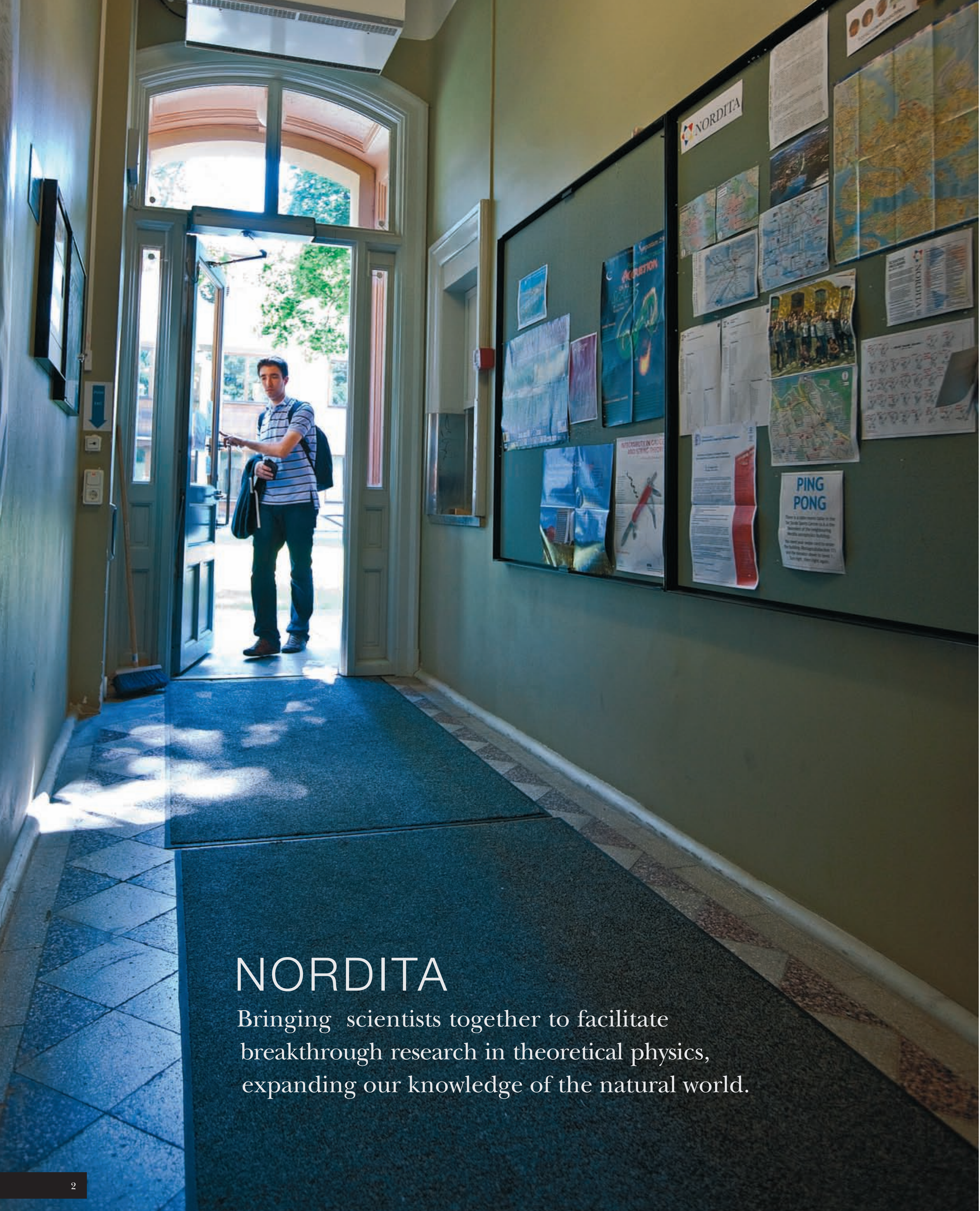
NORDITA

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

The Nordic Institute for Theoretical Physics (Nordita for short) is an international center for advanced study in theoretical physics and related areas. It 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. For most of its history, Nordita was owned by the Nordic Council of Ministers, but, as part of a reorganization of Nordic cooperation, the Institute moved to Stockholm in 2007, where it is jointly hosted by Stockholm University and KTH Royal Institute of Technology.

Our mission is to achieve scientific excellence through cutting edge research and to promote Nordic and international cooperation in theoretical physics. To this end, our academic staff is engaged in theoretical and numerical work on many fronts, numerous scientific meetings are organized at Nordita every year, and we welcome visitors from all over the world. For me personally, it has been a privilege to take part in building up Nordita in its new location and a great pleasure to see it grow and flourish.

We have produced this booklet to introduce the reader to our institute, touching on Nordita's history, introducing the current academic staff, describing some of the ongoing research, and explaining the organization and setup after the move to Stockholm. 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 of taking part in the quest for a deeper understanding of Nature.

Lárus Thorlacius

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 20st 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

> "Prediction is very difficult, especially about the future."
> *– Niels Bohr*

The Nordita Logo

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

"Nordita has a long and distinguished record as a Nordic center 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: Nordiat has re-invented itself in its new environment, to the advantage of the Nordic research communities in theoretical physics and related fields."

– From the executive summary of a 2009 evaluation of Nordita by an international panel of experts.

Council of Ministers (www.norden.org). It was located next to the Niels 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.

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.

A BRIEF SCIENTIFIC HISTORY

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 laboratory. Eventually Geneva was preferred but the theory group of the new laboratory was initially located in Copenhagen.

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.

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.

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 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."

"Nordita has been tremendously important for my scientific career. Nordita is one of the foremost centers of competence for understanding and exploring Nature from microscopic up to cosmological scales. Its scientific output is absolutely impressive and makes it invaluable for the Nordic countries as well as for the global scientific community. Everyone can be proud of what Nordita has achieved already and can be excited about its future promise. With Nordita the Nordic countries have established a world renowned Institute of excellence in modern physics."

– Prof. Stefan Hofmann, LMU Munich

The old Nordita Building in Copenhagen. Photo credits: Axel Brandenburg.

The Nordita Board in 1958

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 1967-71. 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 Veccia, 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 20st 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 non-linear 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).

Nordita main building, Stockholm.

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.

The AlbaNova University building (front) and the two Nordita buildings (behind the Albanova building, to the right). Photo credit: Pontus Walck, Stockholm.

Researchers at Nordita are actively involved in making headway on the understanding of high-temperature superconductivity.

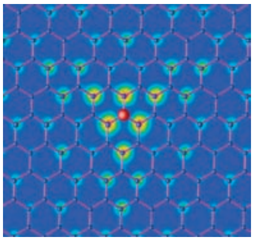
RESEARCH AREAS

Condensed Matter Physics

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.

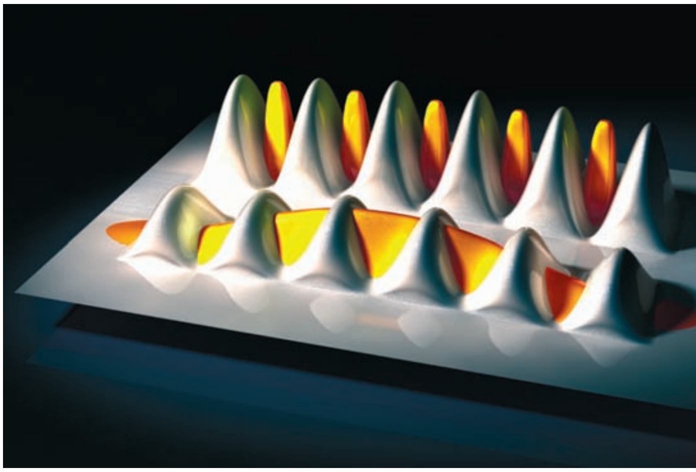
A spectacular new phase of matter was discovered in 1911 by Kamerlingh Onnes. He and his team observed that when mercury is cooled down to very low temperature (4.2 K), it loses its electric resistance completely. Electric current flows without any dissipation and we say the metal becomes “superconducting”. 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.



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

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.



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.

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.

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.

Virtual gluons make up more than 99% of our body weight.

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 Physics

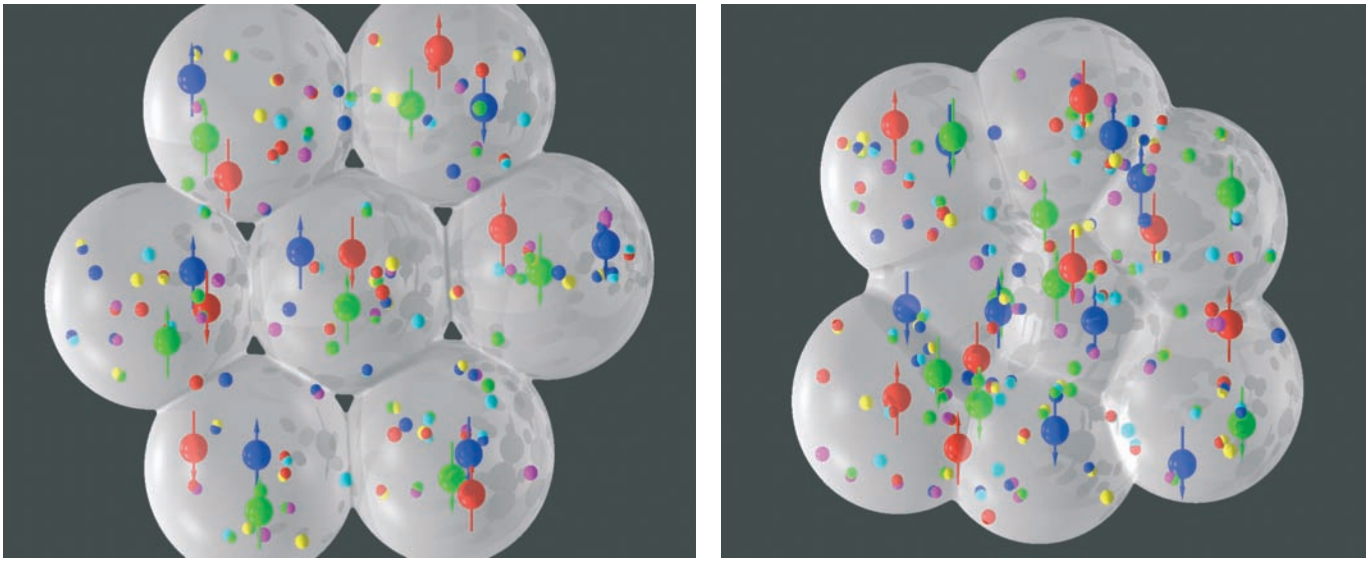
Particle physics is the study of the most fundamental constituents of matter and the interactions among them. To get access to the short distances on which these fundamental constituents make themselves noticeable, enormous amounts of energy have to be released in an extremely small volume.

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.



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.

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!

Holographic duality, also known as the gauge/gravity correspondence, is one of the most active research areas at Nordita.

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

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.

Another research interest of Nordita's particle physics group is to explore the possibilities of finding experimental evidence for quantum gravity in order to guide the development of the theory. This young research area connects many different fields of physics, from astrophysics over cosmology to the foundations of quantum mechanics and general relativity.

Further reading:

» *K. Zarembo and S. Zieme, "Fine Structure of String Spectrum in AdS(5)xS(5)," arXiv:1110.6146*

» *V. Keranen, E. Keski-Vakkuri and L. Thorlacius, "Thermalization and entanglement following a non-relativistic holographic quench" Phys. Rev. D 85, 026005 (2012), arXiv:1110.5035.*

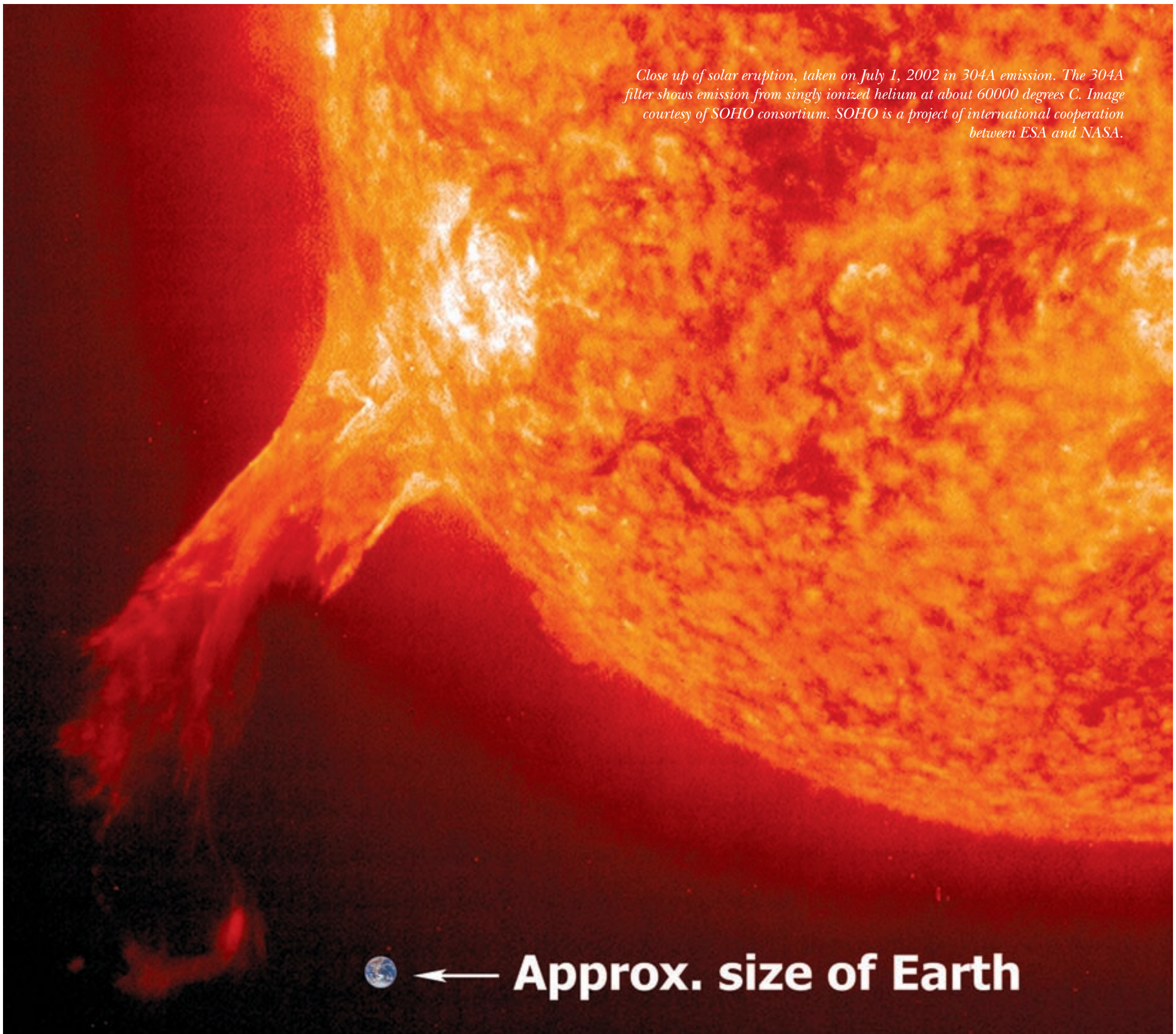
» *S. Hossenfelder, "Experimental Search for Quantum Gravity," in "Classical and Quantum Gravity: Theory, Analysis and Applications," Chapter 5, Edited by V. R. Frignanni, Nova Publishers (2011), arXiv:1010.3420*

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. Meanwhile, cosmology deals with deep questions around the origin of our universe and its evolution through the ages. It is a rapidly developing field where dramatic advances in astronomical observations combine with fundamental physical theories in shaping our future world view. The 2011 Nobel Prize in Physics "*for the discovery of the accelerating expansion of the Universe through observations of distant supernovae*" affirms the importance of cosmology. Obtaining a better understanding of the physics of "dark energy" or other agents that drive the accelerating expansion represents a supreme challenge of theoretical physics, motivating a new faculty appointment at the Assistant Professor level at Nordita planned for 2013.

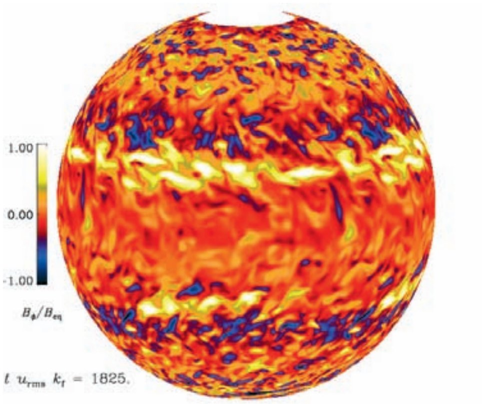
Sunspot activity and its consequences are particular highlights of astrophysics research at Nordita.

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



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.

turbulence in the Sun is being converted into magnetic energy through a large-scale instability.



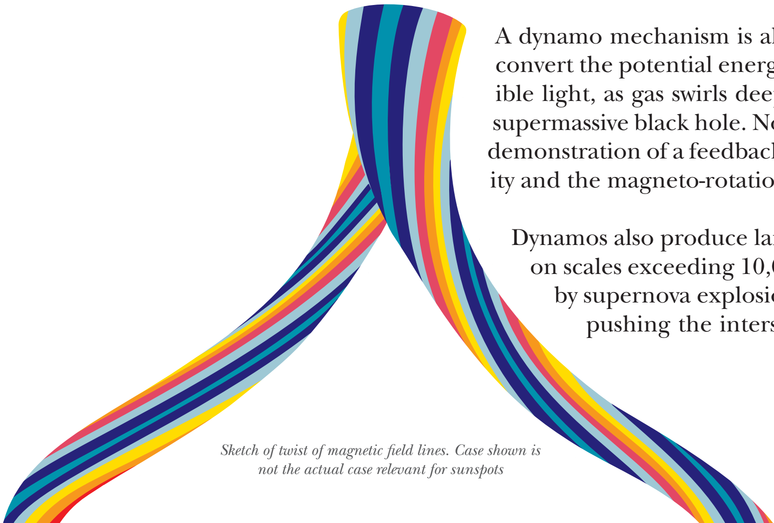
Visualization of the magnetic field from a solar dynamo simulation. Yellow shades indicate eastward direction and blue shades westward direction. The magnetic flux belts are responsible the production of sunspots in low latitudes. Adapted from Käpylä, Mantere, & Brandenburg (2012, Astrophys. J. Lett.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



Sketch of twist of magnetic field lines. Case shown is not the actual case relevant for sunspots volved 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.

Thermal noise effects are everywhere in living organisms below the level of cells. In many of these biological systems the quantitative methods of theoretical statistical physics can be fruitfully applied.

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 is hosting 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.*

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.

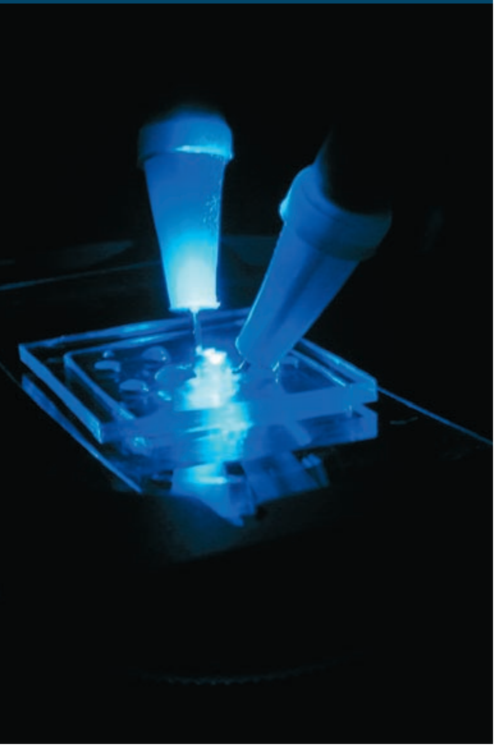
The interface between physics and the life sciences, and the emerging fields of bio- and nano-technology, rely on our growing ability to observe, measure, manipulate, and even manufacture on the molecular scale. At such short distances, when the molecular nature of matter becomes apparent, the thermal 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.

How do the many different molecules in a cell find the specific partners they need to interact with for their biological functionality? Researchers at Nordita study the influence of the cell's environment on the recognition process.

At Nordita, using statistical physics, researchers develop mathematical methods to study how elements in a biological network interact.



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

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".

Another focus of the biophysical research at Nordita is the question how biomolecular systems function at the nano-scale. How do the many different molecules in a cell find the specific partners they need to interact with for their biological functionality? While most of the current research in this area considers an isolated pair of interacting molecules, researchers at Nordita are studying the influence of the cell's environment on the recognition process between the two specific interaction partners.

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. 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.

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.

"I have only visited Nordita once since it moved to Stockholm, for the conference on quantum gravity phenomenology but I found it an inspiring place with the right kind of informal but intense atmosphere which the best scientific institutes have. The conference was one of the best I have ever attended, very well organized and carried off, and I learned a great deal from almost every session."

– Prof. Lee Smolin, Perimeter Institute

Further reading:

- *A. Celani, S. Bo, R. Eichhorn and E. Aurell, "Anomalous thermodynamics at the micro-scale," 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.*

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 to eight 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

Selected Programs

The full list of programs and instructions for submitting program proposals are found at www.nordita.org

Foundations and Applications of Non-Equilibrium Statistical Mechanics
19 September — 14 October 2011
Modern developments in non-equilibrium statistical mechanics both with respect to fundamental aspects (fluctuation theorems, entropy production, fluctuation-dissipation theorems) as well as applications (noise-induced phenomena, biophysical problems).

Origin of Mass 2012
28 May — 22 June 2012
The present and future phenomenological impact of the first years of results from the Large Hadron Collider experiments at CERN.

The Holographic Way: String Theory, Gauge Theory and Black Holes
1 — 26 October 2012
Holography has emerged as one of the most fascinating and powerful new concepts in modern theoretical physics. Some of the most exciting current and future advances in the field build on two amazing prospects of the AdS/CFT correspondence, and thereby the Holographic Principle.

Pushing the Boundaries with Cold Atoms
21 January — 15 February 2013
Lattice models, synthetic gauge fields, orbital physics, disordered systems, non-equilibrium dynamics, dipolar gases, and many-body cavity QED.

Stability and Transition
6 — 31 May 2013
Stability and transition of flows belong to fundamental issues in the field of fluid mechanics. Predicting flow structures and characteristics requires deep understanding of the different routes of transition.

Beyond the LHC
1—26 July 2013
The 14 TeV LHC will look further above the electroweak scale, but where do we go beyond that to improve our understanding of the fundamental constituents of the Universe?

What is the Dark Matter?
5 — 30 May 2014
The nature of Dark Matter is one of the most important outstanding problems in modern physics. Many Dark Matter models exhibit high dimensional parameter spaces with many degeneracies and considerable expected backgrounds, and therefore a combination of all experimental data available will likely be necessary to arrive at robust conclusions regarding the nature of dark matter.

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.

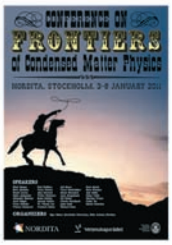
In addition to the programs that last several weeks, Nordita also organizes shorter conferences and workshops, sometimes in combination with the programs. These events can be arranged on short notice, which provides researchers with an excellent opportunity to gather together experts on subjects they 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.

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.



"You did a terrific job organizing the Nordita conference on turbulent combustion, and I thank you again for inviting me. Your meeting provided an excellent way for those of us who are located outside of Europe to interact with the strong team of researchers from within Sweden and Norway, as well as those from France, Germany and other European countries. ... The Nordita format is the best way to foster these interactions, and I felt that all of my time in Stockholm was well-spent. My wife also thoroughly enjoyed Sweden."

– Prof. James Driscoll, University of Michigan

Students attenting a lecture at Nordita's 2009 Winter School.

"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."

– Prof. Frank Wilczek, MIT

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.

Wenner-Gren Stiftelserna

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.

OUTREACH AND EDUCATION

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.

"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

Visiting PhD Fellows

Since 2010 Nordita has offered a new program, intended for PhD students, primarily but not exclusively from the Nordic and Baltic countries. The visiting PhD fellow 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. Applications for the fellowship program are submitted through the Nordita website.

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.

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.

Demonstration of surface tension.

Outreach

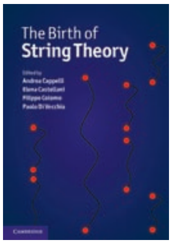
Researchers at Nordita are engaged in a variety of public outreach activities including Stockholm's popular biennial physics fair "Fysik i Kungsträdgården," and the Open House Event that brings people from the street in touch with scientists. Nordita also supported Galileo Mobile during the International Year of Astronomy in 2009, a traveling science education project to bring astronomy closer to young people.

Fysik i Kungsträdgården is a joint projects with the local physics departments which takes place on a Saturday in September. On that Saturday, 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 has introduced discussions on the formation of sunspots and Bose condensates, the geometry of soap bubbles and magnetic knots, and the hidden secrets of the cosmic microwave background and neural networks.

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

Under the username "NorditaStockholm," seminars from the Institute are made available on YouTube (see www.nordita.org/videos), and the further potential of science communication in audio and video is presently being explored.

The Birth of String Theory
This unique book, edited by Paolo Di Vecchia from Nordita, together with Andrea Cappelli, Elena Castellani, and Filippo Colomo, 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.



NOTABLE COLLABORATIONS

Researchers at Nordita work with collaborators from all over the world, for instance from the Niels Bohr International Academy (Copenhagen, Denmark), SISSA (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 the Carnegie Mellon University (Pittsburgh, USA), to mention 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, 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, and the Nordic Network in string theory.

Nordita has close interactions with the universities in the Stockholm area, reflected for example in shared seminar series such as the AlbaNova/Nordita Colloquium, a gravity seminar with Stockholm University, a seminar series in theoretical physics with KTH and Stockholm University, a joint seminar with the Solar Physics Institute, and the theory "Journal Club" with the Stockholm University's group on cosmology, particle astrophysics and string theory (CoPS). Another important point of interaction is the joint supervision of several PhD students who are registered at the local universities.

RECENT PRIZES, GRANTS, AND PRESS

- John S. Wettlaufer, the A.M. Bateman Professor at Yale University and visiting professor at Nordita, was awarded the Tage Erlander Guest Professorship for 2012. Since its inception, this prestigious award has been given to accomplished scientists working on a broad range of topics.

- Professor Christopher Pethick was awarded the 2011 Hans A. Bethe Prize of the American Physical Society *for his fundamental contributions to the understanding of nuclear matter at very high densities, the structure of neutron stars, their cooling, and the related neutrino processes and astrophysical phenomena.*

- "Cycles of the Sun," Interview with Professor Axel Brandenburg by British Publishers, January 2010. Also published in EU Research, "The latest research from FP7," pp. 114-115, June 2010.

- Assistant Professor Sabine Hossenfelder won the 2nd prize of the 2010 essay contest of the Foundational Questions Institute "What is ultimately possible in physics?" for her contribution "At the frontier of knowledge."

- Professor Christopher Pethick was awarded the Lars Onsager Prize in 2008 *for fundamental applications of statistical physics to quantum fluids, including Fermi liquid theory and ground-state properties of dilute quantum gases, and for bringing a conceptual unity to these areas.* Chris shared the prize with Gordon Baym (University of Illinois and former Nordita adjunct professor) and Tin-Lun Ho (Ohio State, and former postdoctoral fellow at Nordita).

- In August 2008, Professor Axel Brandenburg was awarded a European Research Council Advanced Grant for his project *Astrophysical Dynamos* (AstroDyn). The grant was for a total of €2,220,000 over five years and has enabled Axel and Nordita to build a sizable research group and have an even stronger presence in this important area of astrophysical theory than in previous years. The AstroDyn funding is separate from the rest of the Nordita budget and allows a significant increase in the research activities at the Institute.

ORGANIZATION

Governance

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.

The Board nominates the Director (currently Lárus Thorlacius), 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. He is supported by the Deputy Director (currently Axel Brandenburg). In addition to the Nordic governing Board, the Nordic physics community provides direct input into Nordita's scientific activities through three 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 three committees are astrophysics/astrobiology, condensed matter/biological physics, and subatomic physics. Their tasks include evaluating post-doctoral fellowship applications and providing expert advice in their respective areas.

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.

Nordita Board

The Nordita Board in February 2012. Top row, from left to right: Keijo Hämäläinen, Sean Nowling, Karsten Flensberg, Ivan Shelykh, Gunnlaugur Björnsson, Per Osland, Anders Karlhede, Konstantin Zarembo. Second row: Lárus Thorlacius, Marianne Persson Söderlind, Susanne Viefers, Thordur Jonsson, Kalle-Antti Suominen.

REPRESENTATIVES OF THE NORDIC COUNTRIES

Denmark
Prof. Jes Madsen, University of Århus
Ass. Prof. Karsten Flensberg (reserve), University of Copenhagen

Finland
Prof. Kalle-Antti Suominen, University of Turku
Prof. Keijo Hämäläinen(reserve), University of Helsinki

Iceland
Prof. Gunnlaugur Björnsson, University of Iceland
Prof. Ivan Shelykh (reserve), University of Iceland

Norway
Prof. Susanne Viefers, University of Oslo
Prof. Per Osland (reserve), University of Bergen

Sweden
Prof. Lars Börjesson, Chalmers Technical University
Prof. Olle Eriksson (reserve), Uppsala University

Chairperson
Prof. Thordur Jonsson, University of Iceland

OFFICERS OF NORDITA AND OBSERVERS
Nordita
Prof. Lárus Thorlacius (Director)
Prof. Axel Brandenburg (Deputy Director)
Prof. Konstantin Zarembo (Professors' Observer)
Dr. Dmytro Volin (Fellows' Observer)

OBSERVERS FOR THE HOST UNIVERSITIES
Prof. Anders Karlhede, Stockholm University
Prof. Henrik Alfredsson (reserve), KTH Royal Institute of Technology

Scientific Advisory Committee

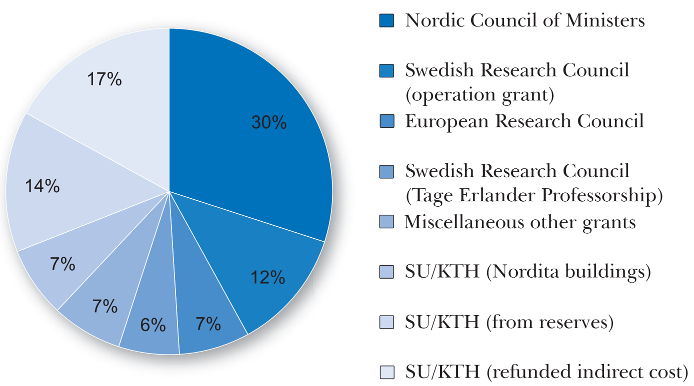
Curtis Callan, Princeton University
Susan Coppersmith, University of Wisconsin
Steven Girvin, Yale University
Eberhard Gross, Max Planck Institute for Microstructure Physics
Graham Ross, Oxford University
Joseph Silk, Oxford University
Gabriele Veneziano, Collège de France and CERN

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.

Nordita Incoming Budget 2012

Total 40400 kSEK



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 2012 are indicated in the accompanying chart.

The move to Stockholm in 2007 was accompanied by the transfer of ownership away from to the Nordic Council of Ministers (NCM) to the host universities. At the same time the funding from the NCM was reduced by 50% compared to previous levels in Copenhagen. Nevertheless, the financing by the NCM remains the largest source of income for the Institute, amounting to approximately 10.7 million DKK/year according to the current contract between the NCM and the host universities in Stockholm. The contract is for the four-year period 2010 – 2013 and is renewable, subject to external performance reviews.

The Swedish Research Council (Vetenskapsrådet) 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 to 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 2013.

Nordita faculty members have successfully applied for external funding for their research projects, both from public and private sources, within Sweden and internationally. The most significant of these grants is the European Research Council Advanced Grant for the *Astrophysical Dynamos* project. Grants from the research councils in Sweden and Iceland have provided support for several PhD students and postdoctoral fellows. Numerous smaller grants have been obtained from different sources (including NordForsk, the European Science Foundation, the Foundational Questions Institute, and the Swedish Research Council) to organize scientific meetings and advanced schools.

PEOPLE

The Institute has a small permanent faculty, complemented by assistant professors in various fields of research and a somewhat larger number of postdoctoral researchers. Postdoctoral fellows are independent in their choice of research projects, but are upon arrival assigned to a faculty mentor for general guidance and advice. Students at Nordita are funded by various means, usually secured by their supervisor, and are officially enrolled in a program at one of the nearby universities.

DIRECTOR

Lárus Thorlacius
Lárus' field of research is theoretical high-energy physics, with emphasis on string theory and quantum gravity, but more generally on the application of quantum field theory to a variety of physical systems. In recent years his main focus has been on black hole physics in the context of the gauge/gravity correspondence.

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.

John Hertz
Early in his career, John worked on condensed matter theory, particularly on magnetism in systems with highly correlated electrons and on phase transitions, which led to his well-known work on quantum critical phenomena. He then turned to 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, and the properties of dense matter and neutron stars. His main current research interests are ultracold atomic gases and neutron stars.

Konstantin Zarembo
Konstantin's field of research is theoretical high-energy physics, with main interests in quantum field theory, string theory and integrable systems. During the last few years 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.

2012 TAGE ERLANDER GUEST PROFESSOR

John S. Wettlaufer

John works on stochastic dynamics with applications to abrupt changes in Arctic climate and in fluid dynamics generally. He hopes also to begin the process of incorporating the microphysical conditions for planetary accretion studied during his previous visit into the computer code developed at Nordita.

ASSISTANT PROFESSORS

Eddy Ardonne

Eddy's research focuses on strongly correlated electron systems in low dimensions. In particular, he is interested in topological phases of matter, which occur in the fractional quantum Hall effect and topological insulators. In addition, he is interested in the symbiosis between the physics and the mathematics needed to describe topological phases in general.

Ralf Eichhorn

Ralf's general research interest is in the area of statistical mechanics of complex systems and its application to biophysical problems. His current research activities are centered around the theory of transport processes in non-equilibrium systems, where thermal noise typically plays a dominant role. Most recently, Ralf became interested in stochastic thermodynamics, a new field in non-equilibrium statistical mechanics addressing the problem of generalizing and extending concepts from equilibrium statistical physics to the non-equilibrium realm.

Troels Harmark

Troels' research is focused on aspects of black holes, string theory and the gauge/gravity correspondence. He has a long-standing independent research programme devoted to finding a quantum mechanical description of black holes via the gauge/gravity correspondence and has also made contributions to the field of integrability of the spectrum of strings in the gauge/gravity correspondence.

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.

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.

Stephen Powell

Stephen's research is in condensed matter physics, focusing on the areas of frustrated magnetism and ultracold atomic gases. His recent work has studied phase transitions in constrained systems, particularly in the spin ice materials and in related theoretical models.

POSTDOCTORAL RESEARCHERS

Dmitri Bykov
Dmitri is interested in understanding two-dimensional sigma models, in particular with regards to their application to the gauge/gravity correspondence. Sigma models provide interesting examples of interacting quantum field theories, in which many complicated questions of quantum field theory can be addressed. Dmitri's recent research focused on developing a particular spin chain regularization of sigma models with homogeneous target spaces.

Alessandra Cagnazzo
Alessandra's research interests are superstring theories that admit a dual in the context of gauge/gravity correspondences, in particular theories that are not maximally supersymmetric and problems involving integrability. She mainly works with the Green-Schwarz formalism for strings, but is also interested in pure spinors and the hybrid model formalism.

Chi-Kwan Chan
Chi-kwan develops numerical algorithms for black hole accretion disks and is especially interested in understanding the accretion disks' variability in order to test general relativity in the strong field regime and the growth of supermassive black holes. To archive more realistic simulations, Chi-kwan's recent work focuses on magnetohydrodynamic turbulence and radiation hydrodynamics.

Ebru Devlen
Ebru is working in the field of magnetohydrodynamic and plasma astrophysics. She is interested in accretion disks, especially on understanding angular momentum transport due to magnetohydrodynamic instabilities, and the heating of the solar corona.

Sreejith Ganesh Jaya
Sreejith uses computational methods to study the physics of quantum Hall effect. Recently, he has been working towards developing a description of the second Landau level fractional quantum Hall effect

Blaise Goutéraux
Blaise's research interests are holographic applications to condensed matter systems and higher-dimensional gravitation. Recently, he has been studying infrared geometries in Einstein-Maxwell-Dilaton theories, which are conjectured to be dual to systems such as high temperature superconductors. He also has been studying the hydrodynamic properties of black branes in AdS and Ricci flat spacetimes.

Oliver Gressel
Oliver's main interests lie in turbulent dynamo theory with applications to the interstellar medium and galactic magnetic fields, as well as accretion disc dynamos. The latter class of objects is of particular interest to him as it comprises a major challenge for the mean-field modeling of large-scale field evolution.

Andong He
Andong works on fluid mechanics, with a focus on Hele-Shaw flows and interfacial dynamics. He uses mathematical methods, including complex variables and asymptotic analysis, and simple lab experiments to tackle these problems. Recently, his research interests have broadened to kinetic theory of gases and capillary interactions between floating objects.

Juha Jäykkä
Juha's current research is divided between superconductivity, the family of Skyrme models, and the numerical techniques required in their study; recently he has started studying topological insulators.

Ville Keränen
Ville works on the interface of high energy physics and condensed matter physics, using the gauge/gravity duality to address problems in condensed matter physics. In this context, he has worked on models of superfluids, constructing gravitational duals of finite temperature solitons. His most recent work focuses on non-equilibrium dynamics of quantum critical systems.

Ville Lahtinen
Ville's research is concentrated on spin lattice systems supporting topologically ordered phases. The focus of his current work is to study the collective behavior of many anyon systems. The microscopics of a particular system can give rise to interactions between the anyonic quasiparticles, which can result in a rich pattern of new topological phases. The aim is to realize such transitions in a context of a spin lattice model and thereby pave way for their experimental realization.

Oksana Manyuhina
Oksana's research is in the area of soft condensed matter. In particular, she is interested in applications of differential geometry and statistical physics to describe shape transformations of self-assembled structures and instability patterns in liquid crystals.

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.

Sigurður Örn Stefánsson
Sigurður's research interests are random graphs and random walks on graphs. Currently he is interested in the continuum scaling limits of graphs and in understanding how different discrete structures yield the same scaling limit. These problems are interesting from a pure mathematics point of view and have in many cases direct relation to physics models.

Juha Suorsa
Juha's research is in the field of theoretical condensed matter physics and focuses on topological and strongly correlated quantum phases of matter. His present research interests are focused on various aspects of low-dimensional topologically nontrivial states of matter, including their transport characteristics and description in terms of effective field theories.

Anthony van Eysden
Anthony's primary research interest is on the state of matter inside the superdense interiors of neutron stars. By considering radio pulsar timing data and gravitational waves, Anthony has shown how the transport coefficients and equation of state of bulk nuclear matter can be constrained through observations of the recovery of a pulsar after a timing glitch. He is also interested in terrestrial superfluids, where his modeling of superfluid neutron and proton condensates has also been successfully applied to explain liquid helium experiments.

Dmytro Volin
Dmytro's main interests are strongly interacting field theories and integrable systems. At present he is working on the bootstrap program for integrable systems at finite volume. This is in line with one of his long-term goals: to understand microscopic mechanisms behind the gauge/gravity duality without direct appeal to string theory.

Kjartan Thor Wikfeldt
Kjartan Thor applies computational modeling to investigate the physical and chemical properties of solids, liquids and interfaces. He is particularly interested in molecular-level properties of liquid and solid water such as the structure and dynamics of water's hydrogen-bonding network. Recently, he has studied nuclear quantum effects in different materials, in particular the tunneling of hydrogen atoms on metal surfaces and in hydrogen-bonded ferroelectric crystals.

Donovan Young
Donovan works on gauge/gravity duality. Recently he has been interested in three-point functions, Wilson loops, and aspects of three dimensional SYM theory.

PHD STUDENTS

Simon Candelaresi
Astrophysics

Babak Majidzadeh Garjani
Condensed Matter

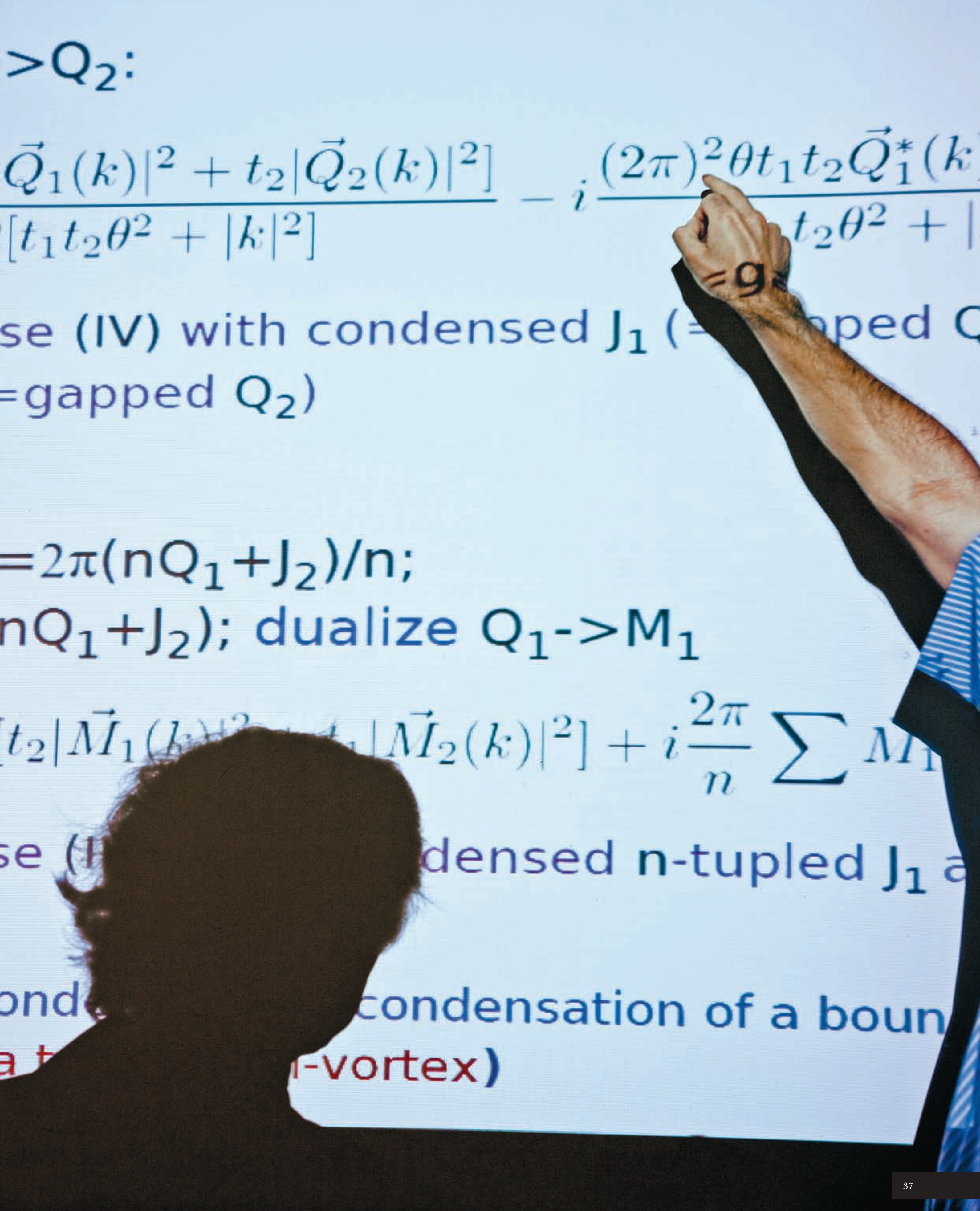
Fabio Del Sordo
Astrophysics

Fernanda Pinheiro
Condensed Matter

Sarah Jabbari
Astrophysics

Jörn Warnecke
Astrophysics

Koen Kemel
Astrophysics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=gapped Q2)
=2π(nQ1+J2)/n;
nQ1+J2); dualize Q1->M1
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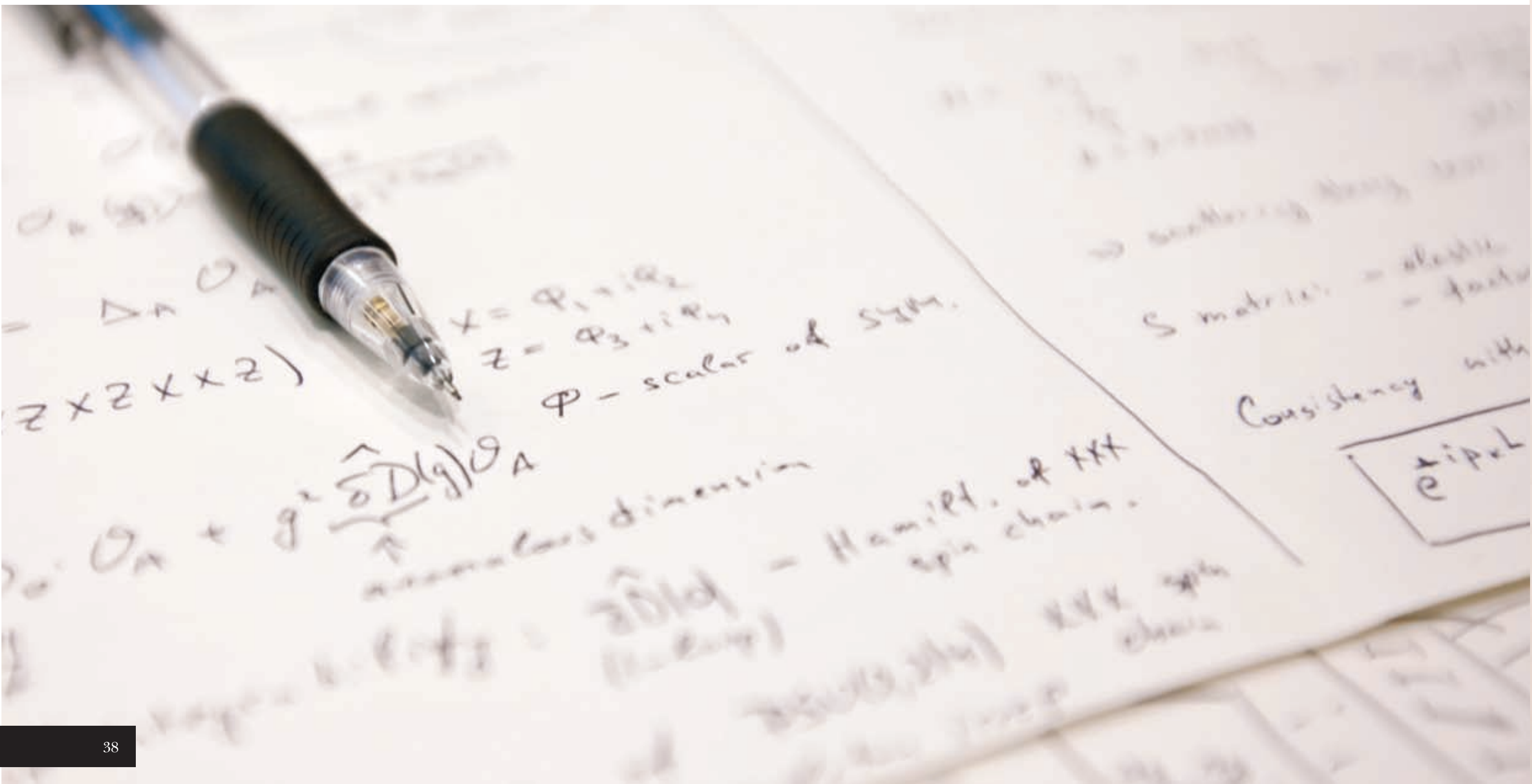
THE FUTURE

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.



Support Nordita

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.

UNRESTRICTED GIFTS
For cash donations within Sweden, please use the plusgiro account of KTH: 1 56 53-9, and write "Nordita donation" in the information box.

For international donations, use the following bank information for Nordita's KTH account:

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Bank Address: Nordea Bank AB, SE-105 71 Stockholm, Sweden
VAT nr (of KTH): SE202100305401
Please write "Nordita donation" in any available information box.

TARGETED DONATIONS
Please contact Nordita's Director to discuss options for targeted donations:

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