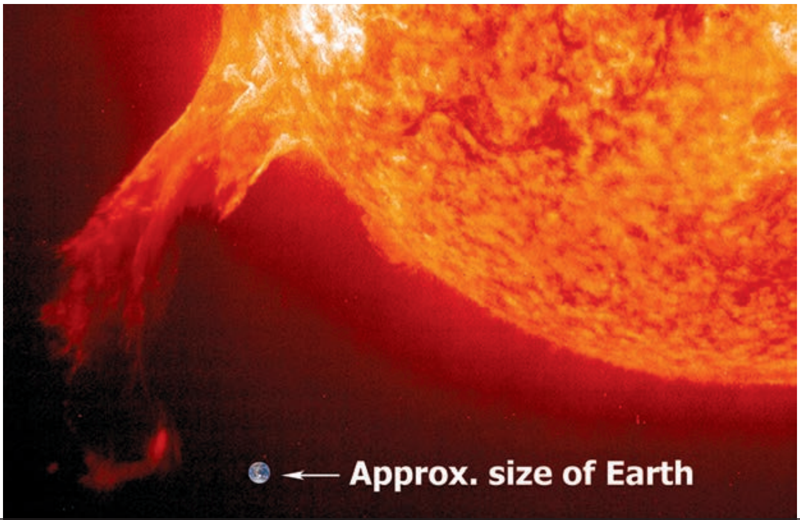
In addition, Nordita's astrophysics group studies the evolution of magnetic fields that can be generated in the early universe, for example during inflation or during the time when the electromagnetic and weak forces became independent of each other. Such magnetic fields can be shaped like a helix and in that case, the nonlinear hydromagnetic interactions are known to produce magnetic power at progressively larger scale. This might still be observable today as large-scale fields between clusters of galaxies, which other astrophysical mechanisms could not have acted to erase.

Research in astrobiology at Nordita has focused on the origin of what is known as "homochirality," that is the fact that on Earth all biomolecules come in one of two possible mirror images. Understanding homochirality is highly relevant for the successful assembly of longer molecule chains such as the first peptides and nucleotides. To advance research in astrobiology, Nordita hosted the 2012 annual meeting of the European Astrobiology Network Association.

Computer simulations provide an essential means of gathering information about the interior of the Sun and other astrophysical bodies. Scientists at Nordita initiated and are still maintaining a versatile computer code that is now used worldwide to solve a broad range of equations describing compressible turbulent gas motions with magnetic fields, dust particles, radiation, self-gravity, and many other effects. It is currently also used for turbulent combustion and other chemical reaction networks relevant, for example, to the dynamics of aerosol particles. This computer code developed at Nordita has also been used successfully for teaching purposes. It is freely available online at pencil-code.googlecode.com

Further reading:

- *P. J. Käpylä, M.J. Mantere and A. Brandenburg "Cyclic magnetic activity due to turbulent convection in spherical wedge geometry" Astrophys. J. Lett. 755, L22 (2012), arXiv:1205.4719.*
- *J. Warnecke, A. Brandenburg and D. Mitra, "Magnetic twist: a source and property of space weather," J. Space Weather Space Clim. 2 A11 (2012), arXiv:1203.0959.*



Close up of solar eruption, taken on July 1, 2002 in 304A emission. The 304A filter shows emission from singly ionized helium at about 60000 degrees C.
Image courtesy of SOHO consortium. SOHO is a project of international cooperation between ESA and NASA.

Statistical Mechanics and Biophysics

The research pursued in statistical and biological physics at Nordita ranges from fundamental aspects of non-equilibrium statistical mechanics, over questions of how biomolecular systems on the nano-scale achieve and maintain their functionality, to possible biotechnological and pharmaceutical applications.

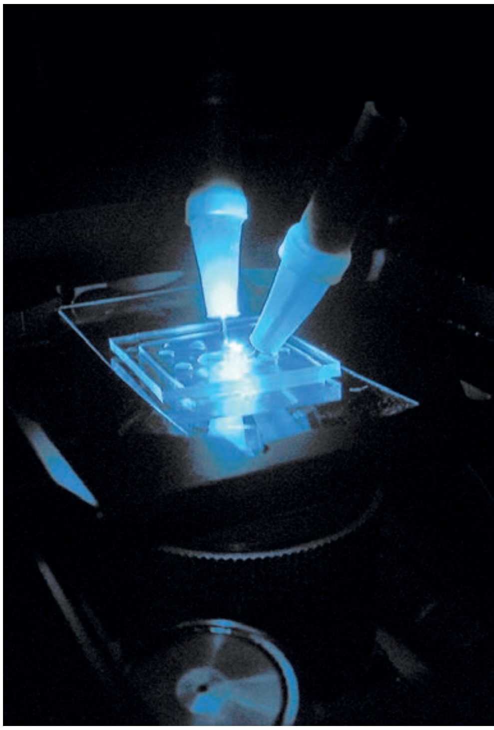
The interface between physics and the life sciences, and the emerging fields of bio- and nano-technology, rely on our growing ability to observe, measure, manipulate, and even manufacture on the molecular scale. At such short distances, when the molecular nature of matter becomes apparent, the thermal agitation of molecules and the associated fluctuations can dominate the properties of the system. Such thermal noise effects are everywhere in living organisms below the level of cells, and give rise to intriguing physical phenomena, in particular if non-equilibrium conditions are involved.

In many of these biological systems the quantitative methods of theoretical statistical physics can be fruitfully applied. This shifts the scope of biophysical research from the categorization of empirical observations to new ways of organizing and analyzing information, and allows uncovering and understanding the physical mechanisms behind the functioning of biological systems on the molecular and cellular level.

Stochastic thermodynamics is a new and exciting research direction in statistical physics, which explores fundamental aspects of non-equilibrium processes. The developments summarized under this term may be characterized by the common idea to adapt and generalize concepts from equilibrium thermodynamics to the non-equilibrium realm, typically at the level of single particle trajectories monitored over the entire system evolution. This approach has proven to be very powerful, and already produced results of remarkable generality – e.g. so-called fluctuation theorems – connecting the system's behavior when driven out of equilibrium with its equilibrium properties.

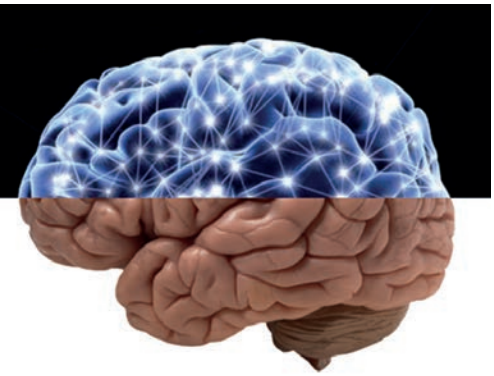
This approach is of interest not only from a fundamental theoretical viewpoint but is also directly relevant to the understanding of biophysical processes, biological motors and artificial molecular machines. Researchers at Nordita study properties of non-equilibrium heat, work and entropy, and derive optimal controls for maximizing the efficiency of molecular "heat-engines" and "motors".

Other research at Nordita provides a complementary view on these complex interaction processes between the macromolecules in the cell by considering them as a biological network of reaction pathways. Statistical physics can be used to reverse-engineer biological networks and build statistical models for these systems. This is a young but rapidly expanding area of statistical physics. It is of major importance for systems biology because biological networks are everywhere. In fact, networks form the fundamental basis of many operations in biology: genes form networks to control protein synthesis and neurons in the brain form networks to process information.

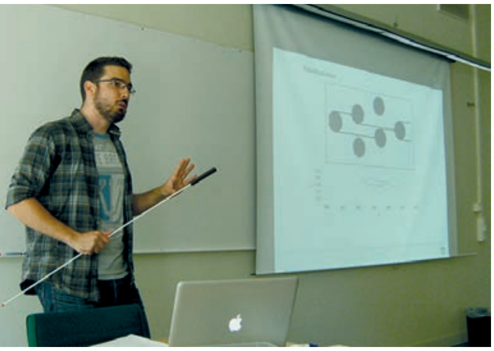


Microfluidic chip with electrical contacts for sorting DNA molecules.
Image credits: Experimental Biophysics, Bielefeld University.

You can learn more about the ideas behind the methods of sorting chiral molecules with multifluidic chips in one of the Nordita Research Presentation videos on YouTube:
www.youtube.com/watch/Jbh9YNzkl4Q
or www.nordita.org/videos



Physicists are trying ot understand biological networks with the help of mathematical and statistical models.



Master student Apostolos Vasileiadis during the defence of his thesis "Particle Diffusion in Periodic Obstacle Arrays".

Understanding biological networks is thus of crucial importance to our societies. It can make it possible to produce novel drugs and therapeutic methods for genetic malfunctions and to influence neuronal interactions in degenerative diseases, such as Alzheimer's disease.

Our understanding of biological networks presently is, however, still very limited because, until recently, experimental tools only allowed studying the properties of one or few elements at a time in a large biological network. Recent technological breakthroughs and advances in experimental techniques have changed the situation. Biologists can now look at many elements of a biological network simultaneously. There is still a major problem: The data obtained using these modern tools are very complex, involving information about many elements, and cannot be analyzed with methodology conventional used in biology. The unprecedented complexity of the output of these new experimental tools demands novel data analysis methods. Using statistical physics, a discipline specifically developed to deal with large systems of interacting elements, researchers at Nordita are developing mathematical methods to analyze biological data and to study how elements in a biological network interact. With these mathematical methods one can then make contact with experimental output in systems biology, and reconstruct the biological network that generated the data. The development, testing, and application of these methods to a variety of data sets allow us to vastly improve our understanding of biological networks such as genetic networks, neural networks, and ecological networks.

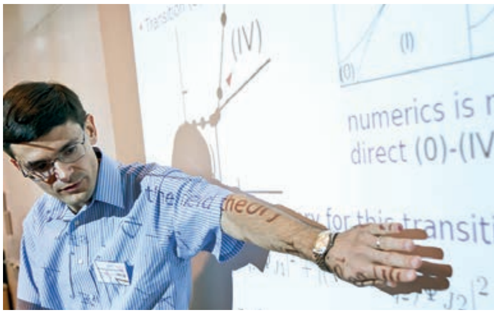
A particularly intriguing potential application of research at Nordita involves the vision of a squeezing a complete bio-chemical laboratory into a single microfluidic chip, a "lab-on-a-chip," encompassing all preparatory and analytical steps of a diagnostic device. Such a lab-on-a-chip requires the minimization of macro-scale standard laboratory techniques to the micro-scale. The big challenge is to cope with the ubiquitous thermal noise. Typically, completely new approaches need to be developed, which make use of thermal noise effects in a constructive way rather than considering the thermal agitation of the molecules as a nuisance.

The Nordita East building in February (AlbaNova main building to the left)

Researchers at Nordita are developing sorting techniques in microfluidic systems for the separation of biomolecular compounds, cells or viruses, which will be an important functionality for a lab-on-a-chip. To that end they use their knowledge of the theory of transport processes gained in stochastic model systems. The sorting of single molecules is an important goal of this research. Many drugs and (bio-) molecules exist in so-called chiral or enantiomeric conformations, which are mirror images of each other, but otherwise identical. Often, the different enantiomers have very different biological or therapeutical impact (one may have the desired clinical effect whereas the other one may be toxic), such that their separation is of immense practical relevance in pharmaceutics and biotechnology. Whereas standard separation techniques rely on a chemically active auxiliary chiral agent, Nordita researchers aim at devising methods for the sorting of chiral molecules based on their physical properties only.

Chiral separation can actually be viewed as a facet of the more general theme to sort (bio-) complexes or molecules according to their morphology. Examples of distinct morphologies are differently shaped cells, different DNA conformations, but also "naked" DNA strands in contrast to the same DNA with some protein or other complex being bound to it. This more general direction of separation according to "shape" is also being investigated at Nordita.

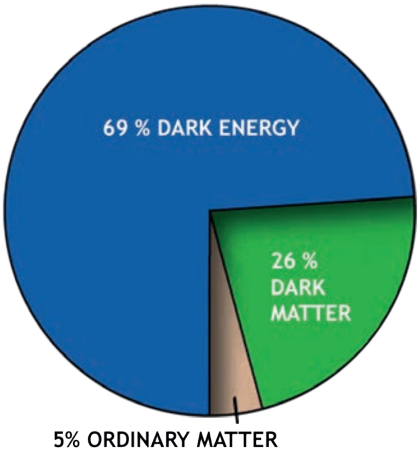
Another interesting new direction of research in biological physics involves DNA sequencing. Novel techniques allowing the sequencing of minute amounts of DNA and other molecules are making possible individualized diagnoses and treatments of diseases like cancer. Sequencing methods using electronic signatures and materials like graphene are pushing the limits of resolution to a single DNA base. New methods for the detection and identification of DNA at such extreme resolution are currently being studied at Nordita.



Further reading:

- *A. Celani, S. Bo, R. Eichhorn and E. Aurell, "Anomalous thermodynamics at the micro-scale," Phys Rev Lett 109:260603 (2012), arXiv:1206.1742*
- *Y. Roudi and J. Hertz, "Mean Field Theory For Non-Equilbrium Network Reconstruction," Phys. Rev. Lett., 106:048702 (2011)*
- *T. Ahmed, S. Kilina, T. Das, J.T. Haraldsen, J.J. Rehr and A.V. Balatsky, "Electronic fingerprints of DNA bases on graphene," Nano Lett. 2012 Feb 8;12(2):927-31.*

Nordita astrophysics out-door group meeting in July



This is how you mix your own cosmic coctaiL:

- *7 oz. dark energy*
- *2.6 oz. dark matter*
- *1/2 oz. hydrogen and helium gas*
- *3 thousandth oz. other chemical elements*
- *5 hundredth oz. stars*
- *5 hundredth oz. neutrinos*
- *5 ten-thousandth oz. cosmic microwave background light*
- *1 millionth oz. supermassive black holes*

The Bullet Cluster: fake color images of the merger of two clusters each containing dozens of galaxies. The dark matter (in blue, determined by gravitational lensing) is clearly separated from the gas comprised of atomic matter (in pink, from X-ray measurements). The separation of the two components is due to the slowing down of the atomic gas when it collides at the center while the collisionless dark matter passes right on through. The name Bullet Cluster refers to the striking illusion that one of the clusters looks like a bullet piercing the other.

Gravitation and Cosmology

Cosmologists seek to answer big questions: What is the Universe made of? How did it begin? What is the future fate of life in the Universe? The field has seen remarkable observational advances in the past two decades. Yet many fundamental questions remain. Research in theoretical gravitation and cosmology at Nordita seeks to unravel the nature of the dark matter and the dark energy that pervade our Universe; to study inflationary cosmology in the first moments after the Big Bang; and to understand the foundations of gravitational theory.

DARK MATTER AND DARK ENERGY

The ordinary atoms that make up the known universe, from our bodies and the air we breathe to the planets and stars, constitute only 5% of all matter and energy in the cosmos. The remaining 95% is made up of a recipe of 26% dark matter and 69% dark energy, both nonluminous components whose nature remains a mystery.

Together, these three pieces, the atomic matter, dark matter, and dark energy, comprise the current standard model of cosmology.

The bulk of the content of all galaxies, including our own Milky Way, consists of dark matter of unknown origin. Cosmologists believe it is made of some new kind of fundamental particle — not protons or neutrons but something completely new — and are hunting to detect it. Nordita's researchers have made significant contributions to understanding the cosmological dark matter sector and continue to push ahead on solving these mysteries. Nordita director Katherine Freese has put forward influential proposals for both direct and indirect detection of dark matter particles, and she pioneered now widely used methods in the field. The underlying theoretical framework and the prospects of eventually experimentally identifying dark matter as well as investigations into the nature of dark energy are studied at Nordita in collaboration with the nearby Oskar Klein Centre.

We also know today that the universe is nearly spatially flat, and continues to expand with an ever increasing speed. Within the framework of Einstein's theory of General Relativity this can only be explained by the presence of a peculiar type of energy that has been called dark energy. We only know that this dark energy must have a negative pressure that effectively provides a repulsive force and be smoothly distributed throughout the universe. In its simplest incarnation, the density of dark energy is also constant in time, in which case it corresponds to the "cosmological constant" that was first introduced, and then again discarded, by Einstein himself. In the more general case, the density of dark energy can also change with time. Whether or not it does cannot be extracted from presently available data, but this may soon be possible.

If dark energy is not just a cosmological constant this would have observational consequences: Dark energy then might be able to interact with dark matter or even with normal matter, and so could be discovered in forthcoming experiments — provided that experimentalists know what to look for. A particularly powerful probe for this is the structure of filaments formed by galaxies and galaxy clusters, which will be measured by the European Space Agency's Euclid satellite to an unprecedented accuracy. Two of the current Nordita researchers are also involved in the Euclid consortium.

INFLATION AND THE EARLY UNIVERSE

One of the biggest challenges for the standard Big Bang model of cosmology is to explain why matter in the universe is spread out so evenly and similarly in all directions. The currently most widely accepted explanation for this observation is that the universe underwent a very rapid phase of expansion before matter had cooled enough for atomic nuclei to form. This phase of expansion has been called “inflation”.

Inflation predicts the generation of small ripples in space that originate from quantum fluctuations in the very early universe that later, after the universe has cooled down, give rise to the galaxies, clusters and other large-scale structures in the Universe. These fluctuations leave marks in the cosmic microwave background radiation. However, there isn’t presently one model of inflation, but several. To really understand what happened in the early universe we have to find a way to distinguish which model is correct. This can only be done by working out the predictions of these models and by contrasting them with data. Recent data from the European Space Agency’s Planck Satellite have ruled out most of inflationary models; Katherine Freese’s natural inflation model remains as one of the few best possibilities.

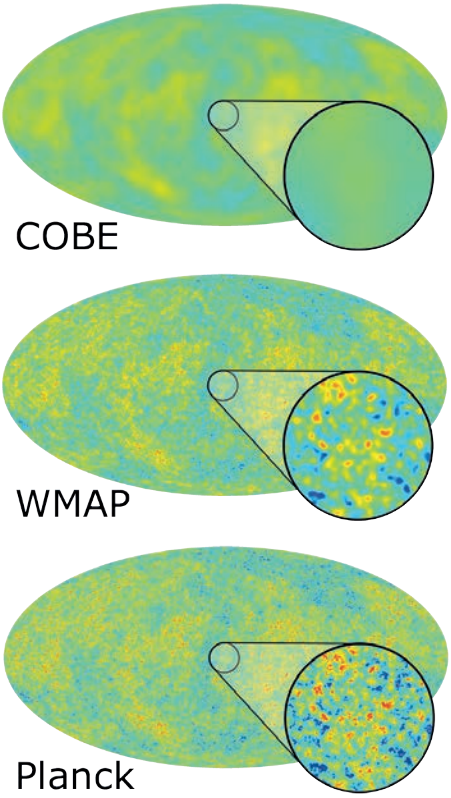
A specific aspect of inflation that is currently investigated at Nordita is the origin of cosmic magnetic fields. Another research project is dedicated to studying how to distinguish whether the universe started in a Big Bang, or if it previously went through a phase of contraction followed by a big bounce into the present phase of expansion.

EXTENDED THEORIES OF GRAVITY

An entirely different possible explanation for the recent cosmological observations is that Einstein’s theory of General Relativity has to be modified on distances exceeding the size of our galaxy, which is an idea also pursued at Nordita. This research is closely connected with studies of the quantum behavior of space and time, which also calls for a modification of General Relativity.

The institute’s research in this area focuses on the formulation of mathematically consistent theories and their observational viability. There are various ways that General Relativity or its coupling to matter can be altered, but it is hard to do this in a way that is both compatible with observation and does not lead to unphysical mathematical artifacts. This theoretical challenge has been taken on by the new fellows Yen-Chin Ong and Lavinia Heisenberg, who have ruled out some and pointed towards new possibly viable directions.

Other approaches to improve the compatibility of Einstein's gravity with observation that are pursued at Nordita take inspiration from certain classes of theories that have been found in limiting cases of string theory. Understanding these theories and their observational consequences is relevant not only for cosmology but has also implications for laboratory experiments, astrophysics, and the physics of black holes and our solar system.



Three generations of satellite-based observatories have recorded the minute fluctuations in the cosmic microwave background radiation with ever increasing resolution: COBE (1992), WMAP (2003) and Planck (2013).

Further reading:

- *Tirthabir Biswas, Erik Gerwick, Tomi Koivisto, Anupam Mazumdar, “Towards singularity and ghost free theories of gravity,” Phys.Rev.Lett. 108 (2012) 031101*
- *Katherine Freese, “The Cosmic Cocktail: Three Parts Dark Matter,” Princeton University Press, 2014*
- *Sabine Hossenfelder, “A Bi-Metric Theory with Exchange Symmetry,” Phys.Rev. D78:044015, (2008).*

After many years in the U.S. I wanted to move back to Scandinavia. I was offered several postdoc positions in Scandinavia but chose Nordita as I hoped it, with its decidedly international atmosphere, both in form of its own employees but also through the constantly running scientific programs… would provide the most stimulating and inspiring physics research environment in the Nordic countries. I was also attracted by the fact that as a postdoctoral fellow at Nordita, I had a large freedom in choice of research topic and was not tied to a particular faculty member. I am very happy to say that all my hopes for my postdoc were fully met, and I had a very productive and stimulating time as a postdoc at Nordita.

Annica Black-Schaffer
Uppsala University

SCIENTIFIC EVENTS AND VISITORS

Programs, Workshops and Conferences

The Nordita Scientific Programs are the centerpiece of scientific interactions at the Institute. Each scientific program extends over a period of four weeks and focuses in depth on a specific scientific topic or collection of topics. The programs bring researchers together and give them the opportunity to discover common interests and start new collaborations. The programs' topics frequently go beyond the traditional borders of theoretical physics and explore interdisciplinary contact points in the natural sciences.

Nordita provides the facilities and administrative support for program participants, and in many cases the academic staff at the Institute is actively engaged in the organization and execution of program activities.

Currently, up to 25 participants can be accommodated at any given time during a Nordita program. This typically includes a core of 8–12 internationally recognized leaders in the subject area of the program, 5–8 invited Nordic scientists, and a limited number of other applicants, including postdoctoral fellows and PhD students. Although there are no quotas, the level of Nordic participation in the programs has been high.

Scientific programs can include focus events — conferences, workshops or schools — with a higher number of participants for shorter periods.

The international scientific community is invited to suggest programs once a year. Program proposals are evaluated and ranked by an external Program Committee and decided by the Nordita Board. Information on proposal submission can be found on the Nordita website.

Selected Programs

The full list of programs and instructions for submiting program proposals are at nordita.org/science/programs.

Extended Theories of Gravity

2—20 March 2015

The cosmological constant and the physics behind dark energy that accelerates the expansion of the universe remain among the biggest mysteries in theoretical physics.

Magnetic Reconnection in Plasmas

27 July — 21 August 2015

Magnetic reconnection is a fundamental multiscale plasma process responsible for plasma transport, plasma heating and acceleration of energetic particles in many astrophysical environments, ranging from planetary magnetospheres and solar wind to solar flares, accretion disk corona, and other astrophysical plasmas.

Control of Ultrafast Quantum Phenomena

18 May — 12 June 2015

New insights into fundamental many-body physics are expected when ultrafast atomic and solid-state processes in the femto- and attosecond time scale can be monitored in real time.

Physics of Interfaces and Layered Structures

24 August — 11 September 2015

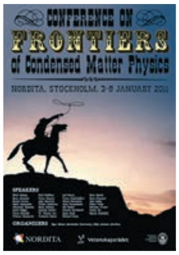
A major direction of research in contemporary condensed matter physics is the effort to design materials with specific functionality by utilizing the unique properties of interfaces between materials of different types.

In addition to the programs that last several weeks, Nordita also organizes shorter conferences and workshops, sometimes in combination with the programs. These events can be arranged on short notice, which provides researchers with an excellent opportunity to gather together experts on subjects they are currently working on. The flexibility of these events also makes them suitable to pick up and expand upon unexpected and recent developments.

In recent years, the total number of participants in scientific events at Nordita has averaged at about 1000 per year. About 40–50% of the participants are from the Nordic countries.

I should like to emphasize the importance of the Nordic dimension: during my stay I became very much integrated into the informal network of Nordic professors and researchers. Its value is not tangible or easily to be measured, but nevertheless quite important because of the shared values. This is often manifest during the various academic evaluation or selection processes. In effect, there is a scientific community much larger than that of a single country, for which we can thank Nordita.

Kari Enqvist
University of Helsinki



Nordic Networks

The purpose of Nordic Networks is to coordinate efforts in selected research areas within the Nordic region. Network activities can for example involve a series of Nordita workshops or programs in a particular area of research, or coordinated visits to Nordita by network participants. Normally, a Nordic Network is organized by a member of the Nordita faculty in collaboration with researchers at Nordic universities.

A very successful example for this activity is the longstanding Nordic Network in String and Gauge Theory that Paolo Di Vecchia has coordinated. This network has brought together Nordic researchers and students for short meetings once or twice a year since 1994, and has been very important to the Nordic string theory community. It has also attracted attention from outside the region with research groups in England, Germany, and the Netherlands actively participating in network meetings.

Visitor Program

Nordita's visitor program provides for numerous short term visits by both junior and senior researchers, and enables several longer term visits each year by scientists who are actively collaborating with Nordita staff. The visitor program is a vital tool to promote and nurture international contacts that strengthen ongoing activities at Nordita, and is an important conduit for bringing new ideas and new research areas to Nordita and to the Nordic region in general. On some occasions, long-term visits to Nordita have been financially supported by the Wenner-Gren Foundation.

In recent years the number of visitors to Nordita, excluding event participants, has averaged at about 50 per year. About one in three of those visitors has ties to the Nordic countries.

Nordita has played a very important role in setting a high standard in theoretical physics in Scandinavia. Many leading scientists in our part of the world were during their young years trained at Nordita. The strength of Nordita is its international faculty and the high scientific standards. Nordita has also been able to quickly reorient itself to new emerging fields in physics.

Hans Fogedby
University of Aarhus

RESEARCH TRAINING

Advanced Schools

Nordita has a long tradition of organizing schools for Nordic graduate students in different subfields of theoretical physics. Following its move to Stockholm, Nordita has introduced a series of annual winter schools run for two weeks in January. The first school was in 2010 on astrophysics, the second in 2011 on condensed matter physics, and the third in 2012 on particle physics. These winter schools have included several series of overview lectures covering a given area of theoretical physics along with more advanced lectures on the most recent and exciting developments in that area. Such courses can rarely be held at a single university because of the small number of students that could follow them, but they can be organized at the Nordic level by collecting together students from universities in all the Nordic countries.

Another activity for PhD students and postdoctoral fellows, organized by Nordita, consists of short meetings, typically two or three days, with pedagogical lectures given by leading experts on recent developments along with talks by the participants themselves on their own research. This activity has been particularly useful for Nordic students trying to follow the research done in rapidly developing fields like string theory and it has provided many young scientists with the opportunity to present their work in an international setting for the first time.

Master Class

For many years Nordita has organized a one-week Master Class for undergraduate students in the Nordic and Baltic countries. The aim of the school is to provide young students with an overview of exciting recent developments in theoretical physics that would normally not be part of the regular undergraduate curriculum at their home university. The goal is to inspire young minds and encourage them to undertake further studies. The lectures are given by internationally recognized experts in the various fields and lecturers are selected for their pedagogical skills as well as excellence in research. The lectures have covered as diverse topics as cosmology, the physics of climate, quantum optics, topological aspects of condensed matter physics, and planet formation, just to mention a few. To further engage the students, they are placed in small groups, working together to solve assigned problems based on the lectures of the day, and discuss with the lecturers.

Students attenting a lecture at Nordita's 2009 Winter School

Courses

Even though Nordita staff members have no formal teaching obligations, many of them give lecture courses on subjects related to their research. In some cases these courses provide an informal introduction to a field, while others are for credit at one of the local universities (Stockholm University, KTH Royal Institute of Technology, Uppsala University). Participants will typically be PhD students and postdoctoral fellows.

Visiting PhD Fellows

Since 2010 Nordita has offered a visiting program intended for PhD students primarily but not exclusively from the Nordic and Baltic countries. This program gives selected students the opportunity to spend time at Nordita and take advantage of the research environment and ongoing scientific activities at the Institute. This can in particular include collaboration on research projects with Nordita academic staff and participation in Nordita Scientific Programs in areas of interest to the students, but is more generally an opportunity to broaden their general knowledge and to interact with researchers working in diverse areas of modern theoretical physics. Visiting PhD fellows may also be interested in taking PhD-level courses offered at Stockholm area universities. A Visiting PhD Fellowship is awarded for a period of one to four months. Nordita provides accommodation and a contribution towards travel and living expenses in Stockholm. Fellows must, at the time of their visit to Nordita, be registered PhD students in theoretical physics or a related subject at a university preferably in the Nordic or Baltic countries, though applications from other countries will be considered. Fellowships are awarded twice a year but starting dates for stays at Nordita are flexible

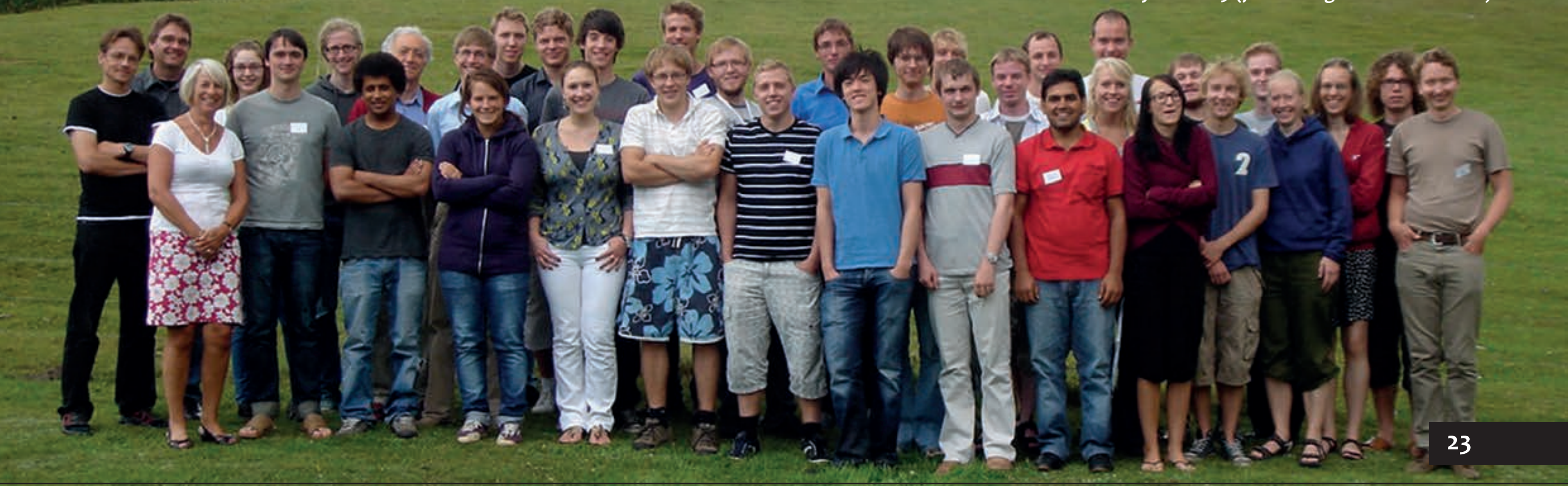
Master Student Internships

Nordita has an extensive postdoctoral program and Nordita faculty members supervise several PhD students, but the Institute does not have any program of master studies. Such programs exist at the physics departments of the host universities, Stockholm University and KTH Royal Institute of Technology. Nordita has, however, hosted several master student internships, where students enrolled at other universities have visited Nordita for a period of one to six months, as part of their studies. This is usually on the initiative of the students. They have sought contact with Nordita staff members, who are generally very open to such inquiries. The source of funding, the time spent, and the extent of the project done at Nordita, vary from case to case.

Getting to know and work with a group of delightful students is a privilege and can never go wrong. The well organized lectures and interesting problems sparked a desire to look deeper into advanced fields of physics. To make it all perfect the food was spectacular which left one only wanting more.

Helgi Sigurðsson,
participant in the
Master Class 2012

Nordita interns in statistical and biological physics Stefano Bo, Christian Karlewski, and Emma Ross and their supervisors Ralf Eichhorn and Erik Aurell in December 2011.



Nordita Master Class in Physics 2009 (for undergraduate students)

Nordita attracts a lot of very gifted postdocs and assistant professors, and several of these have afterwards found other positions in the Nordic countries. In this way Nordita allows our institutions to recruit researchers that might otherwise not have opted for a career in a Nordic country.

Thors Hans Hansson
Stockholm University

Observation with a telescope in Alturas de Marangani on the Peruvian Altiplano. Image credits: La Ventana Cine Itinerante

OUTREACH

Social Media

We know that physics is awesome, but not everybody does, and so we're now on *Facebook* www.facebook.com/nordita.stockholm and *Twitter* www.twitter.com/NorditaSweden to spread word about it, bring our research closer to the public and to actively engage with our audience.

The *Nordita Newsletter* www.nordita.org/news appears four times a year. It informs about recent developments at the institute, new arrivals or visitors, upcoming job opportunities, future meetings and programs, and it gives a list of the latest Nordita preprints since the last Newsletter. In each issue there is also a feature article and news from the five Nordic countries.

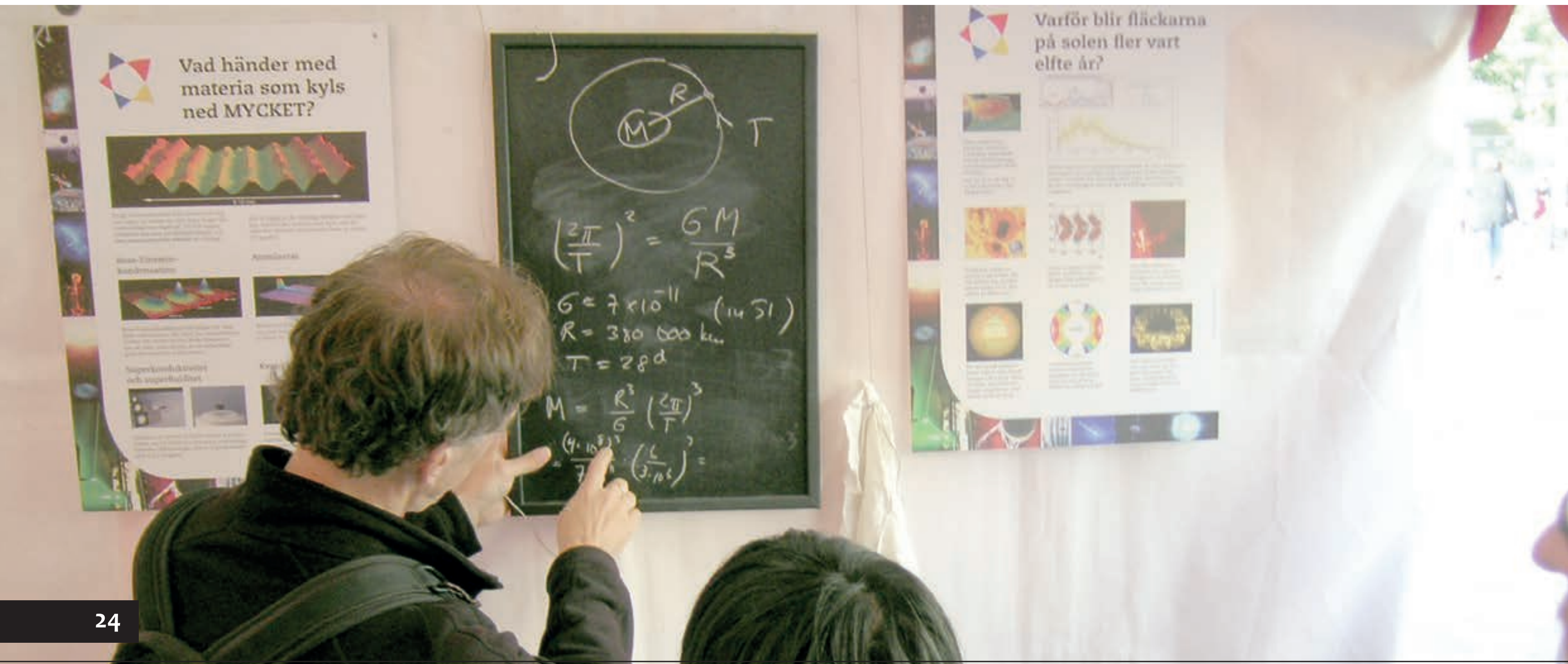
Public Outreach Events

Researchers at Nordita are engaged in a variety of public outreach activities including Stockholm's popular biennial physics fair *Fysik i Kungsträdgården*, and the *AlbaNova Open House* that brings people from the street in touch with scientists.

"Fysik i Kungsträdgården" is a joint projects with the local universities which takes place on a Saturday in September. On that day the central Stockholm park Kungsträdgården is filled with myriads of students and scientists from the Stockholm University and KTH physics departments, astronomy, meteorology, radiation physics, and (since 2008) Nordita, joined by science educators from the House of Science. The public is invited to explore and experience the many facets of physics, ask questions, listen to talks, and try hands-on demonstrations.

Nordita also supported the *Galileo Mobile* project (galileo-mobile.org) during the International Year of Astronomy in 2009, a traveling science education project to bring astronomy closer to young people all over the world.

No theoretical physics without a blackboard ready at hand...



Videos

Seminars from the Institute and from our Scientific Programs, schools and conferences are made available on *YouTube* (see www.nordita.org/videos or www.youtube.com/NorditaStockholm).

Here you also find several five minute long presentations of Nordita and of individual researchers or research groups.

Books

"*The Cosmic Cocktail: Three Parts Dark Matter*"

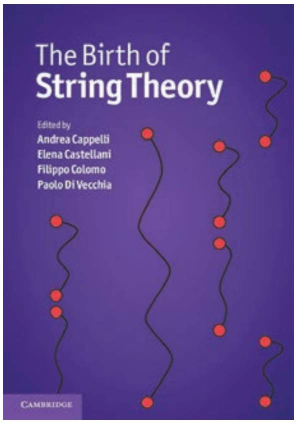
by Katherine Freese
Princeton University Press, 2014

The Cosmic Cocktail is the inside story of the epic quest to solve one of the most compelling enigmas of modern science—what is the universe made of?—told by one of today's foremost pioneers in the study of dark matter. Many cosmologists believe we are on the verge of solving the mystery. *The Cosmic Cocktail* provides the foundation needed to fully fathom this epochal moment in humankind's quest to understand the universe.

"*The Birth of String Theory*"

edited by Paolo Di Vecchia, Andrea Cappelli, Elena Castellani, and Filippo Colomo
Cambridge University Press, 2012

This unique book explores the history of String Theory's early development, told by many of its main protagonists. The book journeys from the first version of the theory (the so-called dual resonance model) in the late sixties, as an attempt to describe the physics of strong interactions outside the framework of quantum field theory, to its reinterpretation in the mid-seventies as a quantum theory of gravity unified with the other forces, and its subsequent development up to the superstring revolution in 1984.



Nordita regularly participates in Stockholm's popular scientific outreach event "Fysik i Kungsträdgården". Image credits: Joakim Edsjö.

NOTABLE COLLABORATIONS

Researchers at Nordita work with collaborators from all over the world, for instance from the *Niels Bohr International Academy* (Copenhagen, Denmark), *SISSA* (Trieste, Italy), the *University of Helsinki* (Finland), the *Leibniz-Institut für Astrophysik* (Potsdam, Germany), *Perimeter Institute* (Waterloo, Canada), the *Ben-Gurion University of the Negev* (Beer-Sheva, Israel), and *Carnegie Mellon University* (Pittsburgh, USA), to mention only a few.

Nordita has signed cooperation agreements with the *Abdus Salam International Center for Theoretical Physics* (ICTP) in Trieste, Italy, the *Asia Pacific Center for Theoretical Physics* (APCTP) in Pohang, Korea, the *Scuola Internazionale Superiore di Studi Avanzati* (SISSA) in Trieste, Italy, the *South American Insitute for Fundamental Research* (SAIFR–ICTP) in Sao Paolo, Brazil, and the *Aalto Science Institute* (AScI) in Finland, to promote scientific collaboration and facilitate the exchange of visitors.

Nordita takes part in many activities in the Nordic countries to strengthen the connections among researchers, for example through the *Swedish Astrobiology Network*, the *Nordic Network of Astrobiology*, the *Nordic Network in string theory*, the *Nordic Network in statistical physics*, and the *GATIS (Gauge Theory as an Integrable System) network*.

Nordita has close interactions with the universities in the Stockholm area, reflected for example in shared seminar series such as the AlbaNova/Nordita Colloquium, seminar series in high-energy physics, condensed matter physics, and complex systems and biological physics with the theoretical physics departments at *KTH Royal Institute of Technology* and *Stockholm University*, a joint astrophysics seminar with the *Solar Physics Institute*, as well as several joint theory journal clubs on specific topics.

Another important point of interaction is the joint supervision of several PhD students who are registered at KTH, Stockholm University and *Uppsala University*. In addition, Nordita and Uppsala University have two joint Senior Lecturer positions, and there are plans for establishing joint postdoc positions with Nordita and the Niels Bohr International Academy.

It is worth stressing that Nordita is a responsible career booster... On the scientific side, Nordita always attracts outstanding young minds, which makes the scientific and personal interaction at this place extremely inspiring... Beyond the institutional embedding, there is an attractive world-class embedding provided by the two Universities in Stockholm with strong physics faculties. The cross section between all these institutions is considerable and has led to many joint ventures which provided benefit for the entire Nordic community... Let me mention that Nordita attracted many first-class lecturers from around the world that complemented the academic education in the nordic countries, where many smaller Universities cannot cover the full range of modern physics.

Prof. Stefan Hofmann
LMU Munich

ICTP The Abdus Salam International Centre for Theoretical Physics

APCTP Asia Pacific Center for Theoretical Physics

ICTP SAIFR International Centre for Theoretical Physics South American Institute for Fundamental Research

SISSA

Aalto University

NORDIC INVOLVEMENT

Nordita is a common Nordic resource for the advancement of theoretical physics. This is a key area of basic research in which the five Nordic countries invest considerable resources. It is a rapidly developing field where co-operation across national borders plays an important role. Nordita activities benefit scientists in all the Nordic countries. In particular, the postdoctoral fellowship program at Nordita attracts young researchers from all five Nordic countries and also serves to bring international talent into the Nordic region.

Nordita organizes advanced summer and winter schools for graduate students and postdoctoral fellows that supplement the regular curriculum at Nordic universities. Nordita is a window to the world for Nordic graduate students via schools and conferences offered throughout the Nordic countries. Nordita Scientific Programs and numerous shorter workshops and conferences provide an important forum for Nordic scientists to interact with each other and with their international colleagues, as does the very active visitors program for Nordic and international scientists at all levels of seniority.

As a recognized center for advanced research, Nordita is a Nordic trademark within the international scientific communit, a beacon to the rest of the world for scientific progress in Nordic countries. With the international trends in globalization, the landscape has changed. As part of this healthy and natural development, Nordita attracts people from outside to the Nordic scientific market. Nordita plays a key role in cross-fertilization of ideas by initiating more international collaboration. Importantly, the message for Nordic scientific success reaches beyond national borders to the entire world.

Nordita has a long and distinguished record as a Nordic centre of research excellence whose importance is recognized at the European and world levels. The recent move to Stockholm has provided an opportunity to renew Nordita with a view to a healthy long-term future. This opportunity has been seized successfully: Nordita has re-invented itself in its new environment, to the advantage of the Nordic research communities in theoretical physics and related fields. The in-house research programs are of the highest quality and attract considerable external funding.

From the report from a 2009 external evaluation of Nordita, carried out on behalf of NMR

Nordita Postdoctoral Fellowships

Nordita has provided extensive training at the post-doctoral level and has contributed to the career development of numerous senior scientists, who are active in the Nordic countries today. Out of 320 young researchers who worked at Nordita in Copenhagen from 1957 to 2006, at least 165 obtained permanent university positions, and Nordita alumni are found in every physics department in the Nordic countries. The emphasis on postdoctoral training continues in Stockholm. The Nordita fellowship program is very competitive with on average 300 applications received and 5–6 fellowships awarded each year. More than 85% of the postdocs that have completed their fellowships since 2007 have obtained other academic positions at the postdoctoral or junior faculty level following their stay at Nordita. Since 2007 the program has been open to applicants of any nationality. Nonetheless roughly half of the Nordita Fellows appointed since then have either been Nordic citizens, have obtained a PhD degree from a Nordic university, or came to Nordita following a previous postdoctoral appointment in a Nordic country.

By encouraging international young researchers to compete for Nordita Fellowships, the program serves to bring new talent into the Nordic region. Some of these international scientists are subsequently recruited into more senior positions in the Nordic countries, while others leave the region for positions elsewhere. In all cases, lasting contacts are built. At the same time, the successful Nordic applicants greatly benefit from interacting with their international peers and having won their fellowships in open international competition contributes to their success in securing other academic positions after their stay at Nordita.

Aurora Borealis. Image credit: Joshua Strang

I have wonderful memories of my semester at Nordita in Stockholm. It was a perfect environment for scientific thinking: supportive, pleasant, and embedded in an environment that was stimulating without being distracting.

Frank Wilczek
MIT
2004 Nobel Laureate

John S. Wettlaufer (left) at the inaugural lecture of the Tage Erlander Guest Professorship for 2012, together with Prof. Sven Stafström, head of the Swedish Research Council. Image credits: Fabio Del Sordo.

RECENT PRIZES, GRANTS, AND PRESS

- Professor *Katherine Freese*, G. E. Uhlenbeck Professor of Physics at the University of Michigan and Nordita Director since 2014, and Professor *John S. Wettlaufer* , the A.M. Bateman Professor at Yale University and visiting professor at Nordita 2011–2012, were in 2014 each awarded grants for 105 MSEK over a 10 year period from the Swedish Research Council under the scheme "Grants for international recruitment of leading researchers".
- Nordita scientists *Axel Brandenburg* and *Dhrubaditya Mitra* are part of a 5 year proposal funded by the Knut and Alice Wallenberg Foundation to study the formation of raindrops in turbulence. Principal investigator of the project is Professor Bernhard Mehlig from University of Gothenberg.
- Professor *Katherine Freese* was portrayed in an article in the December 2014 issue of Populär Astronomi (Popular Astronomy).
- In April 2014, the Royal Swedish Academy of Sciences elected Nordita Professor *Axel Brandenburg* as a foreign member of the Academy's class for astronomy and space science.
- Professor *Konstantin Zarembo* was awarded an ERC Advanced Grant to fund a five-year research project on *Integrable Systems in Gauge and String Theory* (INTEGRAL), starting in March 2014.
- Senior Lecturer *Henrik Johansson* was awarded a 2013 Wallenberg Academy Fellow, which through the Knut and Alice Wallenberg Foundation funds a five-year research project on “Color-Kinematics Duality and Ultraviolet Divergences”.
- In October 2013, the Financial Times listed “The next big names in physics”, including Nordita Assistant Professor *Sabine Hossenfelder,* “a rising leader in quantum gravity research.”
- Professor *Alexander Balatsky* was awarded a five-year ERC Advanced Grant for the project *Dirac Metrials*, starting in April 2013. Together with collaborators at KTH Royal Insitute of Technology, Uppsala University, and Chalmers University of Technology, Alexander Balatsky was also awarded a major grant from the Knut and Alice Wallenberg Foundation (KAW) to fund a five-year research project on *Functional Dirac Materials*, with both theoretical and experimental work at the participating institutions, starting in July 2013.
- In April 2013, Dr. *Ebru Devlen*, who spent a 1-year sabbatical at Nordita, received the Nüzhet Gökdogan Astronomy Science Prize of Istanbul University for her paper "The Anisotropic Transport Effects on Dilute Plasmas" published by Astrophysical Journal in 2011.
- In March 2013, the Royal Norwegian Society of Sciences and Letters announced that Nordita Corresponding Fellow *Yasser Roudi* was the 2013 recipient of the Society's scientific award for young researchers (IK Lykke Fund).

ORGANIZATION

Nordita Board

Nordita has a governing Board, appointed jointly by the Presidents of KTH Royal Institute of Technology and Stockholm University for a three year term, with one representative and one alternate member from each of the five Nordic countries, nominated by the respective research councils, and a chairman who is nominated by the joint committee of the Nordic Natural Science Research Councils, NOS-N. The tasks of the Board include long-range planning, approval of the annual budget, and decisions about appointments of scientific staff following an agreed-on procedure with the host universities.

Director

The Board nominates the Director (currently *Katherine Freese*), who is appointed by the presidents of Stockholm University and KTH for a three-year term. The Director is responsible for the day-to-day administration of the Institute and provides scientific leadership, and is supported by the Deputy Director (currently *Axel Brandenburg*).

Research Committees

In addition to the Nordic governing Board, the Nordic physics community provides direct input into Nordita's scientific activities through four Research Committees, each of which has five Nordic physicists who are experts in a given area of research. Nordita faculty members working in the area in question participate in the work of the Research Committees. The four committees are astrophysics and astrobiology, condensed matter, statistical and biological physics, high energy physics, and gravitation and cosmology. Their tasks include evaluating post-doctoral fellowship applications and providing expert advice in their respective areas.

Scientific Advisory Committee

Nordita also has a Scientific Advisory Committee (SAC) of prominent scientists from the international physics community, appointed for three year terms. The SAC meets in Stockholm every two years to review and comment on a wide range of issues concerning Nordita and provide input into the research strategy and future plans of the Institute.

Members of the SAC are:

Prof. *Curtis Callan*, Princeton University
Prof. *Susan Coppersmith*, University of Wisconsin
Prof. *Steven Girvin*, Yale University
Prof. *Eberhard Gross*, Max Planck Institute for Microstructure Physics
Prof. *Graham Ross*, Oxford University
Prof. *Joseph Silk*, Oxford University
Prof. *Gabriele Veneziano*, Collège de France and CERN

Nordita has been of great importance for me at every step of my career, and lies very close to my heart… In 1995 I attended a very high quality summer school on quantum field theory, on a level that went beyond the courses offered at my own university, because there would not have been enough students for such advanced courses. An important aspect of the Nordic dimension — creating 'critical mass' when the local research environments are just too small… Later, after I had taken up a permanent position in Oslo, I chaired a five-year, highly successful nordic network funded by NordForsk. The backbone of this network was made up of people I knew thanks to Nordita.

Susanne Viefers
University of Oslo

ROYAL INSTITUTE OF TECHNOLOGY

The Nordita Board and Observers in September 2014. Back row, left to right: Jes Madsen, Ivan Shelykh, Leif Kari, David Abergel, Helle Kiilerich, Asle Sudbø. Middle row, left to right: Jonathan Edge, Ulf Wahlgren, Katri Huitu, Susanne Viefers, Måns Henningsson. Bottom row, left to right: Marianne Persson-Söderlind, Kalle-Antti Suominen, Katherine Freese, Mikko Alava, Axel Brandenburg, Gunnlaugur Björnsson. Image credits: Andrew D. Jackson.

Members of the Nordita Board are:

REPRESENTATIVES OF THE NORDIC COUNTRIES:

DENMARK

Prof. *Jes Madsen*,
University of Aarhus

Ast. Prof. *Karsten Flensberg* (alternate), University of Copenhagen

FINLAND

Prof. *Katri Huitu*,
University of Helsinki

Prof. *Keijo Hämäläinen* (alternate), University of Helsinki

ICELAND

Prof. *Gunnlaugur Björnsson*,
University of Iceland

Prof. *Ivan Shelykh* (alternate), University of Iceland

NORWAY

Prof. *Asle Sudbø*,
Norwegian University of Science and Technology

Prof. *Susanne Viefers* (alternate), University of Oslo

SWEDEN

Prof. *Olle Eriksson*,
Uppsala University

Prof. *Måns Henningsson* (alternate), Chalmers University of Technology

CHAIRPERSON:

Prof. *Kalle-Antti Suominen*,
University of Turku

OFFICERS OF NORDITA AND OBSERVERS:

Prof. *Katherine Freese* (Director)

Prof. *Axel Brandenburg* (Deputy Director)

Asst. Prof. *David Abergel* (Faculty Observer)

Dr. *Jonathan Edge* (Junior Staff Observer)

OBSERVERS FOR THE HOST UNIVERSITIES:

Prof. *Anders Karlhede*,
Stockholm University

Prof. *Leif Kari* (alternate), KTH Royal Institute of Technology

Finances

Securing a financial base for the full spectrum of scientific activities at Nordita, both in the short and the long run, remains a top priority for the Institute. In addition, the Institute is actively looking to finance new initiatives and expansion into emerging fields of research.

Research at Nordita is currently supported by a combination of funds from the Nordic Council of Ministers, the Swedish Research Council, the host universities in Stockholm, and via Nordic and European research grants obtained by faculty members. These various sources of income for the year 2014 are indicated in the accompanying chart.

The move to Stockholm in 2007 was accompanied by the transfer of ownership away from the *Nordic Council of Ministers* (NCM) to the host universities. At the time of the move the funding from the NCM was reduced by 50% compared to previous levels in Copenhagen and a further 20% cut of the remaining NCM funding is being implemented in 2014. Nevertheless, the financing by the NCM remains a key source of income for Nordita, amounting to approximately 9 million DKK/year, through which many of the core activities of the Institute are funded. The current contract between the NCM and the host universities in Stockholm is for the three-year period 2014–2016 and is renewable, subject to external performance reviews.

The *Swedish Research Council* (VR) is another important source of funding for Nordita. The Institute will receive 5 million SEK/year in operating funds from the research council during the five years 2012–2016, covering approximately 20% of the current annual operating costs. The grant can in principle be renewed following a performance review.

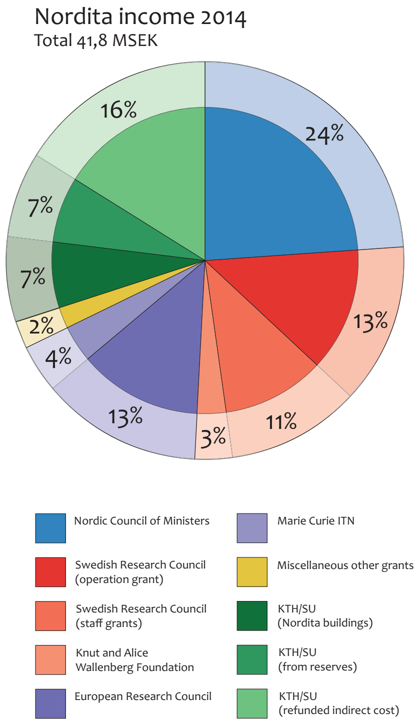
In the long term, *the host universities* have pledged to cover housing costs at the AlbaNova University Centre in Stockholm (currently about 3 million SEK/year) and to provide certain administrative services free of charge (accounting, personnel services, etc.). Furthermore, university overhead charges are reimbursed on external funding obtained by Nordita and this provides indirect financial support to the Institute. The host universities also made available 10 million SEK/year in bridging funds during the first three years of operation in Stockholm (2007–2009). Some of that funding is still at Nordita's disposal but it is expected to run out during 2014.

Nordita faculty members have successfully applied for external funding for their research projects, both from public and private sources, within Sweden and internationally. The three permanent Nordita Professors have all been awarded *ERC* Advanced Grants: Axel Brandenburg for "Astrophysical Dynamos" in 2009, Alexander Balatsky for "Dirac Materials" in 2013, and Konstantin Zarembo for "Integrable Systems in Gauge and String Theory" in 2014. Alexander Balatsky heads a team of scientists at four Swedish universities that has won a major grant from the *Knut and Alice Wallenberg Foundation* for a project on "Functional Dirac Materials" that started in 2014. In the same year, John Wettlaufer, visiting professor at Nordita 2011–201, won a 10-year VR grant which will be placed at Nordita. In addition, grants from the *research councils in Sweden, Norway and Iceland* provide support for several PhD students and postdoctoral fellows. Numerous smaller grants have been obtained from several different sources (including *NordForsk*, the *European Science Foundation*, the *Foundational Questions Institute*, and the *Swedish Research Council*) to organize scientific meetings and advanced schools.

Nordic Council of Ministers

Vetenskapsrådet

Wenner-Gren Stiftelserna



PEOPLE

The Institute has a small permanent faculty, complemented by assistant professors, postdoctoral researchers, and PhD students. At the postdoctoral level, several Nordita Fellowships are awarded each year to exceptional young researchers to carry out an independent program of research. The Institute also offers postdoctoral positions to work on specific externally funded research projects. PhD students are funded by various means, usually secured by their supervisors, and are enrolled in PhD programs at nearby universities or elsewhere in the Nordic countries.

An up-to-date list of people currently employed at Nordita can be found at www.nordita.org/people.

Director

Katherine Freese

Katherine works on a wide range of topics in theoretical cosmology and astroparticle physics. She has been working to identify the dark matter and dark energy that permeate the universe as well as to build a successful model for the early universe immediately after the Big Bang.

Permanent Faculty

Alexander Balatsky

Alexander's field of research is theoretical condensed matter physics. His recent work has mainly been in strongly correlated materials, unconventional superconductivity, and biomolecular electronics.

Axel Brandenburg (Deputy Director)

Axel works in the field of astrophysical fluid dynamics and has also an interest in astrobiology. He is particularly interested in the question of magnetic field generation from turbulent motions with applications to the Sun and stars, accretion discs, galaxies, and the early Universe.

Paolo Di Vecchia (emeritus professor)

Paolo works on the theory of elementary particles by using perturbative and non-perturbative methods both in field and string theories. His recent work deals with the extension of the gauge/gravity correspondence to less supersymmetric and non-conformal gauge theories deriving many properties of these theories from the supergravity solution. Currently he is working on high-energy scattering in string theory.

John Hertz (emeritus professor)

John worked on condensed matter theory earlier in his career, particularly on magnetism in systems with highly correlated electrons and on phase transitions. He then turned to the as well as the statistical mechanics of disordered systems, particularly spin glasses. In recent years his focus has been on biological networks, particularly in modeling the dynamics of neural networks in the neocortex.

Christopher Pethick (emeritus professor)

Christopher has contributed to diverse fields of physics, especially the properties of quantum liquids, both normal and superfluid, ultracold atomic gases and the properties of dense matter and neutron stars.

Anders Rosengren

Anders has worked on several topics in theoretical condensed matter physics, such as phase transitions, statistical mechanics, strongly correlated systems, diffusion and corrosion.

John S. Wettlaufer

John's research is best described as a hybrid between condensed matter theory and experiment, materials physics, and applied mathematics with applications focusing on environmental, geophysical and technological problems. The scales range from atomic to meters, with implications on much larger scales.

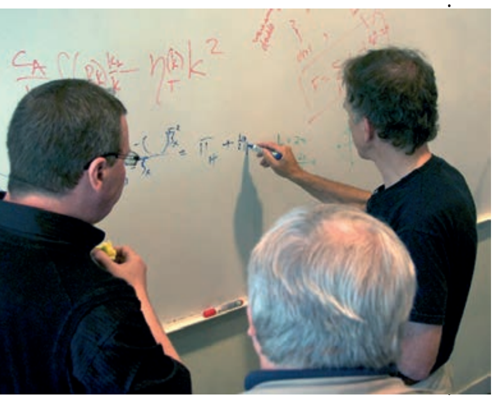
Konstantin Zarembo

Konstantin's field of research is theoretical high-energy physics, with main interests on quantum field theory, string theory and integrable systems. Recently he has been working on the gauge/gravity correspondence, mainly on non-perturbative aspects of the relationship between gauge fields and strings, and on exact results in quantum field theory that can be obtained with the help of integrability.

Assistant Professors

David Abergel

David's research is centered on the theory of electronic properties of two-dimensional materials such as graphene, but he has also worked on three-dimensional topological insulators and other monolayer systems, to try to find new and exciting applications for these and other Dirac materials.



Ralf Eichhorn

Ralf's general research interest is in the area of statistical mechanics of complex systems and its application to biophysical problems as well as the new field of stochastic thermodynamics. He currently works with the theory of transport processes in non-equilibrium systems, where thermal noise typically plays a dominant role.

Monica Guicá

Monica's research is centered around understanding gravity at a fundamental level. Important clues from black hole physics show that gravity is holographic, i.e. that a gravitational theory on a given space-time can be described by a field theory in lower dimensions. Her interests are focused on finding the microscopic description of black holes — especially realistic ones — using holography.

Sabine Hossenfelder

Sabine’s main research interest is physics beyond the standard model, with a special emphasis on the phenomenology of quantum gravity. Her present work is focused on the role of Lorentz-invariance and locality, which might be altered in the fundamental to-be-found theory of quantum gravity and be accessible to experiment.

Henrik Johansson

Henrik's field of research is high-energy physics with special emphasis on quantum corrections to scattering processes in gravity and gauge theories, including analysis of the ultraviolet behavior of supergravity. Recently he has been focusing on novel formalisms that rewrite standard gravity theories as double copies of gauge theories.

Tomi Koivisto

Tomi's field of research is gravitation and cosmology, with emphasis on quantum and classical extensions of the theory of general relativity and their cosmological and astrophysical implications, dark energy, early universe inflation, alternative cosmologies, and nonlocal approaches to the problems of renormalisability.

Dhrubaditya Mitra

Dhrubaditya’s principal field of research is astrophysics with particular interest in astrophysical dynamos, but his research interests are widespread. He is interested in the general field of non-equilibrium statistical mechanics and turbulence including magneto-hydrodynamic turbulence and complex fluids.

Postdoctoral Researchers

Stanislav Borysov

Stanislav has earlier been working on the statistical analysis of complex systems and hierarchical structures using non-Gaussian power-law distributions. His current research interests are nonlinear problems in atomic force microscopy and applying machine learning tools to the search of new materials basing on first principles calculations.

Pawel Caputa

Pawel's research interests are focused on entanglement entropy in many body systems, field theories and holography within the AdS/CFT correspondence. He has also worked on non-planar aspects of the AdS/CFT correspondence and integrability.

Amit Dekel

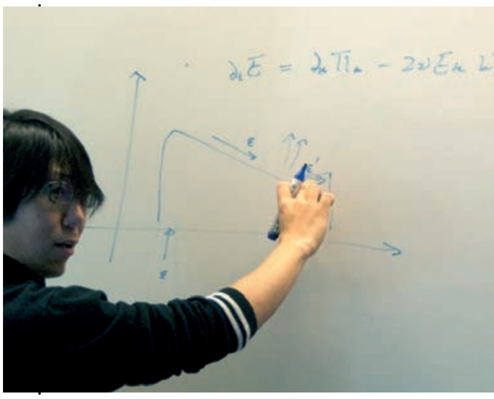
Amit's main research interest is the AdS/CFT correspondence and integrability. Currently he is focusing on aspects related to Wilson loops and minimal surfaces.

Fabio Del Sordo

Fabio, a former PhD student at Nordita, is now a VR International Postdoc, based in Yale University, USA, and Nordita. His main interests are exoplanetary studies, aurora emission, astrophysical dynamos and magnetic fields.

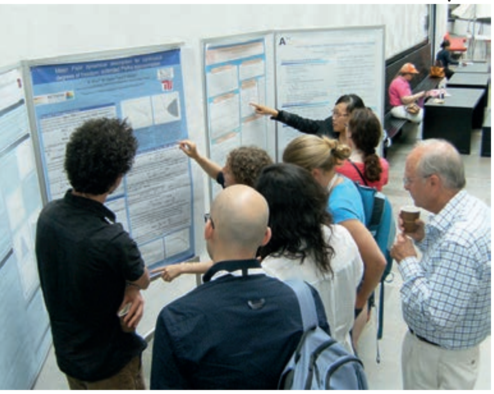
Marcelo Días

Marcelo's research interests lie within a broad range of topics in theoretical soft condensed matter. He uses techniques in differential geometry and continuum mechanics to understand how mechanical properties that an elastic body acquires arise from a careful design of its internal geometry in addition to its material composition.



Jonathan Edge

Jonathan is working on ultracold Fermi gases, in particular on how collective modes can be used to probe the properties of these systems. He has also worked on transport in quantum systems, mostly studying localisation properties at transitions between different topological phases. He is now also investigating problems in superconductivity.



Sven Bjarke Gudnason

Bjarke is interested in field theories and especially gauge theories, their behavior at strong coupling and confinement. In the course of understanding the real physical problems, his interest was caught by toy problems and tools along the way, such as supersymmetry, topological solitons, AdS/CFT, lower-dimensional theories, and non-perturbative methods.

Lavinia Heisenberg

Lavinia's main area of expertise is gravity and cosmology, in particular models of modified gravity in the context of Massive Gravity, higher dimensional scenarios, Galileon and vector fields, comprising the fundamental properties of field theories, their cosmological consequences and observational signatures.

Bidya Binay Karak

Bidya has been working on various aspects of the solar activity cycle including the origin of grand minima and solar cycle prediction. In the near future he plans to focus on three-dimensional simulations of turbulent dynamos.

Yaron Kedem

Yaron is currently working on a few topics within condensed matter theory, including Dirac Materials, odd frequency order parameters and the effect of a ferroelectric phase transition on superconductivity. His previous research was in the field of quantum information.

Alexander Krikun

Alexander's main subject of interest is the application of the gauge/string duality (AdS/CFT) to various strongly coupled systems such as quantum chromodynamics (AdS/QCD) or high temperature superconductivity in condensed matter (AdS/CMT).

Francesco Mancarella

Francesco is currently instead in magnetic properties of 2D high-temperature superconductors of nanoscopic scale. On a completely different side, he is dealing with transmission properties of density waves produced in 1D Bose-Einstein condensates which are described in the Gross-Pitaevskii approximation.

Lars Mattsson

Lars' main scientific interest is cosmic dust and his previous research has largely been about simulating dust formation together with dust-driven winds from carbon stars, and various aspects of the build-up of dust and related key-elements in galaxies.

Mikhail Modestov

Mikhail is interested in the behavior of fronts and their stability properties. He has studied fronts of different nature such as flames, supernovae, laser ablation, quantum plasmas, doping process in organic semiconductors, and in crystals of molecular magnets.

Matin Mojaza

Matin has worked on aspects of four dimensional quantum field theories related to finite temperature dynamics, strong interactions, conformal asymptotics, electroweak physics and perturbative QCD. His current field of research involves continuation of conformal field theories and their applications in particle physics phenomenology and low-energy theorems in scattering amplitudes.

Yen Chin Ong

Yen Chin's area of research involves the applications of differential geometry, topology, and PDEs in theories of gravity and cosmology. He is primarily interested in black hole physics, especially the properties of various types of black holes in both general relativity and modified gravity, at both classical and quantum levels, especially the evolution of black holes under Hawking evaporation, and the Information Loss Paradox.

Sergey Pershoguba

Sergey is interested in various aspects of condensed matter theory, such as: topology and geometry in condensed matter physics, effects of a strong magnetic field in solids, electromagnetic response of novel materials, etc. At Nordita, Sergey will pursue research in Dirac materials, such as graphene, topological insulators and superconductors.

Harsha Raichur

Harsha's research interests are in X-ray Astronomy. She uses observations from the various X-ray satellites to study extreme stellar objects like neutron stars and black holes in binaries, calculating their orbits using spectral information to try and constrain the masses and radii.

Cecilia Rorai

Cecilia has earlier worked on vortex reconnection in superfluid helium and will continue to investigate the nature of turbulence in complex fluids in a collaboration between Nordita and KTH Mechanics.

Christopher Savage

Chris' research focuses on particle dark matter detection phenomenology, with an emphasis on direct searches for dark matter by interpreting various experimental results and using ththem to probe beyond the Standard Model physics frameworks like supersymmetry. Research also includes indirect searches for dark matter via neutrinos and cosmic rays as well as other areas of cosmology such as inflation.

Nishant Singh

Nishant has worked on the astrophysical dynamo problem with non-helical turbulence in the presence of shear, as with the time variability of the viscosity parameter in differentially rotating discs. He is now working on helioseismology to infer the nature of subsurface magnetic fields in the sun.

Konstantin Zakharchenko

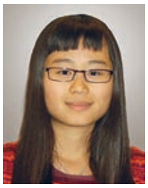
Konstantin's research interests are closely connected to the study of graphene nanostructures and nanodevices. He is interested in their technological applications, in the mechanism of growing, as well as the influence of the atomic structure and distortions on the final performance of graphene nanodevices.

PhD Students

Saikat Banerjee

Saikat started his PhD studies at Nordita and the Theoretical Chemistry and Biology Dept. at KTH in the fall of 2014, under the supervision of Alexander Balatsky and Hans Ågren. He is currently working on creation of Bosonic Dirac Material and Non-Equlibrium superconductivity.

Xinyi Chen

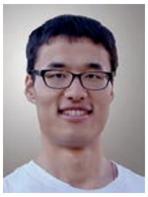


Xinyi joined Nordita in September 2013 to pursue her PhD studies under the joint supervision of Konstantin Zarembo (Nordita) and Joseph Minahan (Uppsala University). She is investigating the integrability of quantum field theories as well as the holographic principle.

Sarah Jabbari

Sarah started her PhD in September 2012 in the astrophysics group at Nordita and the Department of Astronomy at Stockholm University. She has earlier worked on magnetohydrodynamic waves in curved and low plasma-beta solar coronal loops. The topic of her PhD work is the "Origin of solar surface activity and sunspots".

Xiang-Yu Li



Xiang-Yu started his PhD studies at Nordita and the Department of Metereology at Stockholm University in the fall of 2014. He is interested in particle transport and clustering in stratified atmospheric geophysical turbulence, as well as acceleration of raindrop formation in clouds.

Illa R. Losada

Illa started her PhD studies in January 2013 to work within the VR-supported project on the "Formation of active regions in the Sun", with the goal to develop the foundations of a radically new suggestion for the formation of active regions in the Sun. Active regions are magnetic flux concentrations, out of which sun spots form during the lifetime of a region.

Raffaele Marino

Raffaele started his PhD in October 2013 in the condensed matter and statistical physics group at Nordita, working under joint supervision of Ralf Eichhorn (Nordita) and Erik Aurell (KTH). He works on the project "Optimal processes in small systems under thermal noise".

Daniel Medina Rincon

Daniel joined Nordita in October 2014 to start his PhD in the Nordita high-energy group under the supervision of Konstantin Zarembo. His research interests concern integrability in gauge and string theories.

Fernanda Pinheiro

Fernanda started her PhD studies at Stockholm University in June 2010, working under joint supervision of Jani-Petri Martikainen (then at Nordita) and Jonas Larson (Stockholm University, former Nordita Fellow). Her thesis work centers on the physics of cold bosons in optical lattices, in particular the role of excited bands in the physics of these systems.

THE FUTURE

Prediction is difficult — especially about the future.

Traditional saying often attributed to Niels Bohr

The past century brought us changes at an unprecedented rate. Some of these changes are accompanied by daunting challenges that will only be successfully addressed through improved understanding of the world that we live in and by communicating that knowledge to society at large. For more than 50 years, researchers at Nordita have contributed to this endeavor, constantly adapting to remain at the frontier of research. They have studied the most elementary constituents of the matter that we are made of as well as its various emergent features; they have analyzed the large scale structure of the universe, the physics of distant galaxies and that of our solar system; they have made contributions to a better understanding of the human brain and some of the complex systems that govern our lives.

As Niels Bohr observed, it is difficult to predict the future. Yet it appears likely that changes will continue at a rapid pace and to meet the new challenges that they bring will require continuous effort, creativity, and ingenuity. Nordita is dedicated to continue its exploration of Nature, evolving to meet the changing needs of the scientific community, and engaging with other scientists to achieve our common goals. The type of fundamental research carried out at Nordita is very important for the future. It can shift paradigms and fundamentally change the way we view our world. At the same time, it is of enormous importance for future innovation and technological development.

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As a leading international center for advanced physics research with a strong Nordic tradition, Nordita offers exciting opportunities for young researchers. We would like to further enhance and expand the research environment at the Institute and are looking for interested partners to join us in that venture. Private funding opportunities include faculty appointments into named academic chairs, sponsoring invited lectures by prominent scientists, or supporting young researchers to spend time at Nordita, to name a few.

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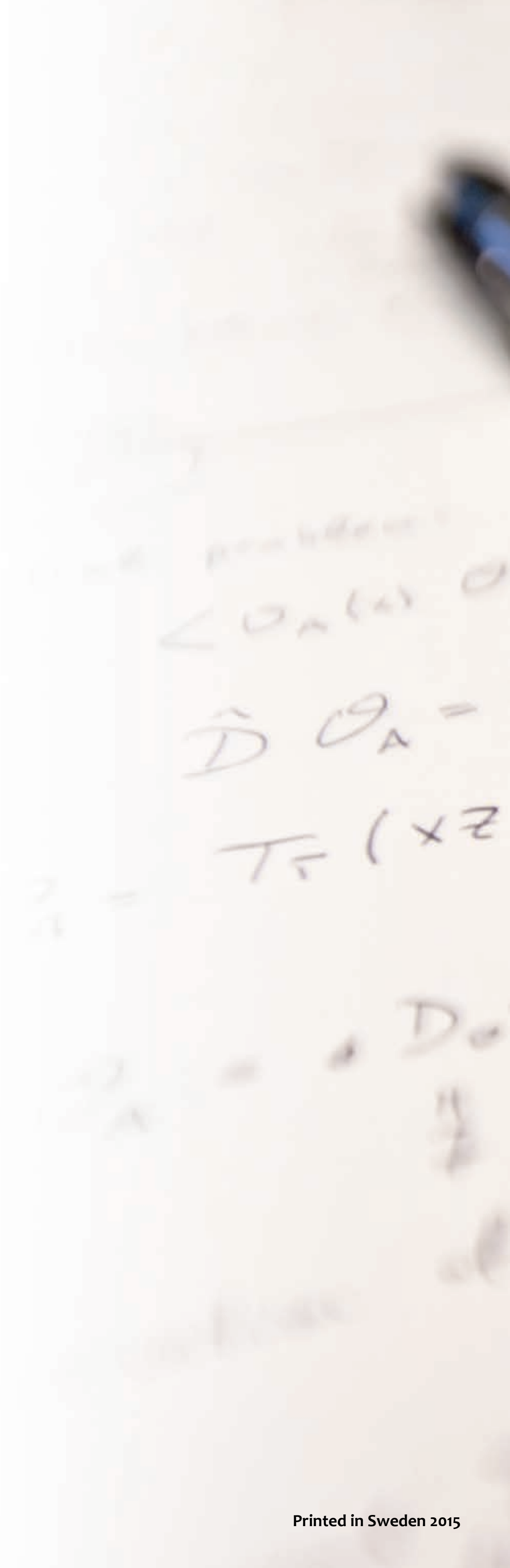

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