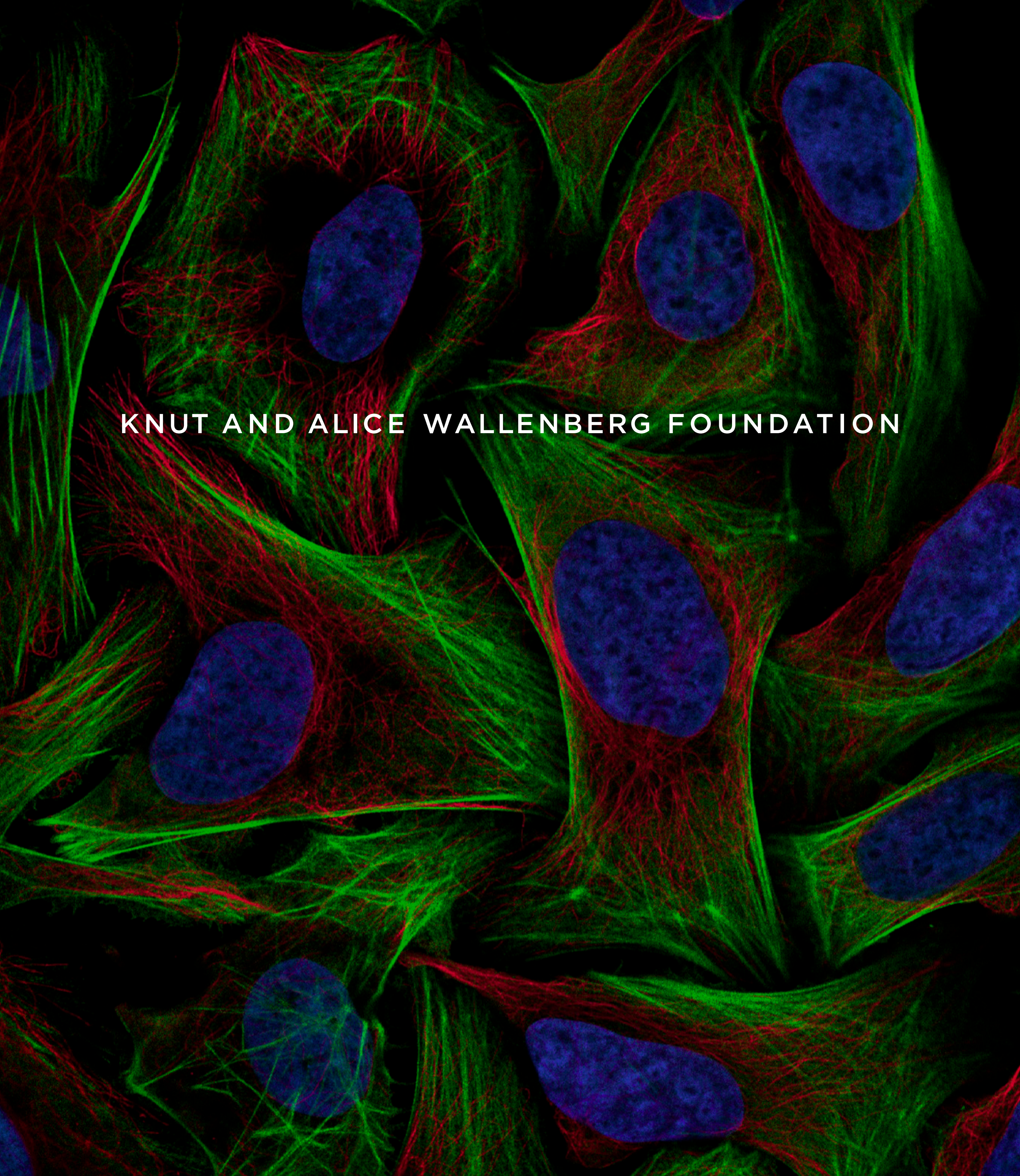


KNUT AND ALICE WALLENBERG FOUNDATION

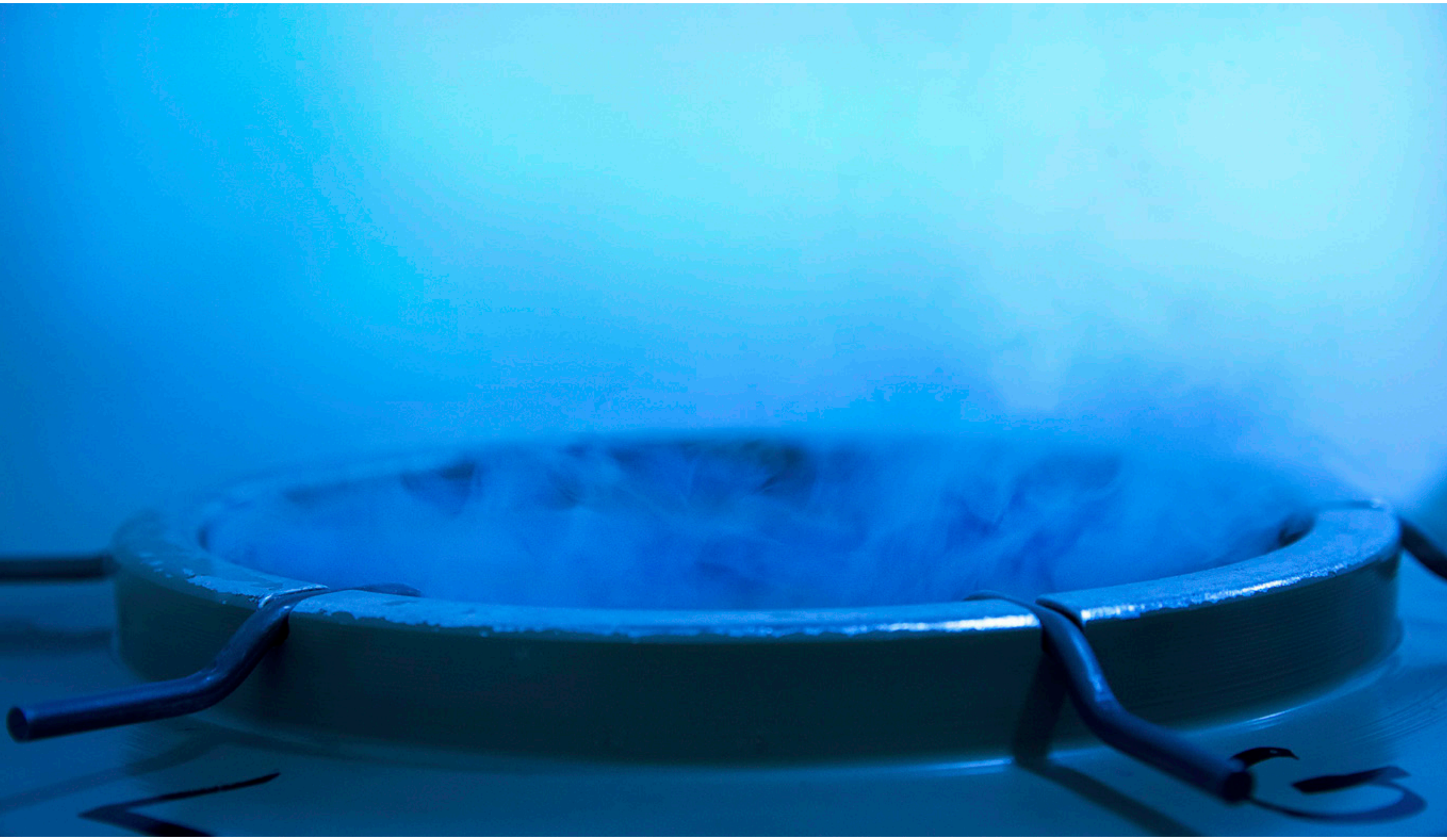
This is a digital version of the book about the Knut and Alice Wallenberg Foundation. The book was published both in a Swedish and an English version in connection with the Foundation's 100-years anniversary. The book can also be downloaded in PDF-format from the Foundation's website kaw.wallenberg.org

KNUT AND ALICE WALLENBERG FOUNDATION

100 YEARS IN SUPPORT OF EXCELLENT SWEDISH RESEARCH AND EDUCATION

“If wealthy people only realized what a pleasure it is to be able to help our country and its people by supporting useful enterprises, then they would not hesitate to arrange for legacies to be bequeathed in their wills, which would benefit and please others. Maybe it is egotistical to give while one is still alive but oh, what fun it is.”

Knut Agathon Wallenberg, in a letter to Sweden’s Crown Prince Gustaf Adolf in 1937



Knut and Alice Wallenberg yachting.

When my great-great-uncle Knut Wallenberg and his wife Alice decided to establish a foundation in 1917, Sweden and the world were very different from now. World War I was being waged; Knut had accepted an appointment as Sweden's foreign minister in 1914 to help lead our nation through that crisis. Despite the war, Sweden's infrastructure and commerce improved.

Against that background, Knut and Alice Wallenberg naturally intended the Foundation to focus on domains beneficial to Sweden: science, trade and industry.

Throughout the Foundation's first 100 years, it has continued to promote those domains that are beneficial to Sweden. Today we use that term to refer to what is good for Sweden and for Swedish research and education in the long term.

When I succeeded my father as chairman in 2015, we could report that the Foundation's assets had increased from SEK 1.9 billion to 80 billion under his chairmanship, and that nearly SEK 20 billion had been awarded in grants. This year, as the Foundation celebrates its 100th anniversary, the total amount awarded in grants to support its objectives will reach SEK 24 billion.

The Foundation's Board of Directors, our employees, and I are all eager to continue this work, and we hope the next 100 years will be just as interesting and filled with progress.

Stockholm, January 2017

Peter Wallenberg Jr

Knut and Alice Wallenberg Foundation

100 YEARS IN SUPPORT OF EXCELLENT SWEDISH RESEARCH AND EDUCATION

Over the late 19th and early 20th centuries, Knut and Alice Wallenberg built up a sizable fortune. Like most other wealthy people in those days, they provided grants and donations to needy people and organizations in addition to financing various construction and public development projects. Handling private donations grew more time-consuming, so the idea of setting up a foundation to handle the grants started to take shape.

On December 19, 1917, the couple founded the Knut and Alice Wallenberg Foundation with a SEK 20 million endowment at Stockholms Enskilda Bank. The assets were mainly in the form of shares in Investor and Stockholms Enskilda Bank. The couple then continued to build up the Foundation through a series of donations over three decades.

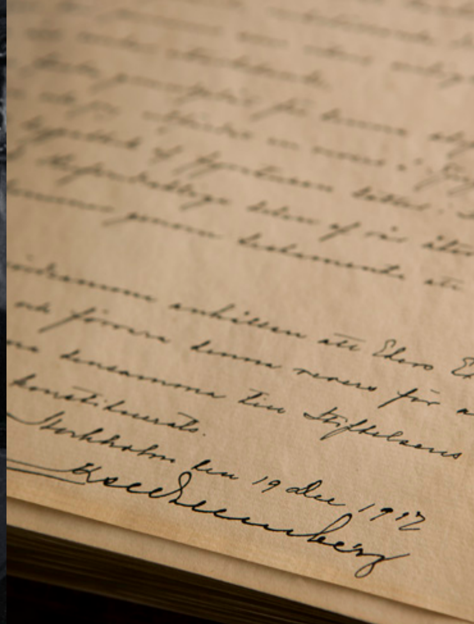
The Foundation's original purpose was mainly to support science and promote trade, forestry, industry, and other commercial activities in Sweden. Since 1928, the aim has been to promote scientific research and education that is beneficial to Sweden.

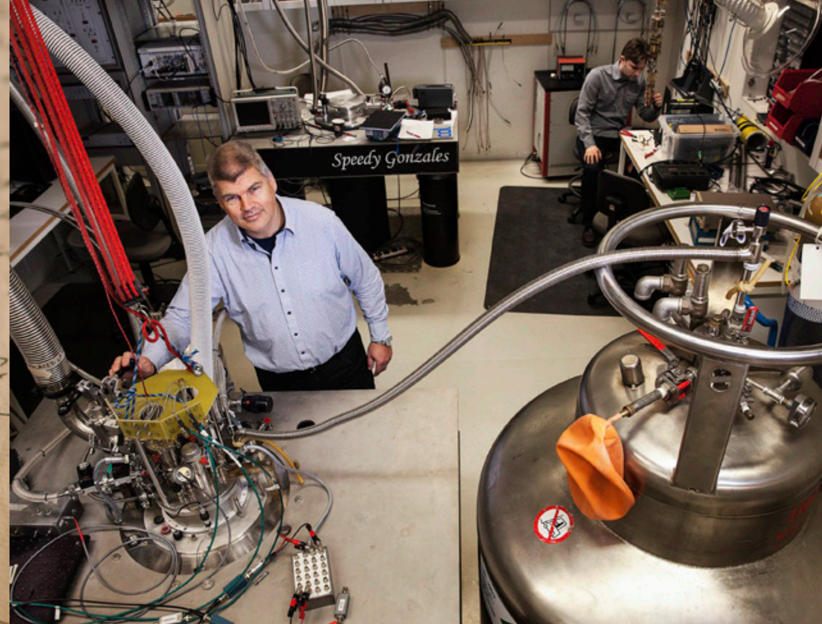
This practical approach and the aim of being "beneficial to Sweden" were both represented in the Foundation's early grants to fundamental activities like agriculture, forestry, hunting, and fishing.

In recent years, support has mainly been in the form of grants to cutting-edge researcher-led scientific projects and to outstanding researchers.

As the Foundation celebrates its 100th anniversary in 2017, it has contributed a total of SEK 24 billion toward its aim of benefiting Sweden, mainly to Swedish universities and educational institutions. Meanwhile, the Foundation's assets have grown from the original endowment of SEK 20 million to SEK 90 billion as of fall 2016, thanks to active, long-term investment mainly in world-leading Swedish companies.

This book honors the memory of Knut and Alice Wallenberg, the founders of the Foundation, and describes the Foundation's progress during its first 100 years, in terms of both its grants and assets. It also portrays the Foundation's current and upcoming activities, chiefly through reports on the researchers and research teams that have received support over the past 25 years ∎




Speedy Gonzales

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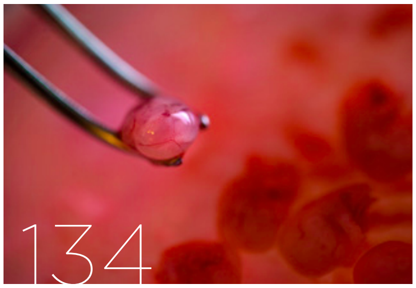
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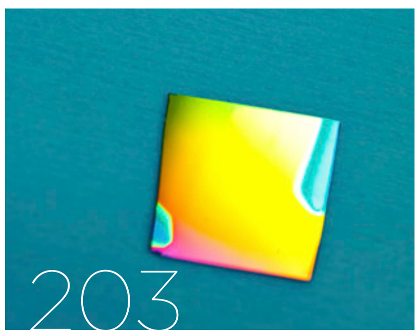
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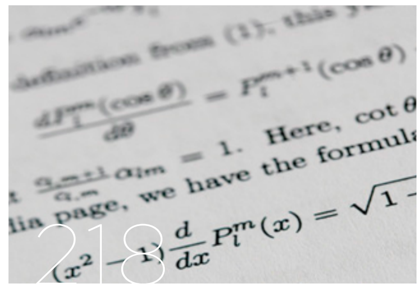
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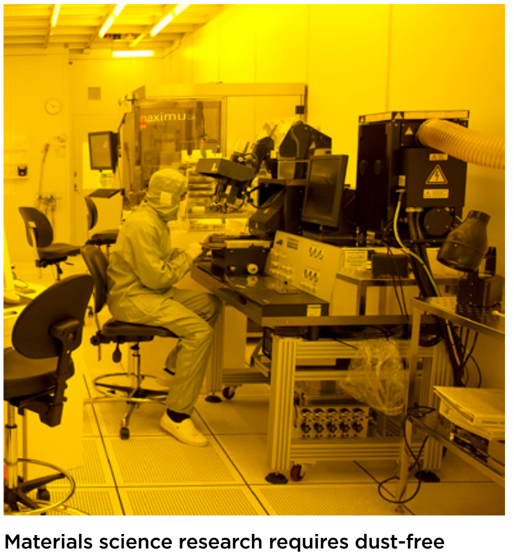
BASIC RESEARCH

The key to life's mysteries

Basic research is unbiased and carried out without regard for immediate applications, but over time, unexpected applications begin to crystallize. Basic research often leads to revolutionary leaps in knowledge and pioneering applications. The results can also be unsuccessful, but even knowing that something does not work can be important. In many cases, an unexpected avenue opens up in a completely new direction.

Basic research is about investigating, understanding, and analyzing tiny constituents such as nanoparticles, proteins, bacteria, amino acids, protons, neutrons, photons, viruses, genes, neutrinos, neurons, quarks, aerosols—the list is long. But it is also about developing procedures, performing complex calculations, and developing technology to interpret and process all the data collected.



Materials science research requires dust-free cleanrooms. Interior at MC2, Chalmers University of Technology, Gothenburg.

DISCIPLINES

The term "basic research" is used almost exclusively in scientific disciplines like medicine, natural sciences, and sometimes in technology. For many years, researchers adhered to strictly defined subject areas. Physicists, chemists, and biologists undertook research in parallel strands, but as more knowledge and data are amassed and analyzed, the need for competence across multiple fields has increased. Today, almost all basic research is interdisciplinary, meaning that researchers with expertise in various scientific disciplines work together to understand and solve problems.

The practical benefits of basic research can be immense, but they are often unforeseeable. History is filled with examples of unexpected benefits, epitomized by the discovery of penicillin, which was awarded the Nobel Prize in 1945.

The Knut and Alice Wallenberg Foundation has supported Swedish basic research for 100 years ∎

BASIC RESEARCH

Also called fundamental research or curiosity-driven science—they all have a common aim: to generate new knowledge and new processes and to systematize them so we can gain a better understanding of the fundamental building blocks of ourselves and our surroundings.

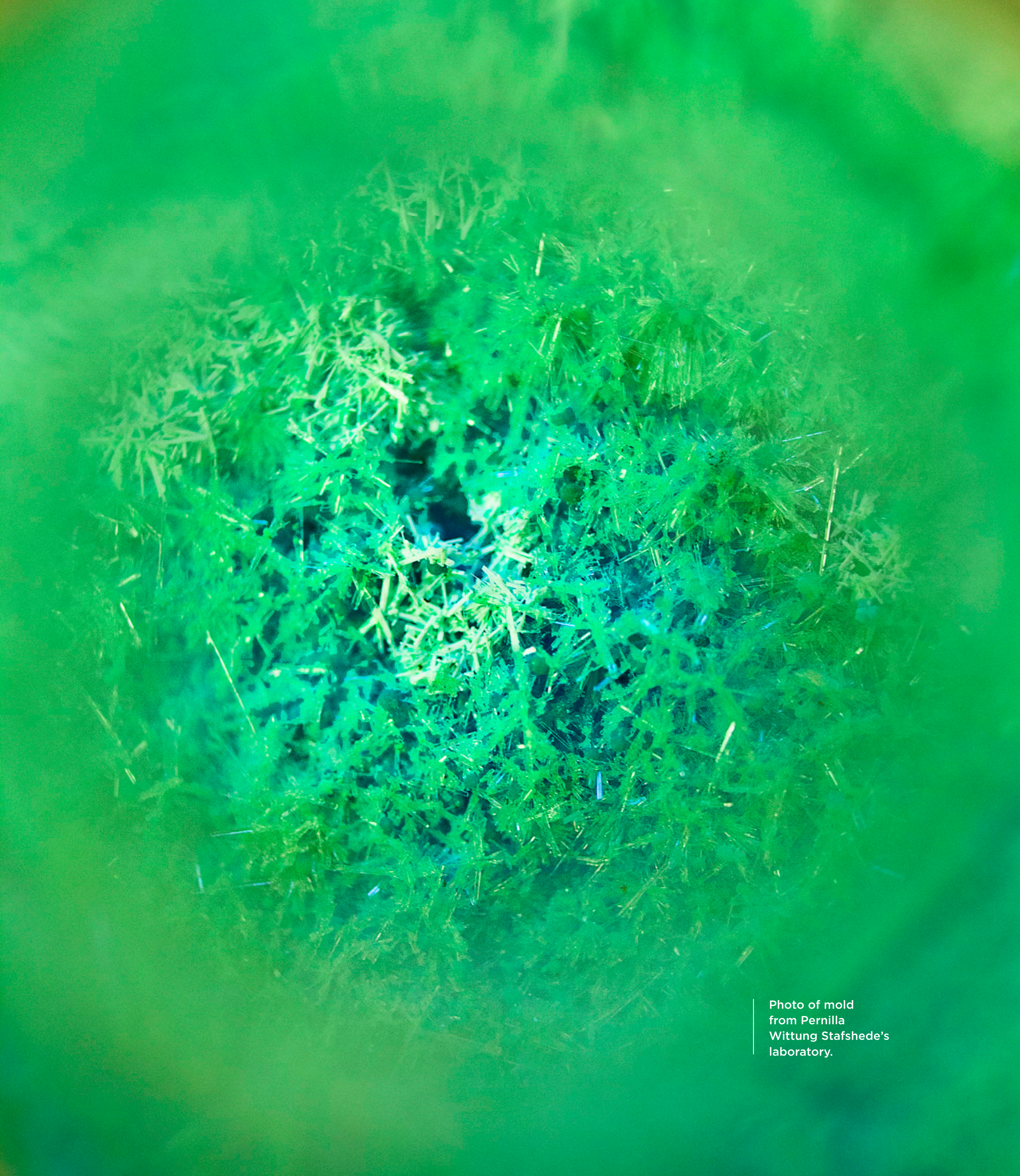


Photo of mold from Pernilla Wittung Stafshede's laboratory.

Tiffany Klingström intensely concentrating in Erik Ingelsson's laboratory.

EXCELLENCE IN RESEARCH

The Foundation has supported excellence in research throughout its history in the form of grants for individual researchers, project grants, and research and scholarship programs. These individual grants are important because they allow researchers to choose how they utilize the funding. The programs initiated in recent years are described below.

WALLENBERG SCHOLARS

This program focuses on Sweden's leading senior researchers. It was implemented because researchers need long-term funding without the distraction of pressure to secure external grants in order to carry out world-class research.

For the first time, in the fall of 2008 the Foundation invited Swedish universities to nominate some of their most outstanding researchers across all scientific disciplines. Swedish and international experts from each field evaluated the applications and nominated candidates for funding decisions by the Foundation's Board.

Between 2009 and 2012 the Foundation awarded grants to 47 Wallenberg Scholars. One key principle is that the grants, totaling SEK 15 million, can be freely used for research for five years with no restrictions.

After the end of the grant period, the research is evaluated by an international panel of experts, and the best researchers are awarded a further five-year grant. In 2016, 14 researchers received such an extension.

WALLENBERG ACADEMY FELLOWS

This program was launched by the Foundation in conjunction with the Foundation's Principals Council as a response to Sweden's declining competitiveness in scientific fields, which required significant intervention to ensure Sweden would remain a leading research center in the future. The aim of the program is to put junior scientists in a position to focus on research and give them the chance to tackle challenging, long-term research issues.

Universities nominate candidates for the program, and then the royal scientific academies evaluate the nominations to select the most promising junior scientific researchers across all fields.

To increase the international dimension of Swedish research, some of the nominations must come from universities outside Sweden. Universities are also encouraged to nominate researchers from other Swedish institutions to increase mobility within the country.

In addition to the research grants there is a mentoring program, which is divided into two sections. One is managed by the Royal Swedish Academy of Sciences and is aimed at developing junior researchers' leadership skills. The other section, led by the Royal Swedish Academy of Engineering Sciences, aims to promote the use of research to benefit society. The accompanying research grants range from SEK 5 million to 9.5 million per researcher over a five-year period. The Foundation funded 150 Wallenberg Academy Fellows for the period 2012–2016.

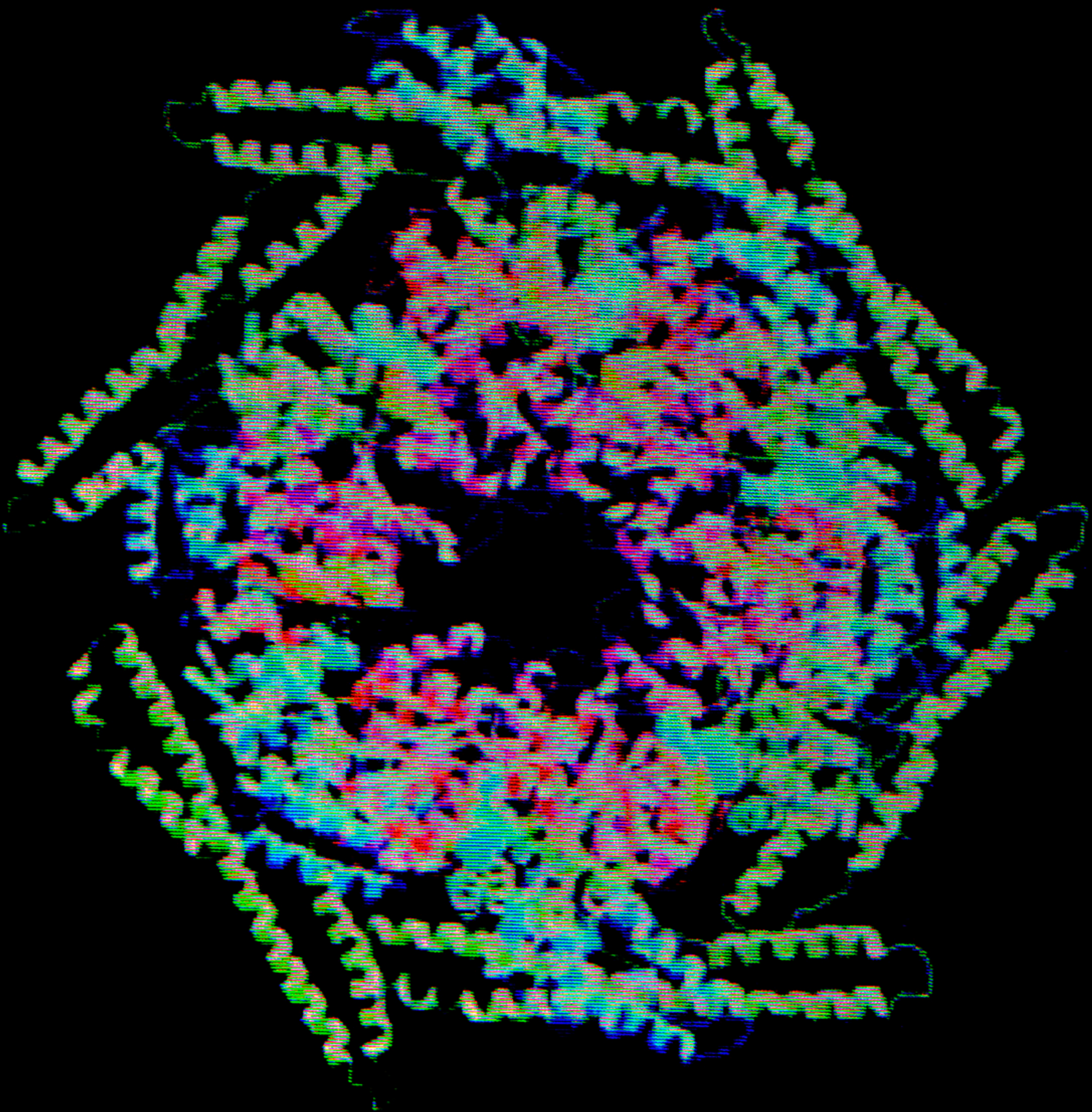
After five years, universities can nominate researchers for extended funding. The nominated researchers are evaluated, and the best candidates can receive a grant for another five years.

WALLENBERG CLINICAL SCHOLARS

In 2014, the Foundation introduced a program to promote clinical research. This program aims to support and stimulate some of the most successful clinical researchers in Sweden. It has a similar format to the Wallenberg Scholars, except that researchers can only be nominated by universities that have a medical school.

Applications are awarded on the basis of scientific excellence in clinical point-of-care or clinical experimental research. Researchers must also work in a clinical setting.

The aim is to provide five-year grants to five senior clinical researchers totaling SEK 3 million per year, with a possible five-year extension following evaluation ■



Proteins are made up of long chains of amino acids. Some proteins contain up to 27,000 amino acids.

AGED CELLS ARE DAMAGED BY PROTEIN CLUMPS

In Thomas Nyström's world, aging is not about wrinkles and forgetfulness, but rather about proteins that form clumps inside cells. He studies why cells grow old and molecular processes that can protect against aging. He also hopes to improve understanding of diseases like Parkinson's and Huntington's, which cause premature aging.

Three robots work day and night in his lab to refine yeast strains. This is the heart of his team's activities. Thousands of yeast cells are crossed with thousands of others. The aim is to develop yeast cells that can live as long as possible.

"We're trying to find proteins and processes that can slow the aging process and prevent the occurrence of diseases like Huntington's and Parkinson's," says Nyström, who is Professor of Microbiology at the University of Gothenburg.

Yeast is a single-celled organism, and its average lifespan is measured in terms of how many daughter cells a mother cell can create. Normally it can divide 25 times. But Prof. Nyström has produced yeast cells that can survive for more than 40 generations.

"That's a lot for yeast," he says as he shows off his robots. "We couldn't have run this project without this equipment. It would have taken a long time—over 80 years. Now it's just eight months."

THOMAS NYSTRÖM

Professor of Microbiology, University of Gothenburg.

Wallenberg Scholar 2009

Main area of research: Yeast as a model for aging and age-related illnesses.

OLD CELLS FILL UP WITH CLUMPS OF PROTEINS

The hypothesis Prof. Nyström is testing says that aging occurs when proteins—which otherwise monitor and control cell chemistry—grow old and form clumps. Proteins are made up of long chains of amino acids, and these form tangled masses that are toxic to cells. Prof. Nyström discovered that this process is connected with aging when he was studying why bacterial cells suddenly collapse.

"Part of the problem is that bacteria damage themselves with their own respiration: free oxygen radicals are formed that damage the proteins," he explained.

All cells that aerobically respire consume oxygen, generating highly reactive free radicals in the process. Cells have several protective mechanisms, but aging cells do not seem able to deal with all the free radicals produced.

To begin with, Prof. Nyström's research team studied protein clumps in bacteria. However, the research project changed direction when a graduate student who preferred to study yeast cells made a surprising discovery: when a yeast cell divides, all the protein clumps remain in the old mother cell. The daughter cell is not burdened with the clutter.

"So even if the mother cell is old, the daughter cell is born young," Prof. Nyström summarized.

His curiosity was aroused. How did it work? Would the daughter cells die earlier if their sorting mechanism were destroyed?

In order to track the cells' aging process, the team developed a process to make the protein aggregates glow green. They took a protein called Hsp104 and bound it to another protein that gives off a green glow. This ingenious construction means the cell starts to glow green when protein clumps form.

In young cells with intact proteins, there are no green flecks at all. But as cells age, the flecks appear and increase in number until the cell collapses.

PARKINSON'S AND HUNTINGTON'S ARE A MATTER OF PREMATURE AGING

Prof. Nyström's research team has also produced yeast models of Huntington's and Parkinson's diseases. These illnesses are caused by particularly toxic, mutated aggregates of proteins. When they studied huntingtin, the protein that causes Huntington's, they found an interesting new defense mechanism.

Cells gather all their harmful protein clumps in one place. But then, as they age, they lose this ability, and green flecks start to show up everywhere.

"We suspect, though this is purely a hypothesis, that it's better for the cell if everything accumulates as one big ball, instead of going all over in the cell," Prof. Nyström said. "The clumps attach themselves mainly to one structure that acts as a transit route in the cell. When there are too many clumps, the route stops working." ■

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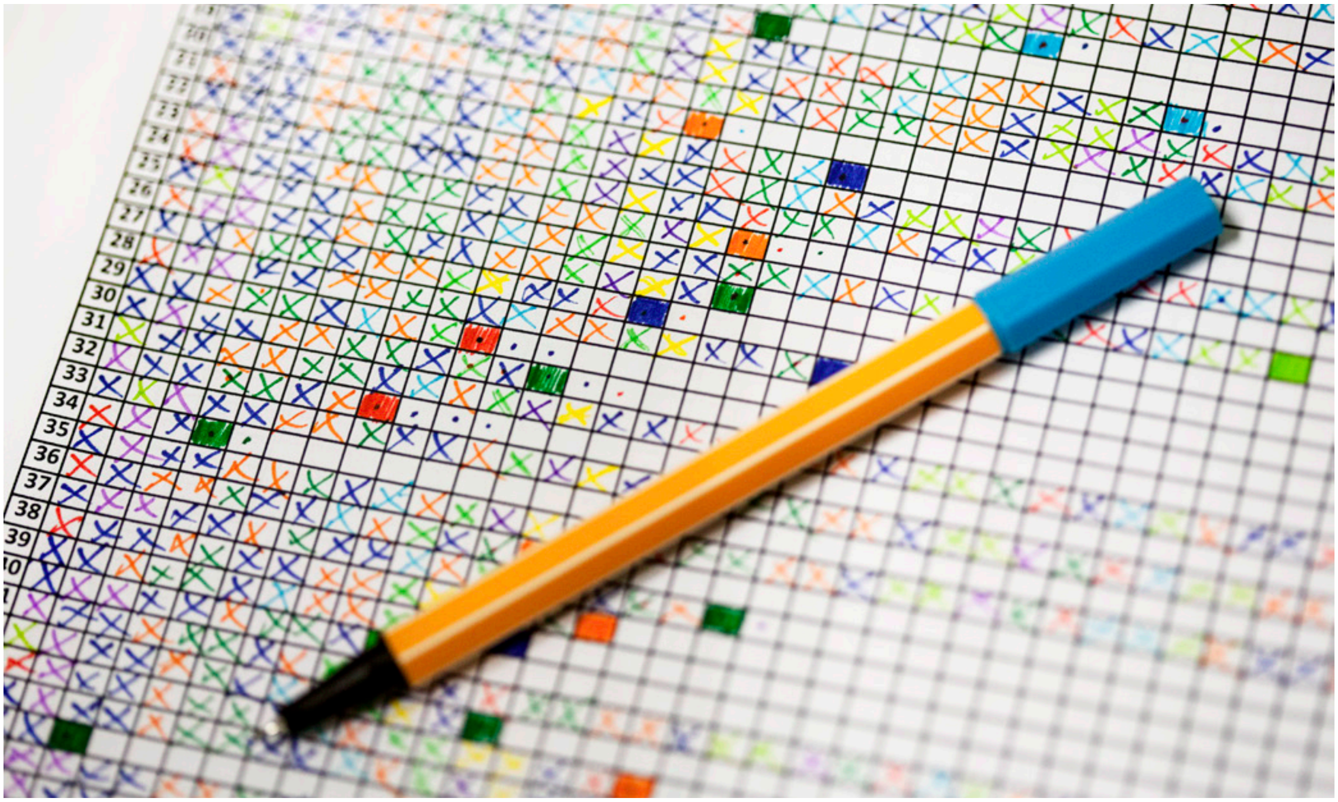
THOUSAND GENES

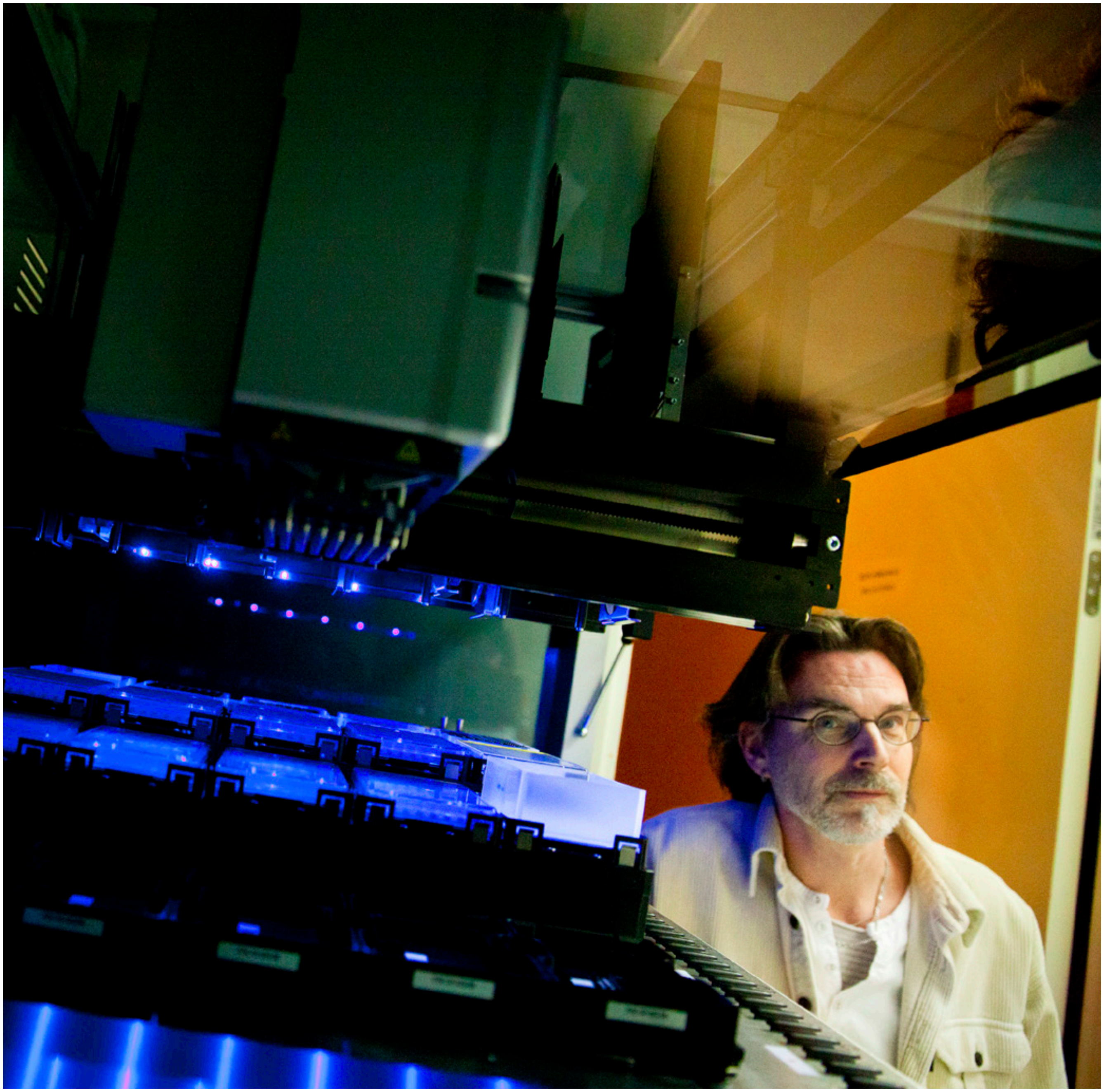
Ordinary yeast can be used in experiments to investigate genetic mutations in human cells because many human genes and proteins are similar to those in yeast cells.

Yeast cells have just 6,000 genes versus an estimated 20,000 in human cells, so yeast can serve as a simplified model of how our cells function.



Documentation of an experiment in Thomas Nyström's laboratory.

"We couldn't have run this project without this equipment. It would have taken a long time—over 80 years. Now it's just eight months," said Thomas Nyström.



ON THE ART OF LEARNING A NEW LANGUAGE

How do we speak and understand languages? And how do we learn a new language? What happens to our gestures? Is our first language affected when we learn a new one? These are some of the questions Prof. Marianne Gullberg is trying to answer in her research, as she rejects several myths about language learning.

"Myths are fun to explode," Prof. Gullberg said.

She speaks rapidly and intensely, giving the impression that language research is not just a job, it's a passion. She is Professor of Psycholinguistics at Lund University. Psycholinguistics is the study of the relationship between language, thought, and the brain—of what we actually do when we speak and understand language, something we don't often think about when we speak our native language.

"It's an incredibly fast process, a matter of milliseconds. In that time we go from a vague idea to choosing the right words, grammar, sounds, intonation, and gestures. The opposite process, of understanding someone else, is just as fascinating," she explained.

After 10 years as a research leader at the Max Planck Institute for Psycholinguistics in the Netherlands, Prof. Gullberg was appointed Scientific Director of the Lund University Humanities Lab in 2010.

"It was an irresistible offer," she recalled. "This lab is unique in the world. We host researchers from every discipline except law." Her team includes several nationalities, and she speaks seven languages herself, despite growing up in a monolingual family.

MARIANNE GULLBERG

Professor of Psycholinguistics, Lund University.

Wallenberg Scholar 2012

Main area of research: Adult second language learning and multilingualism in speech and gesture; language processing, including neurocognitive aspects.

MYTHS AND DOUBLE STANDARDS

Human language is the most complex communication system we know of. Language is also our tool for thinking. It interacts with emotions and memory and is driven by the same neurological apparatus.

"But how do we actually learn a language? It's generally not until we learn a new language that we realize how difficult it is. What interests me is precisely how we learn a language when we already have one in place. How do the different languages interact and influence each other? The area is surprisingly unexplored," she said.

Prof. Gullberg believes there are many myths surrounding language learning and many social policy decisions are ill informed. She also pointed out a strange double standard concerning multilingualism.

"We want our children to learn English at an early age because early learning is a good thing. But a child who is multilingual in, say, Turkish and Swedish is regarded as a problem. That's a peculiar attitude," she noted.

EEG (electroencephalography) is used in the Humanities Lab to study the brain's responses to stimuli such as sounds, images, words, and movements.

The image on the left shows how a blind person "reads" a tactile image of a face with their right index finger (green line) and left index finger (red line). Compare it with a classic image (right) of the way a sighted person moves their eyes over a photo of a face (the lines indicate movements and the dots indicate pauses). The tactile image was made using a process developed in the Tactile Reading project, led by Sven Strömqvist in the Humanities Lab.

Prof. Gullberg says that all research clearly shows multilingualism is a good thing. In global terms, it is strange to speak only one language.

"It's like exercise for the brain and helps protect against dementia. Multilingualism is the norm rather than the exception around the world. Many preschool children in Africa speak three languages, and when they begin school, they learn three more," she said.

GESTURES WITH SMALL DIFFERENCES

Prof. Gullberg has also studied Swedes learning French and vice versa. She has looked not only at how they talk, but also how they gesture, which has enabled her to explode another myth.

"It turns out the French gesticulate just as much as Swedes," she said.

The difference is in the ways the two groups use gestures: "It's a matter of small, subtle differences. French people are restrained but use more rhythmic gestures than we do to emphasize what they are saying," she explained.

TECHNOLOGY FOR THE HUMANITIES

One aspect of how languages influence each other is accent. Prof. Gullberg and her research team will be looking at accent more closely in a new project.

"Accent is not just a question of pronunciation," she said. "We're also going to study how gestures are affected since emphasis, intonation and rhythm are also expressed through the hands. Is a person speaking perfect French but gesturing in Swedish perceived as having an accent?"

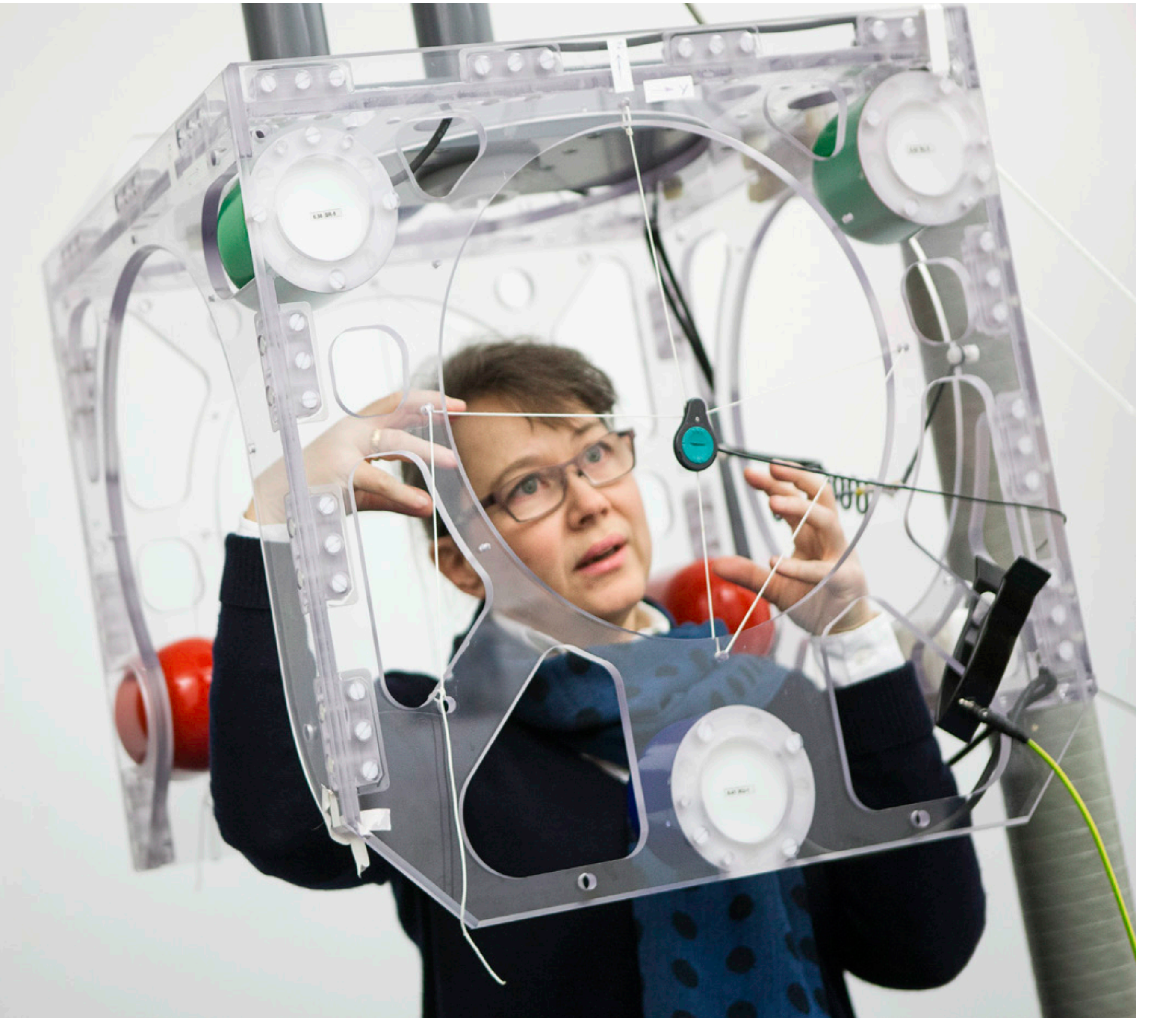
To assist her, she has a number of technical aids at Lund University Humanities Lab, including an articulograph that measures tongue movements, motion-capture devices to measure body movements, and brain imaging technology ■

7

BILLION PEOPLE speak between 6,000 and 7,000 languages. At least half of all people in the world are bilingual or multilingual.

Most of the world's languages are spoken in Asia and Africa. Some 225 languages are indigenous to Europe—around 3% of the total number of languages in the world. Researchers believe half of the world's languages will become extinct in the next 100 years.

"We want our children to learn English at an early age because early learning is a good thing. But a child who is multilingual in, say, Turkish and Swedish is regarded as a problem. That's a peculiar attitude," said Marianne Gullberg.



Helena Edlund studies how obesity leads to the formation of harmful protein aggregates (in bright green) in insulin-producing cells and how that leads to the development of diabetes.

REDUCING OBESITY-RELATED DISEASES

For over 20 years, Prof. Helena Edlund has been studying the pancreas, the hand-size gland behind the stomach that may hold the key to stopping a global epidemic of diabetes and other obesity-related diseases.

"Actually, we already have the answer. It's a matter of exercising and limiting your calorie intake and avoiding fast-release carbohydrates," she said.

But even though most people know that diet and exercise are the key to a healthy life, obesity and Type 2 diabetes are spreading like an epidemic all over the world. The greatest increases are in Asia, the Middle East, and America.

"The US population is eating itself to death. Only one third are a normal weight; 20–30 percent have fatty livers, and there are 12-year-olds that have cirrhosis of the liver due to obesity," she said.

Type 2 diabetes used to be called adult-onset diabetes, but as more and more children developed it, people began to talk about Type 2 diabetes, while "juvenile diabetes" became Type 1 diabetes.

"Type 2 diabetes is a complex disease characterized by both insulin resistance and defects in beta cells," Prof. Edlund explained.

HELENA EDLUND

Professor of Molecular Developmental Biology, Umeå University.

Wallenberg Scholar 2010

Main area of research: The development of the pancreas and causes of diabetes.

FEW EFFECTIVE MEDICINES

Helena Edlund, now a Professor of Molecular Developmental Biology, began her research career by studying the development of the pancreas, from its formation in the embryo to its full maturity. Through continued studies of insulin-producing beta cells and their transmission of signals, she hopes to contribute new knowledge that can reduce diabetes and other obesity-related diseases. Her research focuses on beta cells and a receptor, a cellular component that passes on signals. Another focus of her research is autophagy, the process by which cells break down their worn-out parts.

"I want to understand at the molecular level how obesity affects the insulin-producing beta cells in the pancreas, liver function, and the connection to diabetes. Why do beta cells stop functioning? Why doesn't everyone with insulin resistance develop diabetes?" she summarized.

Of course, she also feels driven to find an explanation that can lead to a drug, although she admits that that is extremely difficult.

"It involves hugely complex interactions," she said. "Today we have few effective medicines because we don't understand the whole process. Better understanding will lead to better prevention and improved drugs, or creation of new ones."

OBESITY AND DIABETES

Prof. Edlund, who is one of the world's leading developmental biologists, and her research team made an international breakthrough in understanding how obesity causes increases in levels of insulin, sugar, and blood fats that can lead to diseases like Type 2 diabetes and fatty liver disease, as well as complications such as cardiovascular disease and chronic liver disease.

"The explanation is that fat enhances the secretion of insulin—you get a turbo effect. We showed that fatty acids stimulate insulin secretion via the GPR40 receptor and that if you develop obesity but lack the GPR40 receptor, you don't develop diabetes or other related diseases to the same extent," she said.

Blocking the receptor should theoretically provide protection against diabetes and other complications.

"But we don't know whether it helps once you've already developed diabetes," she noted. "Since diabetes is often diagnosed several years after the development of the disease, it's an ineffective weapon."

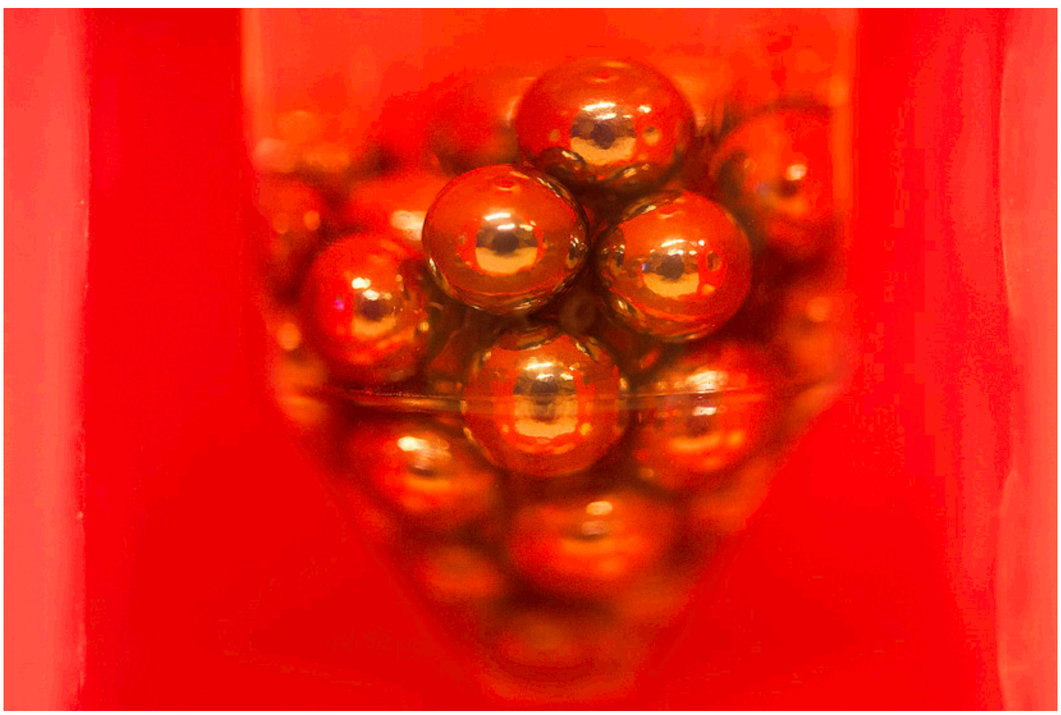
INDIVIDUALIZED TREATMENTS

It has now been firmly established that beta cells are affected by both age and obesity. Prof. Edlund and her research team have turned their attention to autophagy.

"Autophagy, or degradation of worn-out cell parts, is hampered by obesity, among other things. If you stimulate autophagy, you'll live longer. And that brings us back to eating right and exercising," she said, putting in a good word for regular exercise.

Diabetes and other obesity-related diseases are complex. Genetics, hormones, and other factors interact with environmental influences in ways that are difficult to predict. This makes it hard to find effective drugs.

"Different diabetes patients can also have different basic problems, which means that the most effective treatment may be entirely individual," Prof. Edlund explained. "Exploring this is like doing a puzzle. Some pieces are more important than others; once you get them in place, the others fall into place automatically. We hope that someday all the pieces will be in the right places, but still more knowledge and research are needed before the puzzle is complete." ∎



Diabetes and other obesity-related illnesses are complex. A sample tube from Helena Edlund's laboratory.

FACTS ABOUT DIABETES

In 2014 more than 387 million people were living with diabetes. By 2035 the number is expected to rise to around 592 million.

In Sweden at least 390,000 people, or approx. 4% of the population, have diabetes.

The number of people with Type 2 diabetes is rising in every country.

77% of people with diabetes live in low- and middle-income countries.

Diabetes is most common in the 40–59 age group.

179 million people have diabetes without knowing it.

Helena Edlund discusses some results with Jurate Straseviciene.

Ciska Veen, Jonathan De Long, and David Wardle doing field research at Abisko.

CHANGES IN ALPINE AND FOREST ECOSYSTEMS

Climate changes, forest fires, the appearance of new species, and the disappearance of others affect important functions in ecosystems both above and below ground. David Wardle has devoted much of his research career to studying connections in ecosystems and understanding the significance of these changes.

"There's a great deal of research about the importance of new species and about species loss, but few have studied the net effect of these in tandem. It's important for understanding how human activities impact the composition of species in an ecosystem and how this in turn affects the system's productivity, nutrient cycles, and capacity to store carbon," said Wardle, Professor of Soil and Plant Ecology at the Swedish University of Agricultural Sciences (SLU) in Umeå.

One question generating interest is whether new species arriving in an ecosystem take over the role played by the species that simultaneously disappeared.

"This is still an open question, but the new species do behave differently. The native species have been interacting over a long period of time and had adapted to the local ecosystem, whereas the new species evolved under different conditions," he explained.

DAVID WARDLE

Professor of Soil and Plant Ecology, Swedish University of Agricultural Sciences.

Wallenberg Scholar 2010

Main area of research: How ecosystems above and below ground interact and how their interactions are affected by environmental changes.

ARJEPLOG AND NEW ZEALAND

Prof. Wardle is originally from New Zealand, but in the mid-1990s he came into contact with researchers at SLU and started collaborative work with them. The Abisko field station and the islands in Lake Hornavan and Uddjaur in Arjeplog Municipality in the far north of Sweden became the starting points for many of his field studies, which then led to his appointment as a professor at the University in 2007.

But he hasn't fully turned his back on his research in New Zealand. He goes there every winter, primarily to study how new animal and plant species impact the ecosystems in forests.

"New Zealand is one of the countries most affected by animal and plant species introduced by humans. This makes it a highly interesting region to study," he said.

STUDYING TEMPERATURE CHANGES IN ABISKO

On the mountain slopes near Abisko, Prof. Wardle and his research team are conducting a field study where they explore, and attempt to predict, how temperature changes caused by global climate change might affect the ecosystem. The study focuses on a range of temperature changes of about 3° C, similar to the anticipated rise in temperature associated with global warming during this century. Their observations include events above and below ground.

Jonathan De Long and Niklas Nord analyze plants and samples that have been collected.

3°

WARMER MAKES A BIG DIFFERENCE

With a global temperature increase of 3° C there is a high risk of major losses of biodiversity in plants and animals. Many climate models predict large parts of southern Africa could become uninhabitable due to drought and desertification.

In 2015 a resolution was passed at the COP21 summit in Paris that the Earth's temperature must not increase by more than 2° C and setting a target to limit the increase to 1.5° C.

"Because temperatures naturally fall with increases in altitude, the altitude gradients are perfect for studying how plants, animals, and soil are affected by temperature changes," he explained.

The study shows that temperature changes in northern Sweden have already impacted parts of the nutrient cycles. Prof. Wardle now wants to investigate whether these patterns are the same around the globe.

FORESTS AND THE CARBON CYCLE

In the light of global climate change, forests can fulfill a key function by fixing the greenhouse gas carbon dioxide and thereby storing carbon in living and dead plants.

Prof. Wardle's research team has been studying islands in lakes around Arjeplog, some of which have been exposed to natural forest fires in the last 60 years, while others have been untouched for 5,000 years.

Forest fires increase the growth of both trees and ground vegetation. At the same time, they affect the amount of carbon stored in the soil.

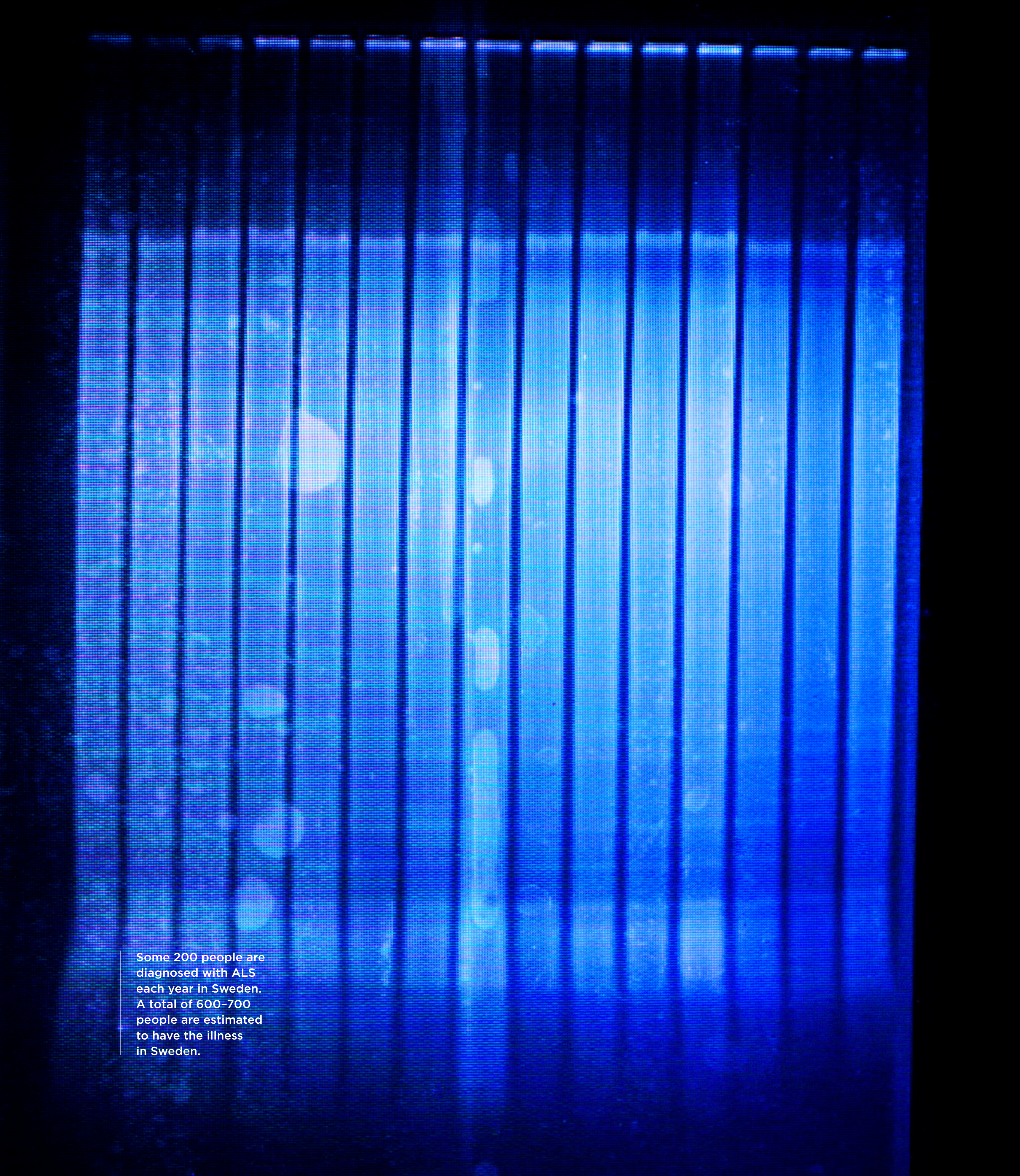
The study shows that as forests grow older, less carbon is stored above ground, while much more carbon is stored in the soil.

"This is because the composition of plant species changes over time. Old undisturbed forests can store much more carbon than younger forests. Without recurring forest fires, soil-bound carbon can be stored for thousands of years," he explained.

Similar research is now underway in forest ecosystems in New Zealand and Australia to see whether the same changes are taking place in other ecosystems that have been undisturbed for thousands of years ∎

David Wardle is concerned. Temperature changes in northern Sweden have affected nutrient cycles. Is this true all over the world?

Epigenetic plant studies in Lars Hennig's laboratory, at Uppsala BioCenter at the Swedish University of Agricultural Sciences.



Some 200 people are diagnosed with ALS each year in Sweden. A total of 600–700 people are estimated to have the illness in Sweden.

SLOWING THE PROGRESS OF ALS

Amyotrophic lateral sclerosis (ALS) causes motor neurons in the brain and spinal cord to atrophy. Peter Andersen has discovered that certain proteins form clumps in the neurons as the disease progresses. Now he hopes his research will help find a way to slow the progress of the disease.

The cause of ALS, also called Lou Gehrig's disease, was long a mystery, but Peter Andersen and his team have found diseased clumps of the protein superoxide dismutase-1 (SOD1) in neurons of ALS sufferers.

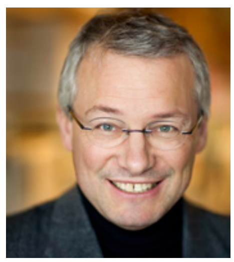
"Our research concentrates on hereditary and molecular factors, particularly the SOD1 protein," said Andersen, who is Chief Physician and Professor of Neurology at Umeå University.

Prof. Andersen has treated patients with ALS since 1992, while also conducting research into the disease.

"As a neurologist, I head a large ALS clinic at the University Hospital of Umeå, where I meet patients from all over Sweden," he explained.

In 1993, a U.S. research team found mutations in the gene that codes for SOD1 in some ALS patients. Around the same time, Prof. Andersen and his colleague Stefan Marklund found an unknown mutation in Swedish and Finnish patients.

"Since then, 188 mutations have been found, including 44 by our team," Prof. Andersen explained. "In some six percent of all ALS patients we find a hereditary mutation of the SOD1 gene, and there are different inheritance patterns. There is a close correlation between the type of mutation and the variety of ALS."



PETER M. ANDERSEN

Chief Physician and Professor of Neurology, Umeå University.

Wallenberg Clinical Scholar 2015

Main area of research: Amyotrophic lateral sclerosis (ALS) and the protein superoxide dismutase-1 (SOD1).

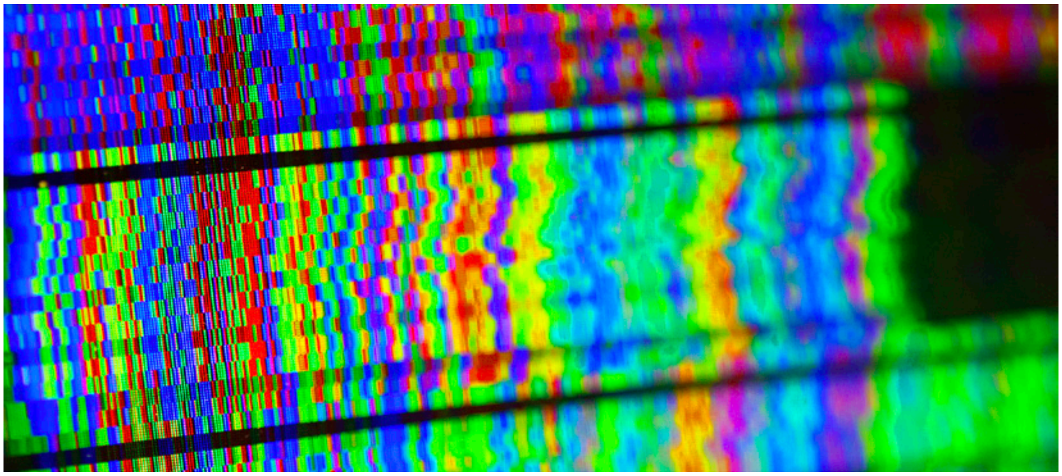
Normally, the long amino acid chain that forms SOD1 should fold into a functioning, compact, well-structured protein that plays a major role in eradicating toxic free radicals. A mutation in SOD1 causes the protein to fold the wrong way, forming clumps. When the research team injected SOD1 clumps into the lower spinal cord of mice, the misfolded SOD1 spread up through the spinal cord and brain, and the mice developed a form of ALS.

"We have concluded that ALS is a prion disease in which misfolded SOD1 spreads from neuron to neuron. Once inside the new cell, the SOD1 prion triggers misfolding of the existing SOD1, which in turn spreads to the next cell," he said.

HOPE IN ANTIBODIES

One key discovery is that misfolded SOD1 has certain surface characteristics that can be demonstrated using antibodies. Prof. Andersen and his team are hopeful that those antibodies will lead to a treatment capable of slowing the progress of the disease.

"We are beginning to understand how the misfolding of proteins can lead to a loss of neurons. One new theory suggests that a peptide called Abeta misfolds in Alzheimer's disease. In Parkinson's disease, the alpha-synuclein protein



Researchers hope antibodies will be able to neutralize misfolded SOD1 protein.

misfolds. Misfolded Abeta and alpha-synuclein have many features in common with misfolded SOD1," he said.

He believes we need to learn more about the misfolding process itself to find out whether it can be slowed or arrested. One idea is to try to stabilize the SOD1 molecule to prevent it from misfolding.

"Several of the mutations we have found in SOD1 are very interesting," he said. "They provide valuable information about the parts of the molecule that have a bearing on the misfolding process."

As a Wallenberg Clinical Scholar, Peter Andersen and his team are attempting to slow the progress of the disease by preventing SOD1 from continuing to misfold and form clumps.

In their research, the team has developed an antibody that binds specifically to SOD1 clumps. They hope the antibodies will be able to neutralize the misfolded SOD1 protein and prevent it from spreading.

"Promising trials on mice are underway, but many more trials are needed before we know which parts of the misfolded SOD1 molecule are the best targets for antibodies," he said.

VARIETIES OF ALS DISEASE

Another part of the project aims to understand different varieties of ALS. Thirty-two known genes are linked to the disease, but the Umeå team found clumps of misfolded SOD1 in autopsies of all ALS patients they examined.

That key discovery indicates that inhibition of SOD1 misfolding must form part of any effective treatment of ALS disease of whatever type.

"Our autopsies show that patients with mutations in gene C9orf72 have large clumps of misfolded SOD protein even though the SOD1 gene is not mutated. Patients who are not carriers of any known disease gene also have misfolded SOD1 of the same appearance," Prof. Andersen said.

Another surprise is that a disease called frontotemporal dementia has many genetic similarities with ALS, and the Umeå team has found misfolded SOD1 in these patients' brains.

Other interesting questions are why SOD1, which is found in all cells, only causes problems in neurons, and why some carriers of gene variants associated with the disease remain healthy.

"We now know of five hereditary features that protect against the disease or reduce the risk of developing it. It might be possible to use them to delay the onset of ALS," he said.

Since the evidence increasingly indicates links between ALS and other neurodegenerative diseases, the ALS team hopes their research will not only add to our understanding of ALS, but also provide new general knowledge that can be translated to other diseases, including Parkinson's and Alzheimer's ■

ALS

Amyotrophic lateral sclerosis, also called Lou Gehrig's disease, is not just one illness but a collective name for several diseases that attack parts of the brain, brain stem, and spinal cord, breaking down motor neurons—the nerve cells that control the muscles.

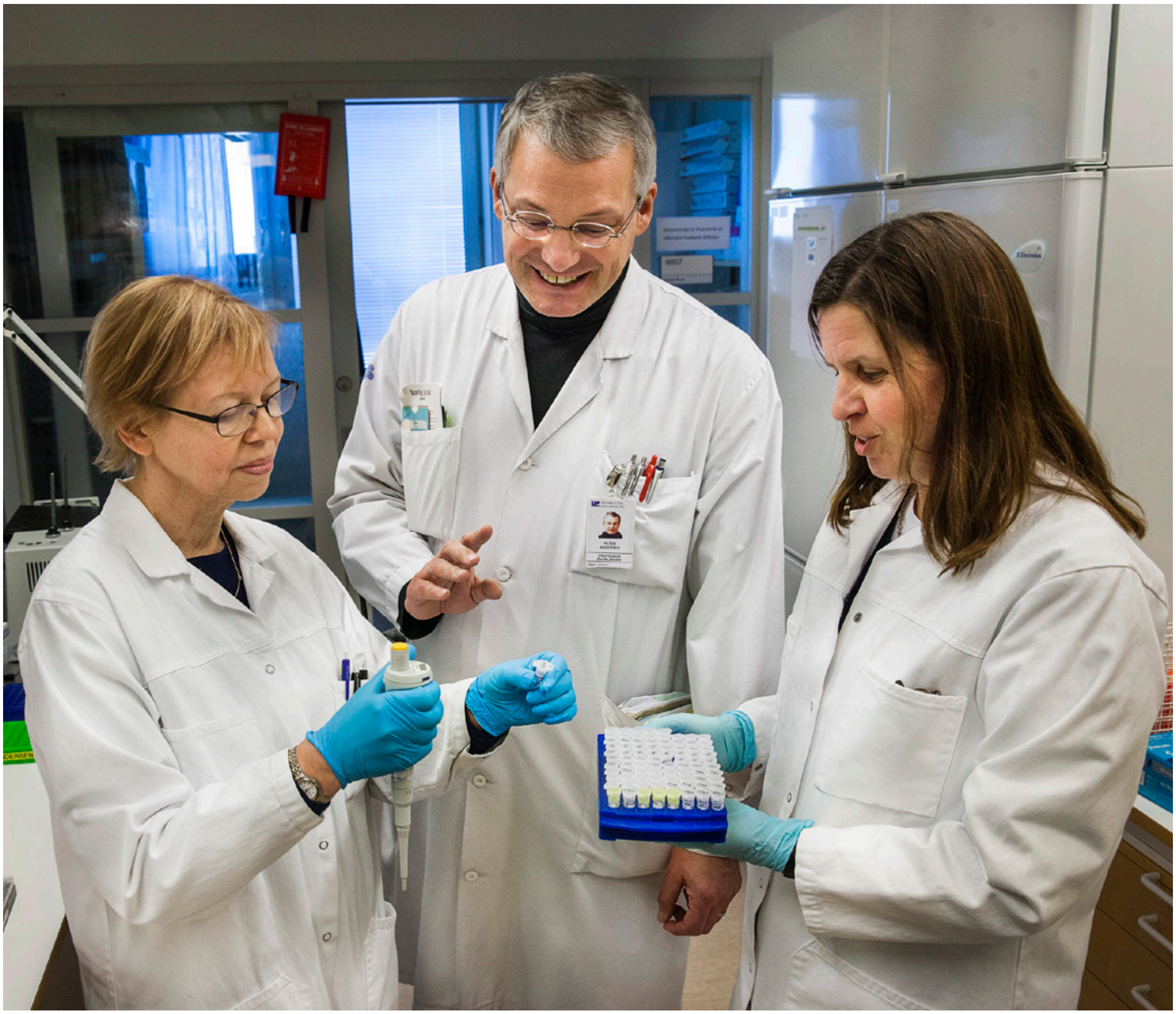
Muscles weaken and atrophy. When the respiratory musculature becomes affected, the ALS sufferer dies.

People are afflicted with ALS all over the world, with around 200 people diagnosed in Sweden each year, mostly of working age. There are an estimated total of 600–700 sufferers in Sweden. One to two in every 10 patients has a known family history of ALS. Men are affected somewhat more often than women.

Around half of patients die between two and four years after onset of the disease, but 10% survive more than 10 years. A few individuals have lived with the disease for longer than 30 years, including the astrophysicist Stephen Hawking.

Today there is just one medicine for ALS, which does not cure the disease but can delay its progress.

"We are beginning to understand how the misfolding of proteins can lead to a loss of neurons. One new theory suggests that a peptide called Abeta misfolds in Alzheimer's disease. In Parkinson's disease, the alpha-synuclein protein misfolds," said Peter Andersen.



Peter Andersen discusses research with Helena Alstermark and Eva Jonsson.

HOPES FOR NEW TREATMENT OF CONGENITAL BRAIN DISORDERS

About one in two thousand children is born with a metabolic impairment, which often results in brain damage. Anna Wedell has carried out a high-tech genetic survey that has revealed the molecular basis for several new such disorders.

"Congenital metabolic disorders encompass many hundreds of unusual conditions. These disorders are often due to hereditary impairment of the body's chemical reactions. The brain is particularly sensitive, although most organs can be affected," explained Prof. Wedell, who is a senior physician and Professor of Medical Genetics at Karolinska Institutet. "Common symptoms are developmental delays, epilepsy or acute conditions that may cause premature death. Many congenital metabolic disorders are treatable if caught early, before irreparable damage occurs."

A phenylketonuria (PKU) test, performed on all newborns, is a blood test that can reveal 24 different congenital disorders, all of which are treatable. But there are several hundred known forms of metabolic impairment, for many of which there is still no effective treatment. Adequate statistical information is also lacking for many of these diseases. As a Wallenberg Clinical Scholar, Prof. Wedell will continue her detective work on these diseases.

ANNA WEDELL

Senior Physician and Professor of Medical Genetics at Karolinska Institutet.

Wallenberg Clinical Scholar 2015

Main area of research: The molecular basis of congenital metabolic disorders.

TECHNICAL REVOLUTION

"Diagnosis of hereditary disorders is being revolutionized now, thanks to new methods of analyzing DNA," she said. "My research team has developed a method for swift and reliable diagnosis of all known monogenic diseases—a revolution for those families affected, who can now receive the right diagnosis and treatment at an early stage."

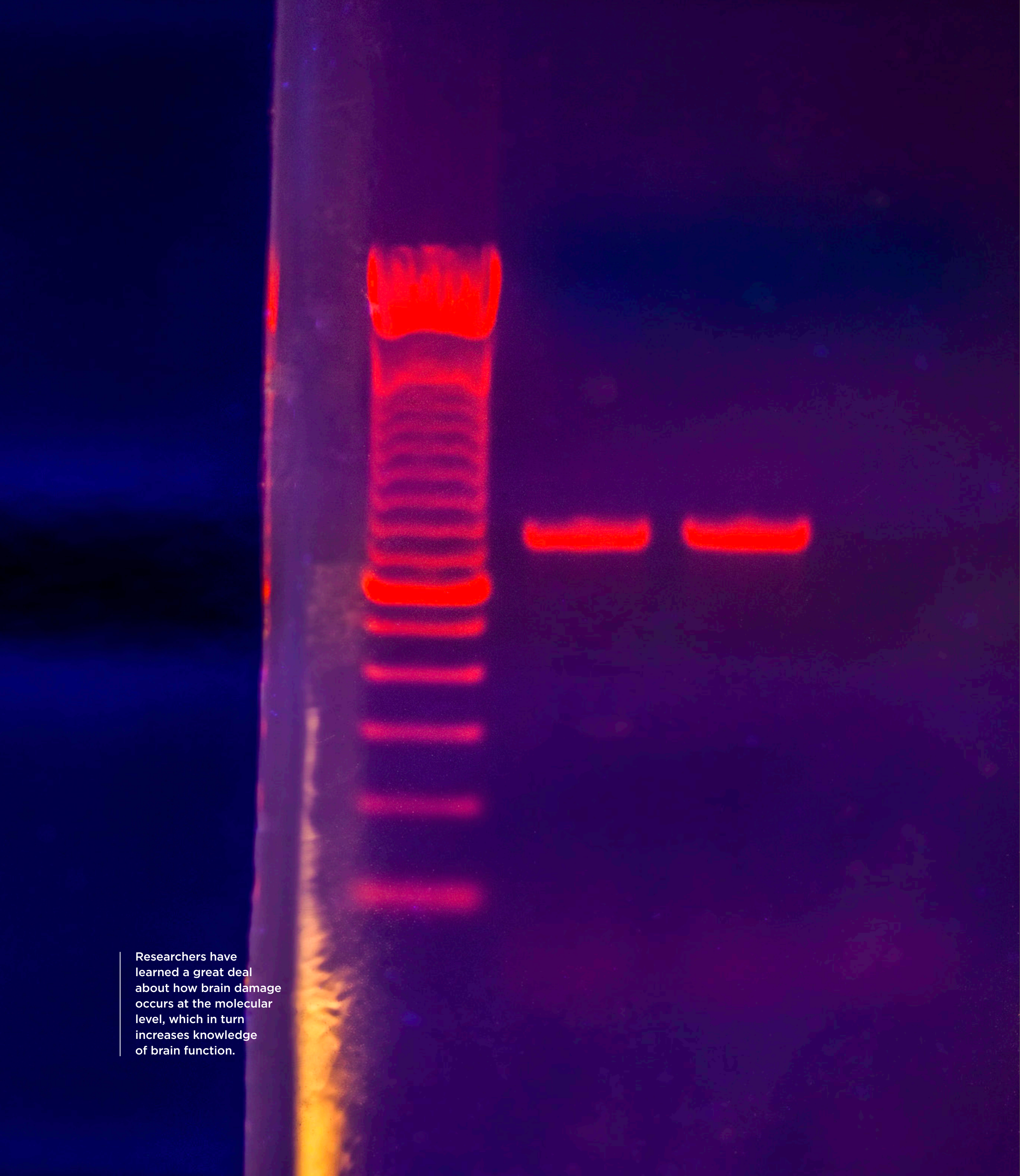
Monogenic disease is the term used for a disease caused by a single defective gene. One such disease is phenylketonuria, the disease for which the first PKU tests were created.

Prof. Wedell and her team want to transform diagnostics for congenital metabolic disorders, which represent 10–15 percent of monogenic diseases.

"Basically, we want to discover new diseases, identify disease mechanisms, and develop new treatments for sufferers," she said.

She believes they have good prospects for success: "We've been saving unique patient material for many years. We've also created a strong interdisciplinary environment combining technical, genetic, biochemical, and clinical expertise. I think we have a unique opportunity

Anna Wedell and her research team want to develop tests for more congenital illnesses in newborns.



Researchers have learned a great deal about how brain damage occurs at the molecular level, which in turn increases knowledge of brain function.

to translate our basic scientific discoveries into immediate benefits for our patients."

PIONEERING TREATMENT

The research team has already presented new findings.

"We've discovered a number of completely new disorders," Prof. Wedell said. "Children with these disorders had all undergone prolonged investigations over many years without result. Our new findings have had a number of positive effects. Families have been told what caused their children to suffer serious brain damage. And we have learned a great deal about how the damage is caused at the molecular level, which in turn has improved our knowledge about how the brain works."

There was great excitement when her team's research resulted in a treatment that improved the brain function of a young girl with serious brain damage.

"Based on the disease mechanism we had identified, we devised a specific dietary treatment for the patient. The result was a dramatic improvement in the little girl's condition," Prof. Wedell said. The treatment compensated for the metabolic defect and, consequently, the girl's brain resumed production of myelin —the "white matter" of the brain.

"No treatment had previously been found to improve myelination, so this discovery is a major breakthrough," she remarked.

Prof. Wedell believes that numerous diseases and disorders are rooted in metabolic defects.

"Disorders of the mitochondrial respiratory chain are of particular interest, since impairment of the chain's function is involved in several common degenerative diseases of the nervous system, such as Parkinson's and Alzheimer's," she said. "By identifying the mechanisms behind rare hereditary diseases, and by studying models of those diseases, we will also be able to understand the metabolic components behind more common diseases. This will ultimately lead to new treatment principles." ■

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CONGENITAL DISORDERS TESTED FOR

Since the mid-1960s, the PKU test has been performed on all newborn infants in Sweden as soon as possible after they are 48 hours old. The aim is to find a number of rare disorders for which swift intervention is crucial.

Initially the test could diagnose five disorders, but since 2010 it has been possible to identify a further 19.

Out of approximately 100,000 babies born in Sweden each year, around 80 will have one or more of these disorders.

A number of diseases including Alzheimer's may be rooted in metabolic defects. Elisabet Venyike studies a sample in Anna Wedell's laboratory.

STRENGTHENING IMMUNE DEFENSES AFTER BONE MARROW TRANSPLANTS

Bone marrow transplant patients receive the makings of a completely new immune system. But patients are susceptible to infections because their new defenses are not complete. Joan Yuan has discovered why.

Bone marrow is a key part of the immune system. It contains stem cells that can transform into various kinds of white blood cells: immune cells capable of fighting infections. Patients with blood illnesses or undergoing cancer treatment can undergo bone marrow transplantation, in which a patient's own stem cells are replaced with those of a healthy donor.

But studies in mice demonstrate that crucial differences emerge when an adult donor's stem cells begin to form new immune cells. Certain cell types are not regenerated; they only form during the fetal stage, and we carry them with us throughout our lives. Hence adult stem cells do not possess the same abilities as fetal stem cells.

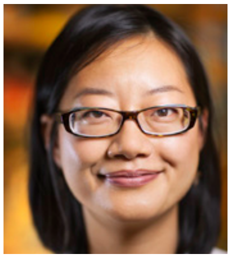
AN EXPLANATION IN A MISSING PROTEIN

During her postdoc in the U.S., Dr. Yuan found the reason why.

"I found a protein that is only present in fetuses and not in adults. It has been shown to play a central role in these cells' regeneration," she said.

Proteins are needed for virtually all activities in living organisms. The one Dr. Yuan found regulates RNA molecules, most of which act as protein-encoding messengers in cells. But they do more than that.

"RNA is essential in the regulation and control of genes, for example when fetal stem cells are developing. This has not been sufficiently clear to researchers before," she said.



JOAN YUAN

Doctor in Immunology, Lund University.

Wallenberg Academy Fellow 2013

Main area of research: Developmental biology and immunology.

EASY TO REPROGRAM

Genes encode all proteins, but proteins can only be formed when the genes encoding them are active. Some genes are only "switched on" for a certain time in life; others are only active in certain types of cells.

The gene for the RNA regulating protein is normally only active at the fetal stage, but when Dr. Yuan and her colleagues activate it in cells of adult mice, the cells start producing the missing immune cells again.

The reprogramming itself was surprisingly straightforward.

"This protein on its own seems to be so powerful that adult cells immediately reacquire their fetal-like characteristics. It's rare to find something so clear and simple in biology," she said.

Joan Yuan discovered a protein in fetal stem cells that is not present in adult stem cells. That explains why adult stem cells cannot reproduce certain cell types.

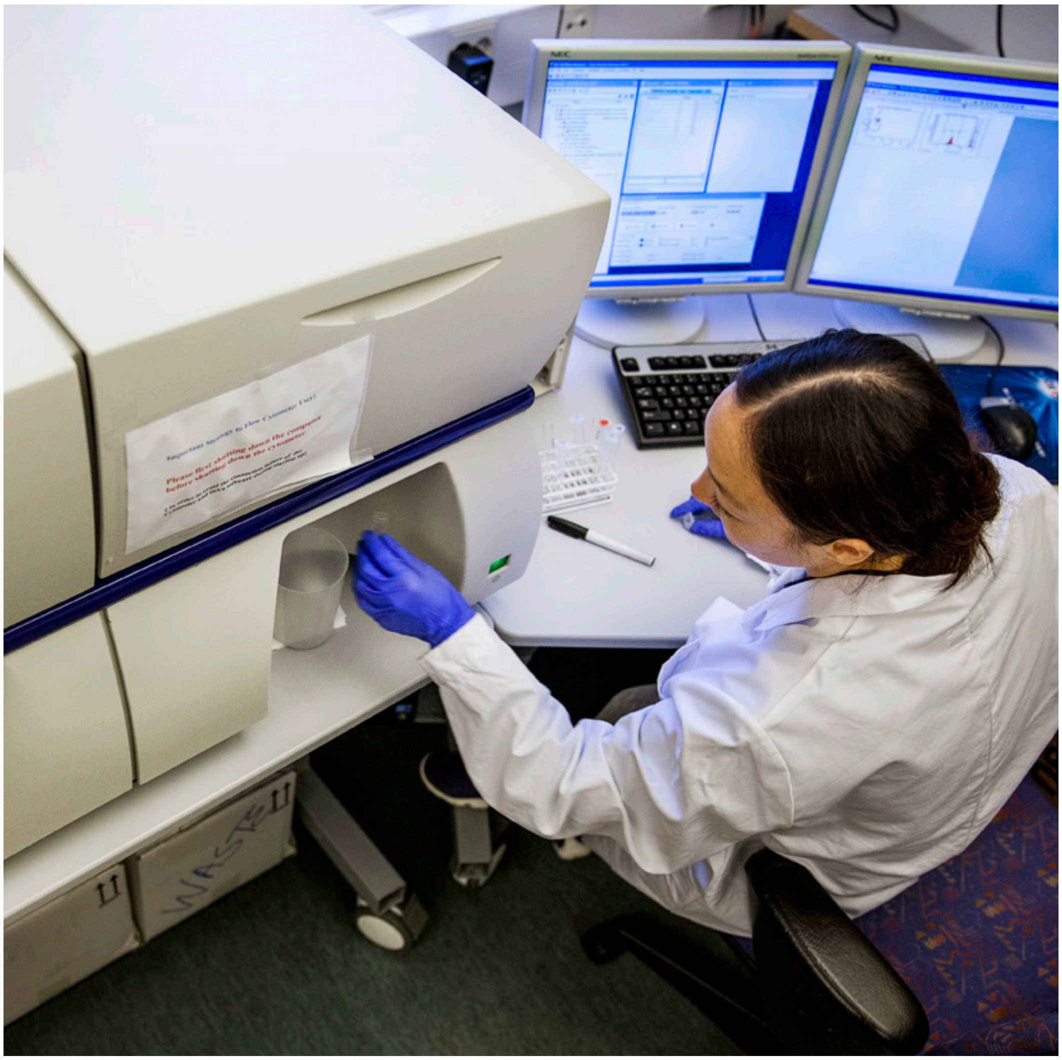
INTERNATIONAL CAREER

Joan Yuan was born in China but moved with her family to Lund, Sweden, when she was ten. She went to school there, and then studied for a degree in biomedicine. She then went to the U.S. as an exchange student at the University of Virginia. That was when she decided she wanted to do research.

Research in graduate school was followed by a postdoc, and Joan could have stayed in the U.S. But in Lund she found like-minded colleagues, and when she was accepted as a Wallenberg Academy Fellow she saw an opportunity to delve deeper into her chosen field.

"That was what made me decide to return to Sweden," she recalled. "I can't imagine a better arrangement anywhere than the one I have here. Right now I wouldn't want to trade places with my friends who have their own labs in the U.S."

Dr. Yuan hopes her research will help improve bone marrow transplant patients' immune systems and avoid many troublesome infections. Knowledge about stem cells may also lead to greater understanding of leukemia. But this lies several years ahead ∎



Trine Kristiansen at work in Joan Yuan's laboratory. Their research might help bone marrow transplant patients avoid harmful infections.

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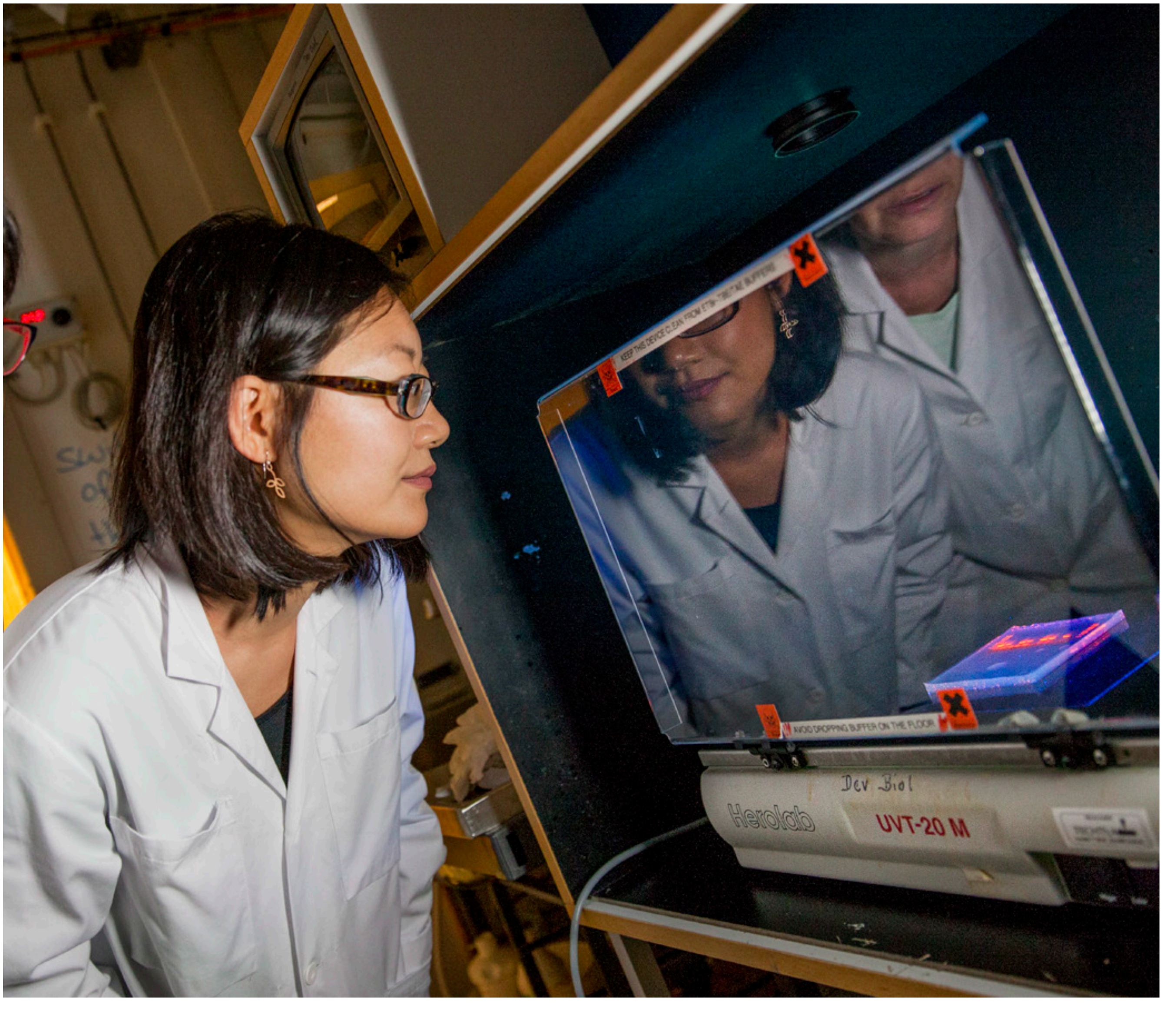
THOUSAND PROTEINS

An analysis of human DNA showed that humans have around 20,000 genes. Each gene generally encodes one specific protein.

Proteins are called the building blocks of life. They are present in nearly all cell components and involved in nearly all cellular processes, so they have many different functions.

A protein's function is determined by the sequence of its chain of amino acids. The chains are produced like a string of beads: the amino acids are added one by one to the end of the chain. Every time an amino acid is added, there are 20 to choose from. Genes determine which amino acid is added each time.



Joan Yuan says it is a great privilege to be selected as a Wallenberg Academy Fellow: "It gives me time and freedom to be creative, as well as the opportunity to compete in the world of global research. The aim of the Foundation—to support curiosity-driven research—gives me faith in the future."

RECREATING ANCIENT CHANNELS AND CANALS IN LUXOR

Did the artificial harbors and canals depicted in Egyptian tombs actually exist? Angus Graham is studying how the Egyptians shaped their surroundings. He uses geoarchaeological and geophysical methods to reconstruct ancient canal systems in Luxor and elucidate their functions in the social and religious contexts of that time.

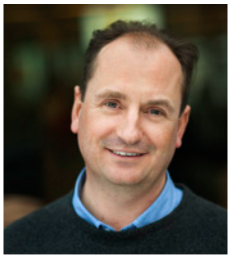
There are scenes in Egyptian tombs near Luxor that depict ceremonial boats taking part in religious processions. The scenes in the tombs also show there were harbors in front of temples and palaces, connecting them to the Nile via canals.

"But we don't know whether they really existed, or whether they are merely idealized visions," Dr. Graham says. "That's what I'm trying to find out."

RELIGIOUS SIGNIFICANCE OF THE CANALS

Angus Graham developed a fascination with Egypt when he traveled around the country as a young man. He later studied archaeology at University College London. In 2002 he began studying the extensive Karnak temple complex, and in 2010 the project was expanded to include the area on the west bank of the Nile.

"There are over 20 temples in the area. Our aim is to understand the degree to which the Egyptians were able to change the waterscapes for their own purposes, and to produce an idea of what the landscape looked like in different eras. It is also a question of learning more about the significance of the canals in religious festivals," he explained.



ANGUS GRAHAM

Doctor in Archaeology and Ancient History, Uppsala University.

Wallenberg Academy Fellow 2013

Main area of research: Analyzing ancient waterscapes and their function in Luxor, Egypt.

Luxor is listed as a UNESCO World Heritage Site. In ancient Egypt the area was a fertile, varying landscape created by the annual flooding of the Nile. The flooding stopped when the Aswan High Dam was built in the 1960s.

Over 2,000 years ago, Thebes (Luxor) was a very important political and religious center, and a number of temples were built to honor the god Amun.

"The canals probably made it possible to transport building materials. We know the Egyptians could transport heavy limestone and sandstone blocks, as well as gigantic statues and obelisks. We are now trying to understand the extent to which the Egyptians were able to manipulate the course of the river as well," he said.

NEW CLUES FROM SATELLITE IMAGERY

Dr. Graham's research team is using a number of geophysical and geoarchaeological techniques to map the history of Theban floodplain. These include taking sediment core samples (unbroken sections of sediment taken from the ground). The researchers then study the sand and clay content of the sediment to determine how and when it was deposited.

Archaeologists use geo-radar, sediment sampling, and other techniques to analyze the temple site.

Images from Google Earth led the team to carry out and study core samples from the area, which proved an ancient waterway was a natural channel, not humanmade. Benjamin Pennington takes sediment samples on the Nile floodplain.

"We use the core samples to understand the nature of the environment and the location of the banks of the Nile at that time. We often also find pieces of broken pottery in the samples. These provide invaluable chronological information," he noted.

Old maps, aerial photographs, and satellite images are also used in the project. Dr. Graham pointed to a satellite image on his computer, explaining that an unexpected discovery was made in spring 2014.

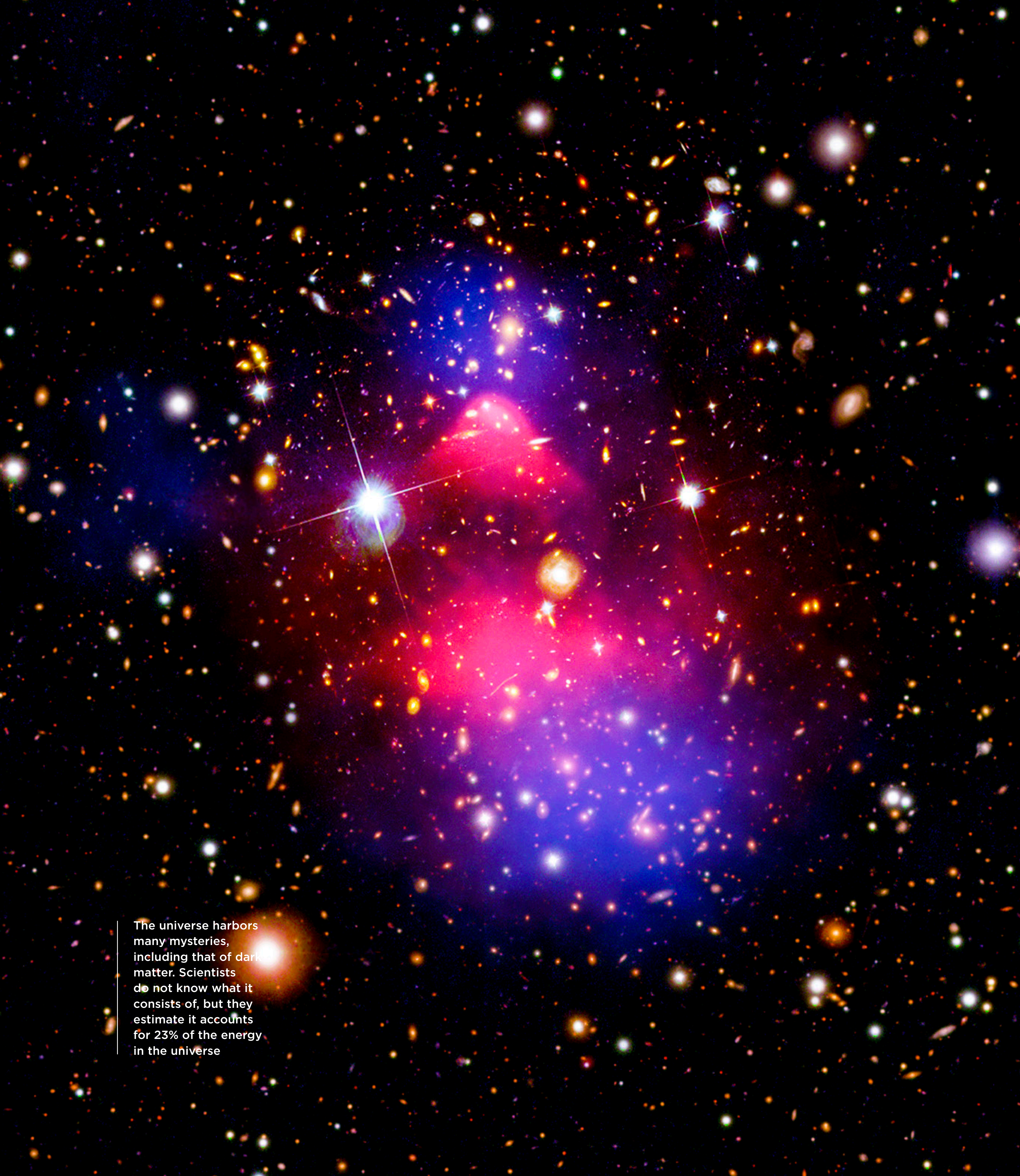
"While preparing to do some fieldwork, a member of the team had a look at some recently released Google Earth images and saw a faint difference in the ground color close to one of the temples we are studying. We thought it showed an ancient channel that had been filled in," he recalled.

The research team traveled to Egypt and tested their hypothesis. Using sediment samples they produced a cross-section of the area, and by examining the sediment sequences they could see they had discovered a natural channel.

"This is a really important find for us, since it means that canals may not have been needed for the temples," Dr. Graham said. "Our examination of ceramic fragments has shown that the natural channel was contemporaneous with the temples built between 1500 and 1150 BCE and was located less than 200 meters to the east of the temples." ■

LUXOR
is located in Upper Egypt. It was called Thebes in ancient times. Thanks to the city's significance as a political and religious center in various historical eras, it is considered an archaeological treasure trove. In addition to a number of temples, the Valley of the Kings and the Valley of the Queens are nearby

"For someone working in the humanities and doing so much fieldwork to be given such long-term funding is invaluable," said Angus Graham.



The universe harbors many mysteries, including that of dark matter. Scientists do not know what it consists of, but they estimate it accounts for 23% of the energy in the universe

CAN SUPERSYMMETRY EXPLAIN DARK MATTER?

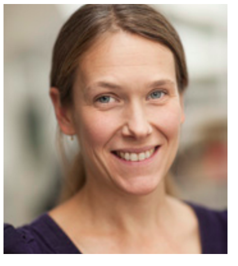
Sara Strandberg has been drawn to the unknown and driven by a desire to understand the world. Now she is searching for something that might not even exist: the supersymmetric partner of the top quark. If she finds it, she will be able to explain dark matter, and solve several other mysteries of the universe.

"I started studying veterinary science, but while my fellow students were talking about intestines I sat wondering what would happen if I fell into a black hole. So I changed my major to physics instead," she recalled.

Modern physics was where she found a place to study the big issues that have always interested her: why does Earth look like it does? How was the universe created? And how do we fit into the global scheme of things?

"Even as an undergraduate I was drawn to particle physics, since that's the sub-field that deals with the totally unknown. It's a scientific field in which it's still possible to make discoveries that nobody has ever thought of before," she explained.

Particle physics involves the study of the very smallest constituents of matter, known as elementary particles, and the forces acting between them. As a grad student, Strandberg studied one of the elementary particles, known as the top quark, at the Fermilab particle accelerator facilities near Chicago.



SARA STRANDBERG

Associate Professor of Physics, Stockholm University.

Wallenberg Academy Fellow 2013

Main area of research: Experimental particle physics.

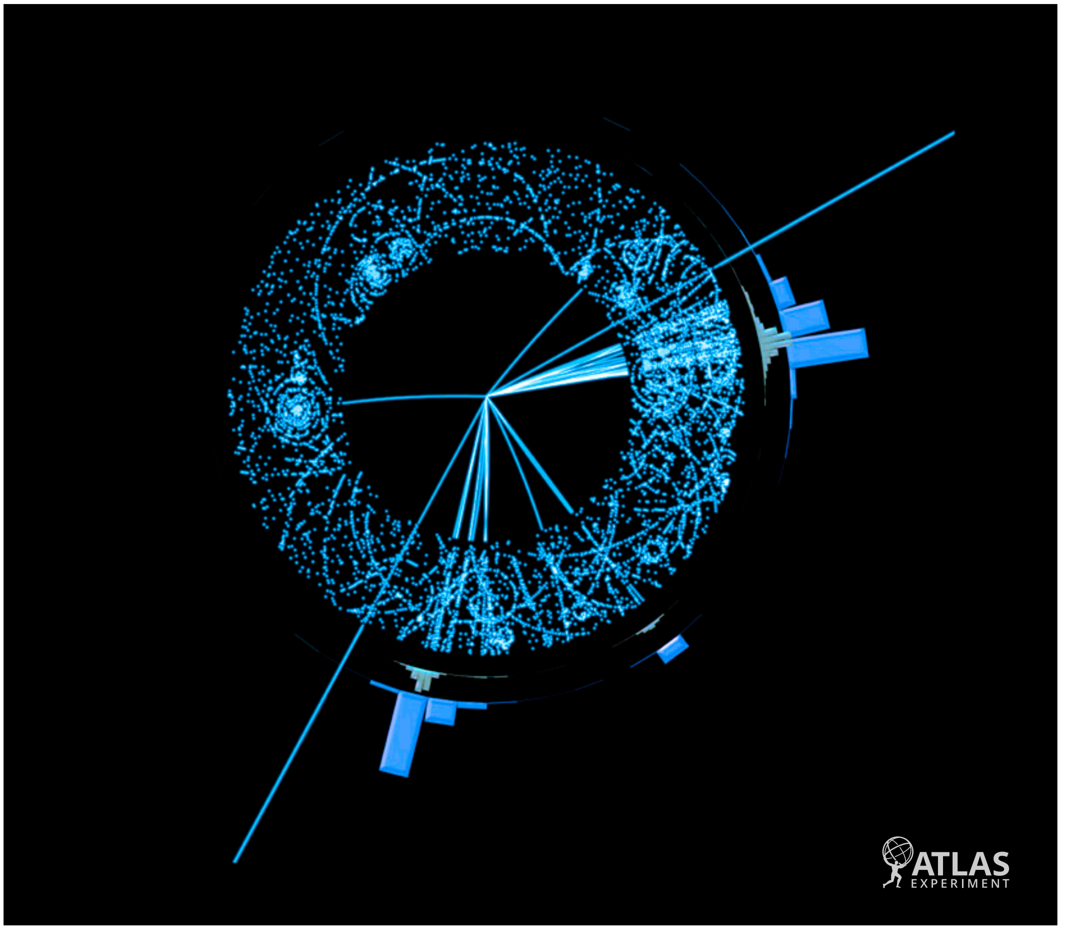
THE STANDARD MODEL

Elementary particles and their interactions in the form of electromagnetic, strong, and weak nuclear forces are described in the "Standard Model." This model has been highly successful as a "theory of almost everything," but it has become increasingly obvious that it is not a comprehensive model. For instance, it does not incorporate gravity, nor does it describe the constituents of dark matter.

All members of the large research teams at CERN in Switzerland are currently trying to work out how to expand the Standard Model to make it more complete.

"To put it simply, we need to expand this theory in order to explain many things we don't understand, such as why dark matter exists, and what it is made of," Dr. Strandberg explained.

She currently has a central role in the ATLAS experiment at CERN. As a Wallenberg Academy Fellow, she aims to help establish how the Standard Model can be extended to better describe our world. To this end, she is conducting research into supersymmetry.



Simulated supersymmetry at the ATLAS project at CERN.

Z

W & X BOSONS

Elementary particles—the smallest components of matter—can be categorized as fermions or bosons.

Bosons are the carriers of the four fundamental forces: the strong force, the weak force, the electromagnetic force, and gravity.

The observed bosons are W and Z bosons, photons, and the recently confirmed Higgs boson. There are also two hypothetical types: gravitons, which explain gravity, and X bosons, which are included in some theories but not the Standard Model.

What, then, is supersymmetry? Well, elementary particles can be divided into fermions and bosons. Fermions comprise quarks, electrons, and neutrinos, i.e. particles that make up matter. Some bosons, such as the photon, and the W and Z bosons, are mediators of the fundamental forces. The theory of supersymmetry is a potential extension of the Standard Model, postulating that each elementary particle has a "supersymmetric partner."

DARK MATTER CANDIDATE

There are a number of indications that the supersymmetry theory is right. First of all, supersymmetry can provide a particle that is a dark matter candidate. Supersymmetry can also help to unify the fundamental forces of nature.

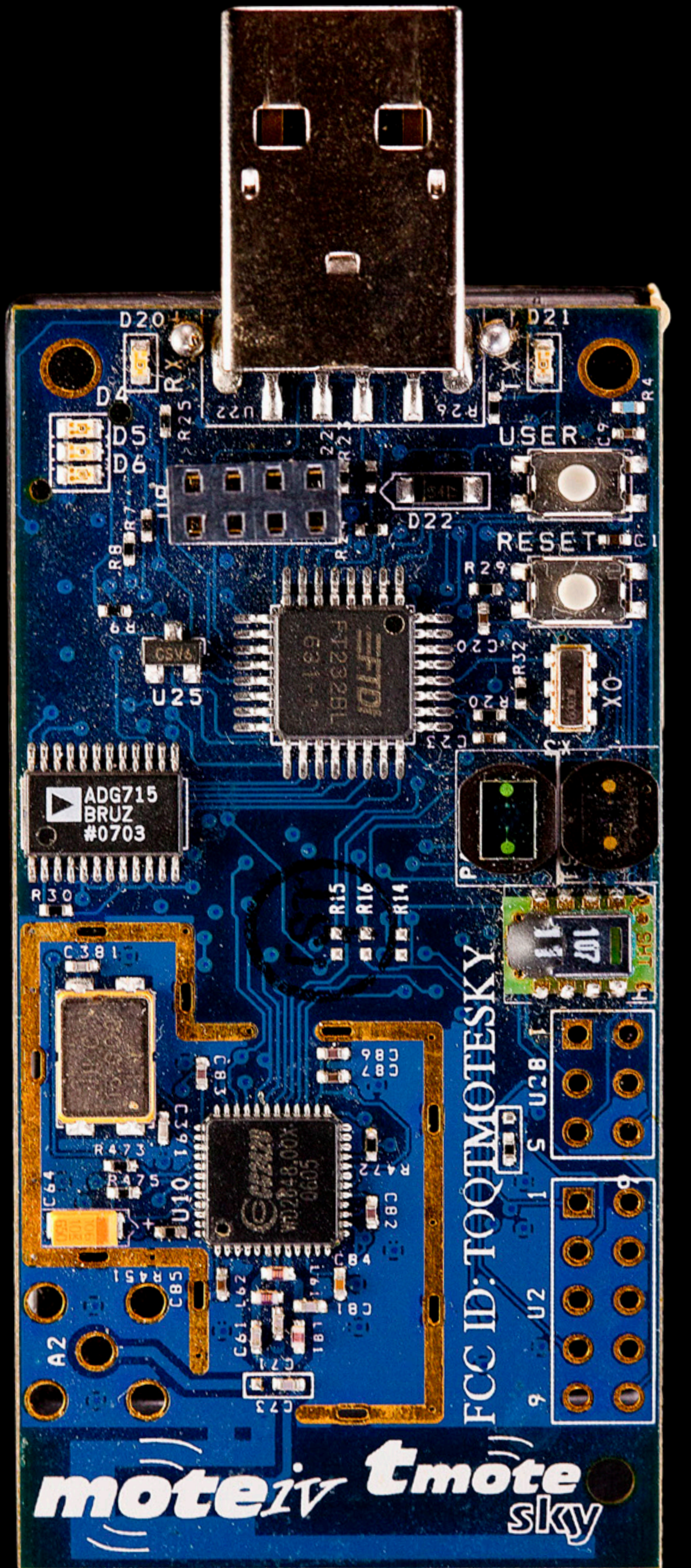
"I'm definitely not 100 percent convinced that supersymmetry exists—we just don't know," Dr. Strandberg said. "All we're doing is trying to find deviations from the Standard Model, something that's not consistent with the Standard Model's predictions. Supersymmetry is a very good way of looking."

More specifically, she intends to use data from the ATLAS experiment to look for the supersymmetric partner of the top quark, i.e. a boson.

"If we find it, we will have proved the supersymmetry hypothesis, and if we find any of the supersymmetric particles at all, we will also in all probability have explained dark matter," she summarized ■

Sara Strandberg says the grant means a great deal: "I have now been able to employ two post-doctoral researchers. Expanding the team is important, because we can now pursue our own goals. We can also work on several levels. This will enable us to be key players in the hunt for new particles, and that feels great."

Sara Strandberg and Veronica Wallängen study some experimental results.



It is estimated that 50 billion objects will be connected to the internet in 2020. A challenge is to create secure wireless systems using sensor modules like Tmote Sky.

MORE SECURE WIRELESS SYSTEMS

A more "intelligent" society is now being shaped with the help of wireless sensor technology. More and more things are being connected to the internet. This brings great advantages, but also involves security risks. Panagiotis Papadimitratos is examining the security protocols of network systems and developing completely new solutions.

As many as 50 billion objects—from clothes and household appliances to power plants and vehicles—will be connected to the internet by 2020. When the Internet of Things (IoT) really gets going, it will have an enormous impact on society and our way of life.

"More and more computer components and sensors are embedded in our everyday environments where we live and work. But state-of-the-art technology is not necessarily secure," Dr. Papadimitratos pointed out.

His research is driven by the desire to ensure everyone who uses the new wireless technology feels secure.

"It's essential to be able to rely on systems," he said. "We shouldn't be afraid of falling victim to a hacker attack."

BIGGER SYSTEMS CREATE NEW PROBLEMS

Dr. Papadimitratos received his master's degree in Greece, his native country, and then completed his Ph.D. at Cornell University. Before joining KTH Royal Institute of Technology in 2010, he conducted research at École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland.

PANAGIOTIS PAPADIMITRATOS

Associate Professor, KTH Royal Institute of Technology.

Wallenberg Academy Fellow 2013

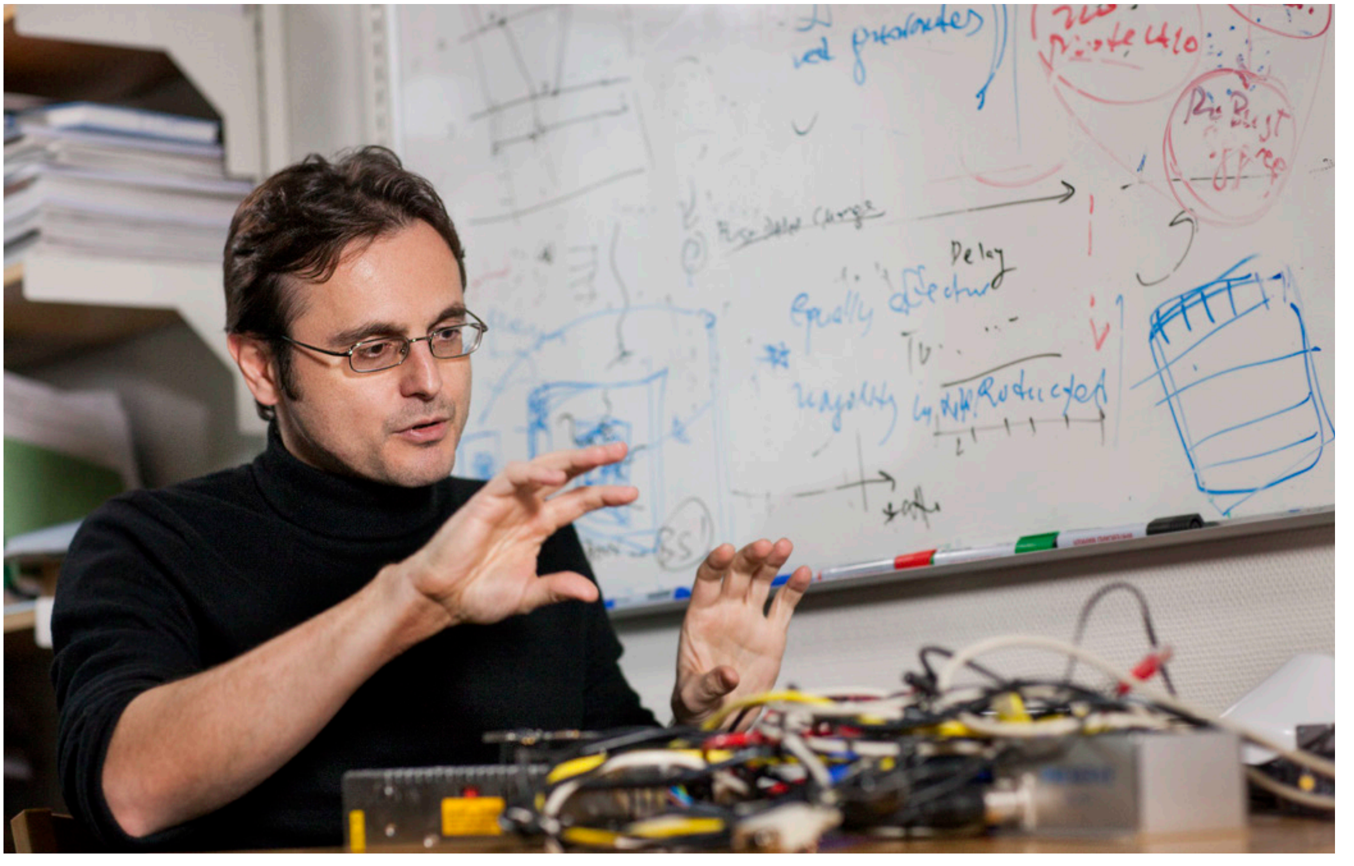
Main area of research: Wireless networked systems security.

He straddles the disciplines of computer science and electrical engineering, a good combination as leader of the NSS (Networked Systems Security Group) research team at KTH. His research involves examining and creating new security protocols for wireless network systems. Protocols are the rules governing how networks or computer software work and communicate with each other.

Connected networks offer huge potential benefits to society, such as more efficient industrial operations. Wireless sensor technology is also being rapidly developed for use in transportation and health care. Dr. Papadimitratos explained that new challenges will arise in the next few years, when these systems are gathered under the IoT umbrella: "Making this massive future network system reliable will entail a paradigm shift in IT security."

He said the difference is that there is no longer a large machine in a server room that is under a single control system.

"All of a sudden we have large numbers of components capable of interacting, which may impact individual privacy. We need to



"I will have more opportunities to talk about my research. I am no longer an island—I am a member of a larger community," says Panagiotis Papadimitratos.

add to the traditional security tools and define new solutions that protect the system itself, the application, and users," he explained.

CONCRETE AND ABSTRACT

The security protocols the team is studying may come either from industry or academia.

Dr. Papadimitratos, describing a vehicle communication project he is involved in, said, "To improve efficiency on the road, we can install a special radio that enables our car to talk to other vehicles or infrastructure along the way."

The device provides information on the vehicle's position and movement, which can help prevent collisions before the driver even sees the danger.

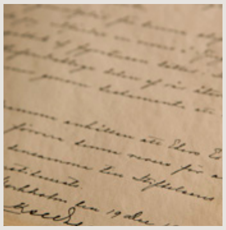
"The safety aspect has been incorporated right from the outset in developing this new sensor system," he said. "We were invited at an early stage to communicate both with standardization bodies and the industry and were able to influence the design." ▪

IOT—INTERNET OF THINGS
is a general term applied to the interconnection of machines, vehicles, devices, and clothing through small built-in sensors and computers. This enables them to recognize and communicate with their environment and adapt their behavior accordingly. By 2020, an estimated 50 billion units will be connected around the world.

The future is wireless. The need for security increases when there is not just one machine in a room but billions of integrated objects to be protected.

Knut and Alice Wallenberg at the grand opening of the Swedish National Museum of Science and Technology in 1936.

1917
December 19
The Foundation established



1918
March 21
Bylaws adopted

Knut and Alice Wallenberg Foundation

1918
March 30—First grant awarded:
Stockholm Public Library

1919
Combating
the Spanish flu
epidemic,
Red Cross

1920
School for Home Economics, 1986:
Crown Princess Margaret Memorial Foundation

1921
The first academic grants
awarded

1922
Studies in Macroeconomics,
Lund University

1923
Construction of main building,
Stockholm School of Economics

1924
Litteris journal, scientific
societies in Lund

1925
SSHL boarding school
founded

1926
Johan Skytte
Professorship,
Uppsala University

1927
Biochemistry lab, 1929 Nobel laureate in Chemistry,
Hans von Euler, Stockholm University College

1928
Amendment of bylaws
in line with Swedish
legislation on foundations

1928
Observatory, Saltsjöbaden, Royal
Swedish Academy of Sciences

1929
Fishery laboratory in Lysekil,
National Board of Fisheries

1930
Studies in Astronomy,
Karlstad teacher
training college

1931
Construction of Maritime Museum, Stockholm

1931
Plant breeding, chromosome research in Svalöv, Swedish Seed Association

1932
Student union buildings, Stockholm University College and Stockholm School of Economics

1933
Construction of Swedish National Museum of Science and Technology

1934
Egg marketing grants, promotion of Swedish products abroad, agricultural attaché in London

1935
Royal Swedish Academy of Sciences research institute for experimental physics, 1924 Nobel laureate in Physics, Manne Siegbahn

1935
Project grant to 1926 Nobel laureate in Chemistry, Theodor Svedberg, Uppsala University

1936
Research on etiology of silicosis, Stockholm University College

1937
Construction of Swedish Institute in Rome

1938
June 1
Death of Knut Wallenberg

1938
Experimental soybean crops, Swedish Seed Association

1939
Plant breeding and experiments with agricultural and garden plants and fruit trees on the Ekerum estate, Öland, Kalmar County Rural Economy and Agricultural Society

1940
Establishment of Institute of Neurophysiology, 1967 Nobel laureate in Medicine, Ragnar Granit, Karolinska Institutet

1941
Balsgård, institute for plant breeding for experimental fruit and berry crops, Swedish University of Agricultural Sciences. The "Alice" apple variety was developed here.

GRANTS AWARDED 1917—1941: SEK 26 MILLION

Knut and Alice Wallenberg loved nature and the sea. Here they are walking on the beach with their dog.

THE FOUNDERS

Knut and Alice Wallenberg

Over the years, Knut and Alice Wallenberg had built up a sizable fortune. In addition to financing various construction and public development projects, they, like most other wealthy people in those days, provided grants and donations to needy people and organizations. Handling private donations grew more time-consuming, so the idea of setting up a foundation to handle the grants started to take shape. The structure of a foundation also meant the large endowment would remain in place after their deaths, thereby continuing their philanthropic intentions, rather than being split among several heirs.

KNUT WALLENBERG

Knut Agathon Wallenberg (1853–1938) was a banker, politician, and philanthropist. After his officer training at the School of Naval Warfare, he was elected to the board of directors of Stockholms Enskilda Bank in 1874. When his father died in 1886, he was named president of the bank.

During his tenure as president, Knut Wallenberg strove to consolidate the bank following the crisis years of 1878–79 and established a comprehensive international network of contacts. He resigned as president in 1911 and served as chairman of the board until his death in 1938, except during the period 1914–17, when he was foreign minister of Sweden.

The year 1917 was something of an *annus horribilis* for him. He had been named foreign minister in the spring of 1914 in a non-parliamentarian government headed by county governor Hjalmar Hammarskjöld as prime minister. The idea was that it would quickly resolve a politically sticky question about Sweden's defense. War broke out that fall, and the government was forced to remain in power for three conflict-filled years. In his own words, Knut was stuck "wearing a straitjacket." The war years were a strain, and after three years the government was forced out. In that time, Knut had not persuaded the government to support his efforts concerning what he saw as the main priority: concluding a trade agreement with the United Kingdom. He felt let down by his colleagues and the leader of the Conservative Party, Arvid Lindman. In addition, in the fall of 1917 the Swedish and international press accused him of some embarrassing blunders in the foreign ministry during the war.

Knut Wallenberg was in his 65th year and simply exhausted. He had had the idea of starting a foundation in the past, but now he felt it was high time to start thinking about what would happen when he and his Alice were gone; they had no children.

At that time he was a wealthy man—one of the wealthiest in Sweden. For a quarter-century, between 1886 and 1911, he had been the head of Stockholms Enskilda Bank and was very active in the many projects pursued by the Wallenberg family and the circle around the bank during these years. He had inherited an entrepreneurial tradition from his father André Oscar, along with his position at the bank, but it cannot be said that he inherited his fortune. He had five brothers, but he was clearly the richest of them all. He had created his wealth himself.

With his language skills, analytical mind, and a good dose of boldness, he had established himself as one of the major organizers of capital imports to Sweden in the late 19th century. Above all, his good contacts with French banks were the key to his business profits. Furthermore, he had been a major player during the industrial transformation and exploitation of natural resources in both Sweden and Norway around the turn of the century. He had made huge investments in developing forest industries, mines, and power plants.

There were other bold entrepreneurs during these years, but most of Knut's competitors had disappeared when their inventions fizzled and their speculations got out of hand. He, on the other hand, had seen his fortune grow, especially in the form of shares in his increasingly profitable bank. By buying more and more lots, as the shares were called at the time, in the bank, he had cemented it as a family bank, which it would remain until it merged with Skandinaviska Banken in 1971, creating today's SEB. The family's influence would later increase further. But at that time, in 1917, his brother Marcus was running the bank, and Knut had been set aside.

Partly because Knut Wallenberg had become well known during the war years, the number of "begging letters" was growing. Like most other wealthy people, he supported both needy individuals and public establishments with grants and donations, but they had to be reviewed, decisions needed to be made, and answers delivered. It became ever more burdensome, and he complained: "... petitions for support for this, that, and the other are falling like a torrential fall rain that no umbrella could cope with. I am inclined to give away most of my fortune at once, in order to be left alone and to simply say no to everyone."

In other words, the creation of the KAW Foundation was a defensive move motivated by exhaustion. But it would soon prove to be the start of a new and active period in Knut Wallenberg's life. For two decades, he would devote himself with gusto to his Foundation. This work would bring new meaning and joy to his life. Or, as he put it in a letter to Sweden's Crown Prince Gustaf Adolf in 1937, when his Foundation had donated funding for the Swedish Institute in Rome to construct its own premises: "Maybe it is egotistical to give while one is still alive but oh, what fun it is."

KNUT AGATHON WALLENBERG

Knut's path through life was set early: boarding school, navy officer training, business school, Crédit Lyonnais in Paris. President of the family's bank at age 33; Chairman of the Board 25 years later.

It was he who got the bank back on its feet after the serious crisis of 1878–79 and created the unique Wallenberg family tradition.

Read more about his life in the biography by Ulf Olsson: *A Prince of Finance, K A Wallenberg 1853–1938*.

Alice and Knut Wallenberg on board their steam schooner, the *Fujiyama*, purchased in 1898.

Knut Wallenberg with his dogs on a hunting trip. Skalstugan, Jämtland, Sweden.

As a widow, Alice Wallenberg recommended causes she thought the Foundation should support.

Alice and Knut Wallenberg with friends on the terrace of Villa Täcka Udden.

ALICE WALLENBERG (*NÉE* NICKELSEN)
Alice Olga Constance Nickelsen (1858–1956) was born in Kristiania (the former name of Oslo), Norway. Her father, Nicolai Gottfried Nickelsen, was a businessman, and her mother, Sophie Budde, was originally from Germany. Alice's father, who had inherited the family's shipping and trading company, got involved in speculation on the coffee market. His activities ended in bankruptcy and suicide in 1866. Alice's brother, Oscar, and sister, Jennie, both remained childless.

The family landed in straitened circumstances. Alice, who had a fine voice, started taking singing lessons. In 1875 an opera company was launched at the Christiania Theater as part of the efforts to establish Kristiania as a cultural capital on a par with Copenhagen and Stockholm. Some of the singers were brought over from Sweden, including the tenor Fritz Arlberg, who became the opera company's unofficial musical director. He sang the title role in the company's opening production of Mozart's *Don Juan*. The following season featured Wagner's *Iphigenia in Aulis*. Appearing in the title role was Arlberg's pupil Alice Nickelsen, who was taken on as a member of the company and sang the part of Cherubino in *The Marriage of Figaro* the following spring. Friends of the family set up a scholarship fund to enable her to receive further training in Paris. In the spring of 1877, she arrived in the French capital and began her studies at the Conservatoire National de Musique. On January 3, 1878, she met her future husband, Knut Wallenberg, at a reception hosted by the Swedish-Norwegian military attaché. A few weeks later Knut proposed to Alice, whom he called his "little troll." They announced their engagement on March 20 and were married on October 10 that same year in the Trinity Church in Kristiania.

In 1888, Knut purchased the property at Täcka Udden on the island of Djurgården in Stockholm. Alice devoted herself to cultivating fruit and vegetables. New greenhouses were built, along with a cottage for a master gardener. Knut and Alice Wallenberg had previously been involved in gardening and farming at Malmvik, a farm owned by the Wallenberg family. Alice accompanied Knut on his travels, and in 1906–07 they and their foster daughter Nannie undertook a six-month journey to the Far East on board the vessel *Birma*.

Alice and her husband founded the Knut and Alice Wallenberg Foundation in 1917. Alice never held a position on the Foundation's Board of Directors, but she did propose many causes for the Foundation to support throughout her life. In the 1940s, the Foundation began to provide support for Balsgård, a fruit plant breeding and research facility. A new variety of apple developed there in the 1950s was named Alice. It was registered in 1962 and is a medium-sized fruit, almost entirely red, with fine-grained, white, juicy flesh and a mild, tart flavor. Alice apples ripen in early September, and the variety is a popular choice in commercial orchards and domestic yards. It was bred from the Ingrid Marie variety and is suitable for use in cooking before it is completely ripe.

For their golden anniversary, Knut and Alice donated SEK 50,000 (around SEK 1.5 million in today's money) toward stained-glass windows in the Trinity Church choir loft. The sum was put toward five large stained-glass panels by Frøydis Haavardsholm ∎

ALICE WALLENBERG *NÉE* NICKELSEN

Alice Nickelsen was Norwegian. She began taking singing lessons in Oslo and continued training to be an opera singer at the Conservatoire National de Musique in Paris after friends of her family set up a scholarship fund.

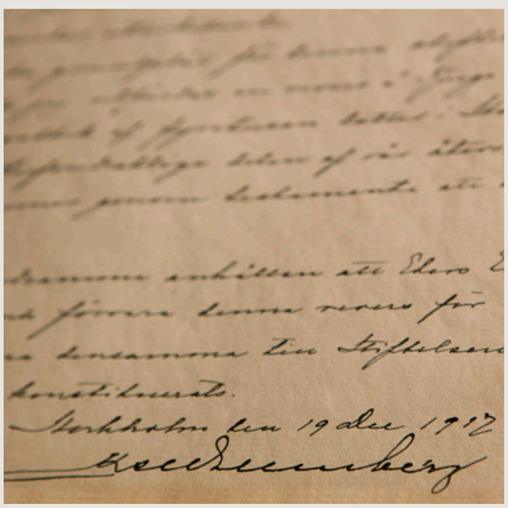
She met Knut Wallenberg in 1878 at the home of the Swedish-Norwegian military attaché in Paris.

After their marriage, Alice continued to sing only for family and friends.

BENEFICIAL TO THE NATION

Supporting Swedish research and education

When, on December 19, 1917, Knut and Alice Wallenberg signed the documents establishing the foundation that would bear their name, they declared that the purpose of the Foundation would be not only to support scientific endeavors, but also to promote trade, forestry, industry, and other commercial activities in Sweden. These aims were included in the Foundation's first bylaws, dated March 20, 1918, and remained until the the bylaws were amended 10 years later in conjunction with new legislation.


Stockholm den 19 dec 1917

Memorandum of association establishing the foundation, dated December 19, 1917.

Since 1928, the Foundation's stated purpose has been to promote scientific research and education that is beneficial to Sweden.

What does "beneficial to Sweden" mean? According to the Swedish Academy Dictionary, the Swedish-language word used in the bylaws is an archaic, poetic term that means that something is of practical use to the nation.

BENEFICIAL TODAY

Research today is increasingly complex and global. Obtaining new knowledge requires collaboration between outstanding researchers, across national borders. Internationalization is a guiding principle—not just at Swedish universities, but also around the world. Exchanges between researchers, graduate students, and undergraduates are ever more important.

Swedish research benefits from bringing in skills from other countries just as much as from researchers and students from Swedish universities who participate in research teams and educational settings abroad.

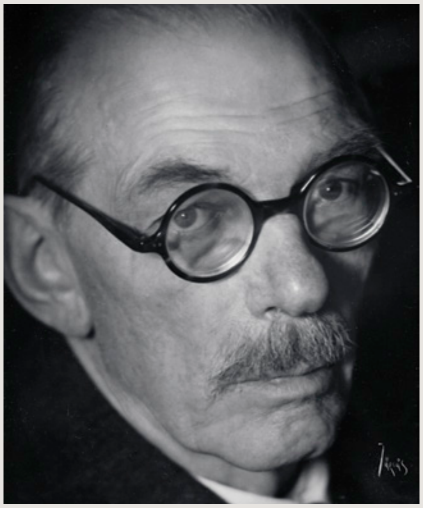
Today, "beneficial to Sweden" refers to what will contribute to Swedish progress in research and education. For many years, the Foundation's primary policy has been to fund research at Swedish educational institutions to help build international centers of knowledge that enhance Swedish higher education and research efforts ▪

FOREIGN MINISTER

Knut Wallenberg was appointed president of Stockholms Enskilda Bank in 1886. He resigned from that position in 1911 and then served as Chairman of the Board until his death in 1938, except during his term as Sweden's foreign minister from 1914 to 1917.

Sweden's Foreign Minister Knut Wallenberg on his way to an audience with the King at the Royal Palace in February 1914.

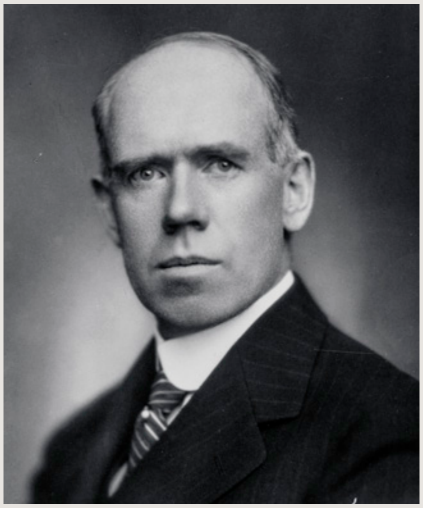
Knut Wallenberg



Marcus Wallenberg Sr

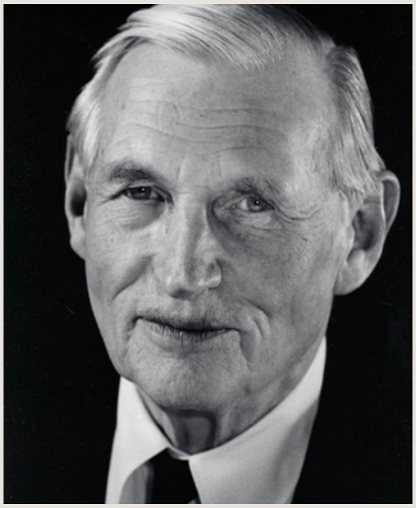
Johannes Hellner

Axel Wallenberg

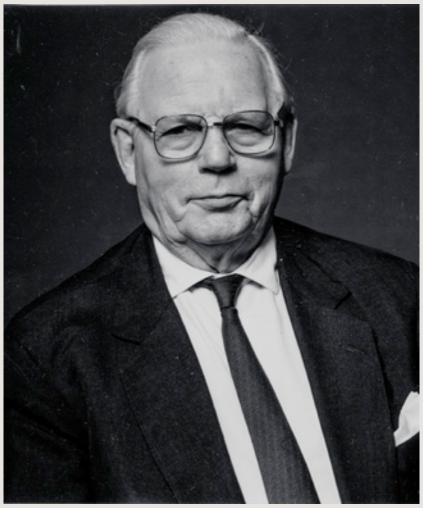


Nils Vult von Steyern

Jacob Wallenberg



Marcus Wallenberg



Peter Wallenberg

Peter Wallenberg Jr

CHAIRMEN OF THE BOARD

Knut Wallenberg *(1853–1938), Founder of the Foundation and first Chairman of the Board until his death in 1938*

1938–1943 Marcus Wallenberg Sr *(1864–1943)*

1944–1946 Johannes Hellner *(1866–1947)*

1946–1961 Axel Wallenberg *(1874–1963)*

1961–1966 Nils Vult von Steyern *(1887–1966)*

1966–1980 Jacob Wallenberg *(1892–1980)*

1980–1982 Marcus Wallenberg *(1899–1982)*

1982–2015 Peter Wallenberg *(1926–2015)*

2015– Peter Wallenberg Jr *(1959–)*

Peter Wallenberg Jr

EXECUTIVE DIRECTORS

Göran Sandberg

1918–1949 Josef A. Ekholm *(1886–1963) (Secretary)*

1949–1981 Oscar af Ugglas *(1901–1984) (Managing Director)*

1981–1991 Gunnar Hoppe *(1914–2005) (Executive Director)*

1992–2001 Jan S. Nilsson *(1932–2010) (Executive Director)*

2002–2009 Erna Möller *(f. 1940) (Executive Director)*

2010– Göran Sandberg *(f. 1955) (Executive Director)*


Josef A. Ekholm


Oscar af Ugglas


Gunnar Hoppe


Jan S. Nilsson


Erna Möller


Göran Sandberg

THE FOUNDATION'S FIRST BOARD OF DIRECTORS

Knut Wallenberg

Joseph Nachmanson

Otto Printzsköld

Marcus Wallenberg Sr

Oscar Wallenberg

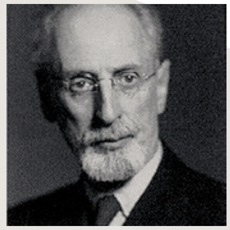
MEMBERS OF THE BOARD OF DIRECTORS

Knut Wallenberg, *Chairman 1918–38*
Otto Printzsköld, *Vice Chairman 1918–30*
Joseph Nachmanson, *1918–27*
Marcus Wallenberg Sr, *1918–43, Vice Chairman 1930–38, Chairman 1938–43*
Oscar Wallenberg, *1918–39*
Jacob Wallenberg, *1927–80, Vice Chairman 1961–66, Chairman 1966–80*
Johannes Hellner, *1930–46, Vice Chairman 1938–44, Chairman 1944–46*
Marcus Wallenberg, *1938–82, Vice Chairman 1966–80, Chairman 1980–82*
Axel Wallenberg, *1939–61, Vice Chairman 1944–46, Chairman 1946–61*
Robert Ljunglöf, *1946–50*
Nils Vult von Steyern, *1946–66, Vice Chairman 1946–61, Chairman 1961–66*
Marc Wallenberg Jr, *1958–71*
Arne Tiselius, *1966–71*
Ulf von Euler-Chelpin, *1971–83*
Peter Wallenberg, *1971–2015, Chairman 1982–2015*
Bror Rexed, *1973–78, Government Representative*
Birgitta Odén Dunér, *1973–85, Deputy Government Representative*
Lennart Stockman, *1976–86, Principals' Council Representative*
Christina Rogestam, *1978–83, Government Representative*
Gunnar Hoppe, *1981–91, Executive Director*
Sune Bergström, *1983–94, Vice Chairman*
Curt Nicolin, *1983–99, Vice Chairman 1995–99*
Anders Dahlgren, *1983–86, Government Representative*
Nils-Erik Wååg, *1985–95, Deputy Government Representative*
Gunnar Brodin, *1986–92, Principals' Council Representative*
Thorbjörn Fälldin, *1986–95, Government Representative*
Jacob Wallenberg, *1989–, Vice Chairman 1999–2001*
Marcus Wallenberg, *1989–, Vice Chairman 2015–*
Jan S. Nilsson, *1992–2001, Executive Director*
Håkan Westling, *1992–2000, Principals' Council Representative 1992–95*
Jan Holmgren, *1995–2016*
Mårten Carlsson, *1995–2001, Principals' Council Representative*
Björn Svedberg, *1999–2004*
Peter Wallenberg Jr, *1999–, Vice Chairman 2005–15, Chairman 2015–*
Axel Wallenberg, *2000–11*
Janne Carlsson, *2001–07, Principals' Council Representative*
Erna Möller, *2002–09, Executive Director*
Björn Hägglund, *2006–16*
Michael Treschow, *2007–*
Bo Sundqvist, *2007–13, Principals' Council Representative*
Göran Sandberg, *2010–, Executive Director*
Caroline Ankarcrona, *2012–*
Kåre Bremer, *2013–, Principals' Council Representative*

1942
Research into causes of adrenal gland insufficiency, Karolinska Institutet

1943
Study of the effect of liming on agricultural profitability, KTH Royal Institute of Technology

1944
Economic History of Sweden, Eli F. Heckscher



1945
Construction of laboratory, Swedish Seed Association

1946
Research on the Peace of Westphalia, Swedish Defense Staff

1947
The Institute of Jurisprudence Research in memory of Knut and Marcus Wallenberg

1948
Electron microscope, Karolinska Institutet

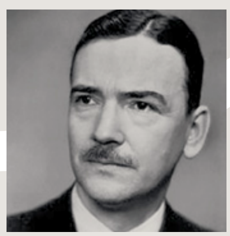
1949
Viruses in sugar beets, 1948 Nobel laureate in Chemistry, Arne Tiselius, Uppsala University

1950
Biochemical effects of radiation, 1943 Nobel laureate in Chemistry, George de Hevesy, Stockholm University

1951
Research on geomagnetic storms, 1970 Nobel laureate in Physics, Hannes Alfvén, KTH Royal Institute of Technology

1952
Institute for Forest Improvement, Swedish University of Agricultural Sciences

1953
Mechanisms triggering some forms of high blood pressure, 1970 Nobel laureate in Medicine, Ulf von Euler, Karolinska Institutet



1954
The influence of carbohydrates on dental health, Swedish National Board of Medicine

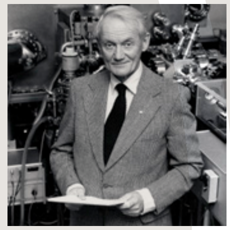
1955
Instruments for studying cancer diseases, Karolinska Institutet

1956
March 1
Death of Alice Wallenberg

1956
Metabolic problems in fat and other environments, 1982 Nobel laureate in Medicine, Sune Bergström, Lund University

1957
Spinco electrophoresis equipment, 1955 Nobel laureate in Medicine, Hugo Theorell, Karolinska Institutet

1958
Low-temperature equipment, 1981 Nobel laureate in Physics, Kai Siegbahn, Uppsala University

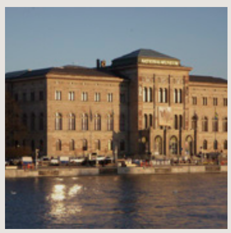


1959
Construction of laboratory for short-term research projects, 150th anniversary of Karolinska Institutet

1960
Epilepsy research, Lund University

1961
Nuclear resonance spectrograph, KTH Royal Institute of Technology

1962
New wing, Nationalmuseum, Stockholm



1963
Equipment for electrophysiology lab, Umeå University

1964
Institute of Osteology at Ulriksdal, Stockholm University

1965
Mass spectrometer, Lund University

1966
Fiscal Policy Research Institute

GRANTS AWARDED 1942–1966: SEK 90 MILLION
GRANTS AWARDED 1917–1966: SEK 116 MILLION

THE FOUNDATION'S ASSETS AND GRANTS

A rare history

PRIVATE RESEARCH FOUNDATIONS IN SWEDEN AND THEIR ASSETS

There are estimated to be more than 50,000 "Swedish" foundations. At the end of 2012, their combined total assets amounted to some SEK 513 billion. That total is somewhat theoretical, at least regarding the very largest foundations. The value of their assets would, of course, fall drastically if they all divested their holdings due to the sudden glut of equities on the market. Around 17,400 of those foundations were registered with a county government, pursuant to more stringent requirements introduced in amendments to the Swedish Foundations Act. In 2002, around 14,500 foundations had endowments exceeding SEK 350,000. Meanwhile, only slightly more than 50 foundations had assets of over SEK 1 billion, and 30 of those were charitable foundations. (See Bibliography.)

Of far greater importance than the foundations' assets—at least from the perspective of potential grant recipients—is their ability to distribute funds. Sweden's private charitable foundations awarded over SEK 2 billion to Swedish research in 2001. That represented just under 10 percent of total grants made to the nation's universities and other institutions of higher education. If grants from abroad are included, grants from Sweden's private foundations accounted for nearly 14 percent of the total research budget, or SEK 4.3 billion, in 2010.

The foundations that support research and education had assets totaling just over SEK 120 billion in 2012, and pursuant to legal regulations, they distribute an average of at least 80 percent of their direct profits over a five-year period. The remaining profits and any proceeds from sales of assets are added to a foundation's assets as protection against currency losses and to maintain grant-making capacity at a consistent, slowly rising level. Half of these foundations were established in the last 35 years. For historical reasons, the majority of this foundation capital is concentrated in the Stockholm region. As is the case in most other Swedish counties, private donations dominate, representing two-thirds of the total capital.

The private research foundation that stands out in terms of the scale of its assets and grants awarded is the Knut and Alice Wallenberg Foundation. At the end of 2012 its assets were at SEK 34.696 billion, or around 29 percent of the capital held by all of Sweden's private research foundations. Knut Wallenberg's fondness—indeed, love—for Stockholm, the city of his birth, is a significant reason for the concentration of capital and grants in that city. During his own lifetime, up to 1938, a significant majority of the grants awarded by the Knut and

USING FOUNDATIONS TO BUILD CAPITAL

A foundation has some unusual characteristics, in that it builds up capital in the long term, which enables it to make grants to beneficiaries.

This unusual nature is not primarily due to charitable foundations' tax-exempt status, which comes under fire from time to time; rather, it has more to do with their opportunities to invest their assets in high-return investments, thereby generating liquidity.

Knut and Alice Wallenberg outside Villa Täcka Udden, which they purchased in 1888.

Alice Wallenberg Foundation (SEK 15 million out of a total of 23 million) went to Stockholm-based recipients. As half of the remaining grants also ended up in the same region one way or another, at least 80 percent of the grant money went to Stockholm. There are historical reasons for this. One is that many of the underlying private fortunes were made in the city: financial capital exerted its greatest influence over GNP during that same period from 1890 to 1939. The other main reason was the limited geographic distribution of Swedish academia in 1917–18, when the Foundation was set up and began its activities. Quite simply, most institutions and researchers that received grants were located in or near Stockholm.

A foundation differs from other institutes in the ways it builds up capital in the long term and creates opportunities for making grants. This is not primarily the result of charitable foundations' frequently debated tax-exempt status, but rather their opportunities to invest their capital in high-return assets that generate liquidity. This does not apply to all foundations, though. Take the Nobel Foundation, for example. It was established before the Knut and Alice Wallenberg Foundation but dates from the same era, and it is probably the only Swedish foundation that can serve as a comparison, or indeed role model. In its early years, the Nobel Foundation cautiously invested its endowment mainly in interest-bearing securities. Today, the Nobel Foundation has a very different investment philosophy, but it differs significantly from the Knut and Alice Wallenberg Foundation in investing largely in foreign equities, securities, and other financial instruments.

For many years, stocks in large publicly listed Swedish corporations constituted the bulk of the Knut and Alice Wallenberg Foundation's capital. Those corporations are not just any companies, though: most are firms that are or have been part of the Wallenberg sphere. Their progress has, therefore, played a crucial part in the Foundation's capacity as a research funding body. This is not just a matter of general stock market trends or the influence of the global economy on a small export-dependent country on the edge of northern Europe. Rather, the Foundation has maintained a direct interest in these companies via the Wallenberg sphere's representatives with their policy of active ownership ever since the serious financial crisis that affected Stockholms Enskilda Bank, "the family bank," in the late 1870s. That crisis left a deep impression in the minds of subsequent directors, and the resulting ownership philosophy continues to form the fundamental business concept at Investor, the sphere's industrial holding company. The companies' ties to this bank, which enjoys a relatively strong capital position and reputation, especially after the recession of the 1920s and the 1932 "Kreuger Crash," were a happy marriage up to the early 1970s. While the impression given may be one of a highly stable group of companies over the years, a large number of businesses have left the sphere as new ones have entered, so things have certainly not stood still.

PETER WALLENBERG'S EPOCH

The changes during the long chairmanship of Peter Wallenberg (1926–2015) are particularly striking. One of the most impressive developments in the Foundation during his time at the helm from 1982 to 2015 was in the cumulative value of its assets, and particularly its grant-making capacity. At the start of 1971, the year he was brought onto the Foundation's Board of Directors, the endowment had a book value of just under SEK 91 million, and a little over SEK 11 million was awarded in grants. At the end of 1982, the year Peter Wallenberg was appointed chairman, the assets were valued at close to SEK 360 million, and grants of SEK 62 million had been awarded that year. From the Foundation's establishment up to that point, over SEK 480 million had been granted to Swedish science and research. The Foundation's subsequent growth was due in no small part to Peter Wallenberg's leadership, both at Investor and the Foundation, in tandem with sweeping changes in the structural conditions in the Swedish economy from the 1980s onwards. This applies particularly to his specific interventions, along with several key people from all the companies in the Wallenberg sphere, toward increased internationalization, value creation, and shareholder value.

How was it possible for the Knut and Alice Wallenberg Foundation's assets to increase from

PETER WALLENBERG

For 33 years, Peter Wallenberg was the head of a family that influenced the economy of its country more than any other in Europe. He continued to meet world leaders and celebrities throughout his life.

His life is portrayed in a biography by Ronald Fagerfjäll entitled Peter Wallenberg 1926–2015. *Den förlorade sonens återkomst* ("The return of the prodigal son").

the original donation of SEK 20 million listed in the 1917 memorandum of association to SEK 79.571 billion, the Foundation's "value" at the end of 2015? Over the same period, the capacity for grants rose from just over SEK 1 million in 1918 to nearly SEK 1.740 billion in 2016. Even taking inflation into account, these figures show a steep rise.

There is certainly no doubt that the original endowment was a significant sum. Knut Wallenberg was probably the wealthiest private citizen in Sweden at that time, and the sum represented roughly half of his fortune. With regard to the changes in the general price index in Sweden over that period, it is likely that several mutually reinforcing factors enabled this increase, including organizational changes in capital management. Compared to other heavyweight Swedish research funders that might invest their capital more widely, thereby necessitating greater administrative input, the Knut and Alice Wallenberg Foundation has required far fewer employees to manage its capital, thanks to the degree of continuity in its holdings, despite all the changes over the years.

CHANGING CIRCUMSTANCES

In recent decades, the institutional conditions, both cyclical and legal, for the accrual of capital in Sweden received a boost from political economic reforms in the 1980s, first in monetary policy and later through deregulation of loans and investments. This period of deregulation started back in 1978, when banks were first permitted to set their own interest rates on deposits. Corporate bond rates were deregulated in 1980. Then, in 1985, lending interest rates followed suit, and lending limits were abolished. This led to a huge credit expansion, since competition meant the banks were unable to utilize interest rates as instruments to control their customers or sectors. The result was an asset-market bubble, particularly in the real-estate sector. It was a tricky situation, because currency regulations prevented an excess of liquidity from flowing to other countries. Stock-market investments abroad were gradually permitted starting in 1987.

A completely new era began in 1989 as a result of the deregulation of capital transactions, including investments in foreign stocks, and the changes in monetary policy that now allowed banks to make better use of their control mechanisms. The introduction of new financial instruments was also encouraged on the market without control from the authorities. This resulted in a totally new role for securities markets: namely, a shift from bonds to stocks in the 1990s, led by supply as well as demand. There was no absence of leverage in supply and demand although the market did become very volatile with short-term risk from time to time. From 1993, Swedish payment transfer legislation meant that foreign banks could compete with Swedish banks, both for foreign-currency deposits and trade in foreign securities. Sweden's entrance into the EU and the creation of the European Monetary Union (although Sweden remained outside the latter) brought various political treaties with strict criteria for national budgets, which led to a rapid reduction in the range of bonds available. This in turn caused a swift fall in profitability in bond trading, while corporations' capital requirements were increasing.

The same processes led to economies of scale among companies as well as a focus on mergers with ever bigger players. The Nordic countries were several steps ahead of the rest of Europe along the path of deregulation.

Modern growth theory has shown that research-based knowledge has a direct impact on economic growth. The stock market anticipates economic trends, either because of the capacity of stock-market transactions to generate growth or merely because investors expect greater future economic growth. Experts are divided. As a result of the increasing significance of private research foundations thanks to their assets, the rest of society has experienced positive changes purely with regard to capital.

This has led to a real win-win situation. One important condition is that the financial system continues to function well, so the desired economic progress remains sustainable.

In other words, the circumstances surrounding the Knut and Alice Wallenberg Foundation have undergone a complete transformation in recent decades, in ways that have increased its influence.

10-RIKSDALER BANKNOTE
issued by Stockholms Enskilda Bank, 1856.

THE ORIGINS AND EARLY HISTORY OF THE FOUNDING ENDOWMENT

The first 75-year history of the Foundation's assets were covered in a previous publication released to commemorate that occasion, but there has not been a similar account of developments during the last 25 years. A few words are in order here about the origins of the initial endowment and its previous development, to compare and contrast with its later progress.

Knut Wallenberg, the Foundation's original donor, was in a unique position at Stockholms Enskilda Bank, founded in 1856 by his father André Oscar Wallenberg, which enabled him to amass a sizable personal fortune. That outcome was not a foregone conclusion. After his father's death in 1886, Knut was appointed president of the bank by virtue of his family's majority ownership of the bank. The serious economic crisis of the late 1870s had hit both the bank and many of its business customers involved in heavy industry. The bank had made good progress in its recovery, but the crisis would continue to affect companies for some time to come. Knut's confidence in his own future and that of the bank remained firm, and by the 1894 company meeting, when it showed a profit, the bank was definitely back on track. Thanks primarily to a series of consortium deals among people with close ties to the bank as well as some profitable bond issues, profits and commissions were generated for the bank and for Knut personally. From 1886 to 1918, the value of the bank's "lots," as shares were then called, on the Stockholm Stock Exchange increased almost tenfold.

Knut Wallenberg preferred to invest his increasing personal capital in lots in the very bank where he worked. It is not just because of the Wallenberg family's presence on the bank's Board of Directors over several generations that it can be called "the family bank." The bank also served as a center both for the family's accumulation of wealth through direct ownership of the bank and for its associated companies. Bonus issues and new acquisitions of lots, sometimes with money borrowed from other banks, helped Knut to personally amass around a 20 percent stake in the bank's total share capital. The original Foundation endowment, made in his and his wife's names, consisted of a SEK 20 million promissory note, mortgaged on 4,000 lots in the bank. Ultimately, 9,200 shares came to constitute the founding endowment of the Knut and Alice Wallenberg Foundation at the time of Knut's death. The bank had been converted from a company with joint and several ownership liability to a joint-stock company in 1934.

Another major portion of the endowment consisted of 10,000 shares in Investor, an industrial holding company founded by the bank. This was the Foundation's stake in the shares allocated to the bank's lot owners in 1916, representing close to 14% of Investor's share capital. The family's fortune was transferred to Investor after previously being administered by AB Providentia as a kind of legacy from A.O. Wallenberg and Aros, his private asset fund. Unlike the shares in the bank, Investor shares would not generate any dividends for over 10 years, until the effects of the 1920s crisis had passed. This stake would become significantly more important much later.

Knut and Alice Wallenberg made a number of further donations of stocks throughout their lives, totaling SEK 7 million. These included shares in Ostasiatiska Kompaniet, Stockholm-Saltsjön, Hambros Bank, Orkla Grube and Norsk Hydro. At Knut's death on June 1, 1938, the Foundation's total endowment consisted of assets with a market value of over SEK 55 million, including bank shares worth SEK 38 million. The book value of the assets was over SEK 32 million, and over SEK 23 million had been awarded in grants. The process of transferring the couple's capital to the Foundation continued up until Alice Wallenberg's death in 1956, with major additions in 1947 and 1958.

Over the years, the bank had also issued free shares, which were converted into shares in a new investment vehicle, the Providentia holding company, in 1946. The new Providentia included assets Jacob Wallenberg (1892–1980) had generated over 30 years, with the old Providentia in liquidation as an instrument. The Foundation received 46,000 shares in the new Providentia, which would later be worth more than the bank shares. This solidified the Foundation's key role as a long-term administrator of the Wallenberg sphere's collective industrial interests.

ANDRÉ OSCAR WALLENBERG

"No self-reliant man is sufficiently strong to break through the rock of ignorance and preconception on his own.

But by joining forces, through cooperation and the intense conviction of the rightness of one's plans, nothing is impossible ..." —A.O. Wallenberg to Axel Adlersparre, September 26, 1851.

An account of his life is given in Göran B. Nilsson's biography, *The Founder*.

From 1917 to 1945, the composition of the Foundation's portfolio largely reflected Sweden's economic history around the turn of the last century. This was followed by a period, beginning in 1945 and lasting until the 1970s, marked by rapid postwar expansion and structural changes in Swedish commerce. The Foundation's investments were still primarily in Swedish-listed companies, and the strongest growth in value occurred in the decade from 1957 to 1967. However, even though the market values increased, dividend yields shrank to barely 4% of market value or 18% of book value.

From 1972 to 1992, three-fourths of the Foundation's book value was in Swedish stocks, so the increase in value reflected the movement on the Stockholm Stock Exchange over the same period. For the first 10 years of that period, values increased by around a third, but the next 10 years saw a very expansive phase take hold, turbocharging the increase. Indexes increased sevenfold. The deregulation of financial markets had a major impact on liquidity, and the devaluation of the Swedish krona by 16 percent added to listed companies' profits.

Around 1980, the Foundation's assets started to become less stable due to increased capital management activity. Swedish stocks became less important than short-term investments, so current assets became extremely important from time to time. The stake in Skandinaviska Enskilda Banken remained as before, at around 14% of the Foundation's endowment. In order to increase the dividend yield, A shares were swapped for B shares, and in 1989 the Foundation invested SEK 131 million in the bank's new stock issue.

In the 1970s, 25% of the Foundation's dividend yield emanated from its stake in the bank, but after 1982, its holdings in Investor and Providentia grew in importance. In 1991, the contribution from the bank stake was 18 percent. The following year, three-fourths of the Foundation's assets consisted of shares in Investor and Skandinaviska Enskilda Banken.

The continuity of the founding endowment has been evident. Fixed-interest securities remained a small proportion of the total, and foreign stocks never accounted for more than 10 percent. Capital gains had minor significance before 1982, but then accounted for SEK 903 million from 1982 to 1986 and SEK 1.235 billion from 1986 to 1990.

THE FOUNDATION'S DEVELOPMENT OVER THE LAST 25 YEARS

Against this background, it might be interesting to examine some aspects of the Knut and Alice Wallenberg Foundation's capital investments of the last 25 years in more detail, rather than just present a list.

To what extent has it been possible to grow the endowment and dividends, i.e. the market value of the assets minus debt (the endowment) and the Foundation's grant-making capacity? How has that growth been achieved through investments, in listed or unlisted Swedish and foreign stocks? How much have capital gains contributed? What role have fixed-interest investments played over time? Have new financial instruments been adopted? Certain organizational changes in the asset management are also of interest in this context.

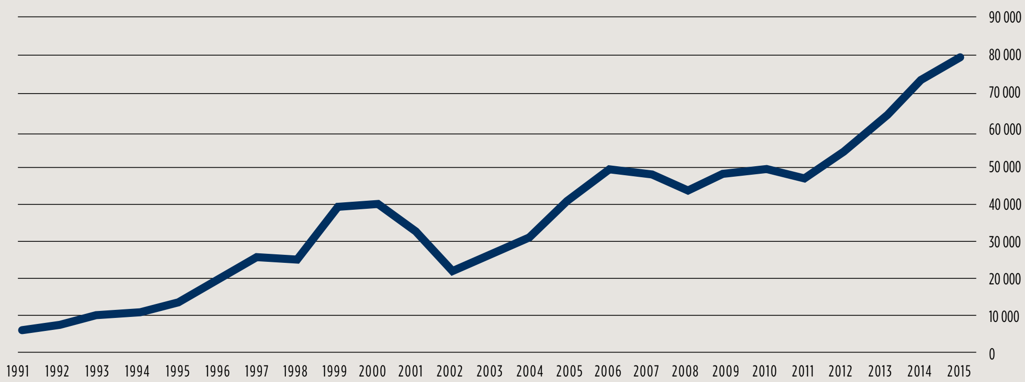
First and foremost, capital gains appear more important than before. Their significance began

THE FOUNDING ENDOWMENT

"As an initial endowment, which will form the cornerstone of the Foundation, my wife and I have signed a promissory note to the value of twenty million kronor, secured against four thousand shares in Stockholms Enskilda Bank. The bulk of our assets will be left to the Foundation in our wills."

GROWTH OF THE ASSETS

1991–2015, current prices (in millions of SEK)



Source: Appendices to minutes of the Foundation's Board of Directors' meetings and annual reports, 1991–2015.
Note: "Assets" refers to the sum of the value of the capital fund (book value of assets minus debts) plus investment asset goodwill (net asset value).

to increase from around 1982 until the early 1990s and became even more striking during the following five-year periods, amounting to SEK 3.229 billion in 1991–95, SEK 1.636 billion in 1996–2000, SEK 21.339 billion in 2001–05, SEK 10.545 billion in 2006–10, and SEK 1.950 billion in 2011–15.

A number of major events in the companies within the Wallenberg sphere contributed to this large increase in capital, including the merger of Investor and Providentia in 1991, the divestment of Diligentia in 2000, the change of Investor ownership in 2001, the selloff of Gambro in 2004–2005, transfer of Stora Enso and SKF to FAM in 2007 (see below), and the final selloff of Scania in 2008. A large extra dividend from Investor in 1996 occasioned by Investor's divestment of 55 percent of its stake in Scania upon Scania's stock-market listing, was allocated to the non-restricted equity, and gave a large boost to the Foundation's grant-awarding capacity for several years thereafter. By and large, the continued increase in the Foundation's capital management since 1980 has had an increasingly large effect on the development of the assets over the last 25 years.

By contrast, there has been a high degree of consistency in the distribution of the Foundation's investments across various asset types. Swedish stocks in large publicly listed corporations have continued to dominate the long-term securities portfolio, accounting for around 87–90% of total value, with foreign stocks accounting for around 4–5% and interest-bearing investments for the rest. There has been no trade in derivatives or other similar financial instruments.

One core investment that has remained particularly significant ever since the original donation is the stake in Investor, as previously mentioned. On February 1, 2013, the Foundation announced yet another major acquisition of Class A shares, bringing the total combined stake held by the Knut and Alice Wallenberg Foundation, the Marianne and Marcus Wallenberg Foundation, and the Marcus and Amalia Wallenberg Foundation to 50.01% of the voting shares and 23.29% of the capital in Investor.

In recent years, a number of investments in unlisted companies have been added to the Foundation's indirect holdings, held in FAM AB. Unlisted positions are also increasing in Investor—the Foundation's core holding—and its Patricia Industries division.

Along with the results of the Foundation's long-term financial investments, various organizational changes may well have played a role in the Foundation's continued growth.

In October 1999, a separate investment committee was formed as a link between the

INVESTOR

Investor AB is an industrial holding company founded in 1916. The Wallenberg Foundations own 23% of share capital and hold over half of the voting rights in the company. More information about Investor is available in Ronald Fagerfjäll's book *Investor 100*, which commemorates the company's 100th anniversary.

Foundation's ongoing administration and its Board of Directors. The committee's duties include maintaining a certain level of continuity by monitoring the role of the original donations among the Foundation's financial investments.

In 2001, the Knut and Alice Wallenberg Foundation acquired and assumed ownership responsibility for stakes in SAS, SKF, and Stora Enso while divesting Class A shares in Ericsson and a stake in Skandinaviska Enskilda Banken via a stock swap with Investor AB.

In 2004, the Foundation, along with the Marianne and Marcus Wallenberg Foundation and the Marcus and Amalia Wallenberg Foundation, established two holding companies—AB Svensk Stiftelseförvaltning and W Capital Management AB (WCap)—to handle ongoing capital investment management and consulting, respectively. Along with investment in the share capital, the Foundation invested SEK 232 million in WCap that was earmarked for "seed investments." In 2006, AB Svensk Stiftelseförvaltning and W Capital Management AB merged with Thisbe AB.

In November 2007, the Knut and Alice Wallenberg Foundation, along with the Marianne and Marcus Wallenberg Foundation and the Marcus and Amalia Wallenberg Foundation, then founded a new jointly owned company called Foundation Asset Management Sweden AB (renamed FAM AB in 2015), also known as FAM, for capital management and consulting in capital investment and ownership matters, and Thisbe's role ceased. At that time, the Foundation also divested its stakes in Stora Enso and SKF to FAM. Since then, the Foundation has kept the bulk of its assets invested in listed stocks, partly directly and partly indirectly via FAM. In exchange, the Foundation received shares in FAM and a long-term shareholder loan.

The Foundation's own management of its endowment has played a major role in its economic growth in recent years. This growth cannot be understood merely against the background of the changes in institutional conditions that started in the 1980s. Those conditions have had more of an impact on the companies in which the Foundation holds a stake, and therefore on the continued development of active ownership in respect of those holdings.

In a way, one could say the Foundation is carrying on the legacy of Stockholms Enskilda Bank and is thus a 100-year-old representative of tradition and innovation backed by 160 years of experience. Thanks to its unique position as a shareholder in Swedish commerce, the Foundation's endowment has been successfully managed on several different fronts simultaneously. The results are evident, not least in the Foundation's increasing grant-awarding capacity, which has been of great benefit to Swedish science and research.

THE FOUNDATION'S GRANT-AWARDING ACTIVITY

While the endowment itself was the starting point that enabled the Knut and Alice Wallenberg Foundation's involvement as a long-term active investor in major corporations, its capacity to generate dividends has been crucially important for Swedish science and research. A detailed account of the significant grants the Foundation awarded over its first three-fourths of a century was published to mark its 75th anniversary. This volume includes descriptions of the major beneficiaries of the most recent 25 years. So this section gives a brief overview of the types of grants prioritized by the Foundation and how they have been developed.

The grant policy applied has varied and been refined over time. Initially, it reflected founder Knut Wallenberg's personal involvement in the Board of Directors, enabling him to distribute funding to the projects and subjects closest to his heart. Today, more sophisticated criteria are applied to make sure all grants support: (1) research projects with high scientific potential; (2) outstanding individual researchers; (3) strategic objectives; and/or (4) scholarship programs.

For many years, a great deal of the essential background work for evaluating and prioritizing applications was done by Knut Wallenberg himself. There are many records of his painstaking fact-finding work in the Foundation's archives. The original constitution and regulations provided for a relatively free rein in the cultural arena alongside research and education. The Foundation displayed remarkable agility in dealing with applications. An amendment to its constitution in 1928 underlined an already-established policy: the Foundation would award grants for research, either directly to recipients or to institutions in support of research

FOUNDING

"My wife and I have decided to establish a foundation under the name 'Knut and Alice Wallenberg Foundation' with the purpose of providing financial assistance primarily to religious, charitable, social, scientific, artistic, or other cultural endeavors, and to encourage trade, industry, and other business pursuits within our country. None of these areas is to be given preference over the others."

or operations. That also marked an end to grants for religious, charitable, social, and artistic purposes and to trade, industry, and other commercial purposes. A guiding principle was laid down: "The Foundation shall not grant funding for others to invest or manage."

The 1928 amendments to the Foundation's constitution had another objective besides limiting the pool of potential recipients—anticipating an imminent change in tax legislation that might have affected the Foundation's tax-exempt status.

Despite these adjustments, the Foundation's grant-awarding activities remained fairly consistent throughout the period from 1918 to 1945. Although the founder passed away in 1938, his influence remained in evidence through the Foundation's undertakings from his era. Knut's widow Alice Wallenberg continued to dedicate herself to the Foundation in various capacities connected with the Board of Directors of the Foundation that also bore her name, even though she was never formally a member of the Board.

The Foundation's resources declined during the wartime years (1939–45) and its grant-awarding capacity fell drastically due to the war's economic impact, as well as the imposition of tax liability on the Foundation for four years. However, the postwar years were favorable, thanks to the rapid expansion of Sweden's previously relatively staid academic world and the corporations in which the Foundation was an investor. The research community's rising demand for scientific and research funding had an invigorating effect, and the Foundation's assets generated increasing dividends.

At various points, then, the Foundation's grant policy has been reformulated to bring it into line with the needs and wishes of the research community. Since 1972, the Foundation has worked directly with representatives of Swedish universities, higher education institutions, and royal academies, partly through its Principals' Council Representative. In recent years, increasing value has been placed on evaluations by independent experts from all over the world, particularly Nobel laureates. Their evaluations form the basis for the Board of Directors' funding decisions.

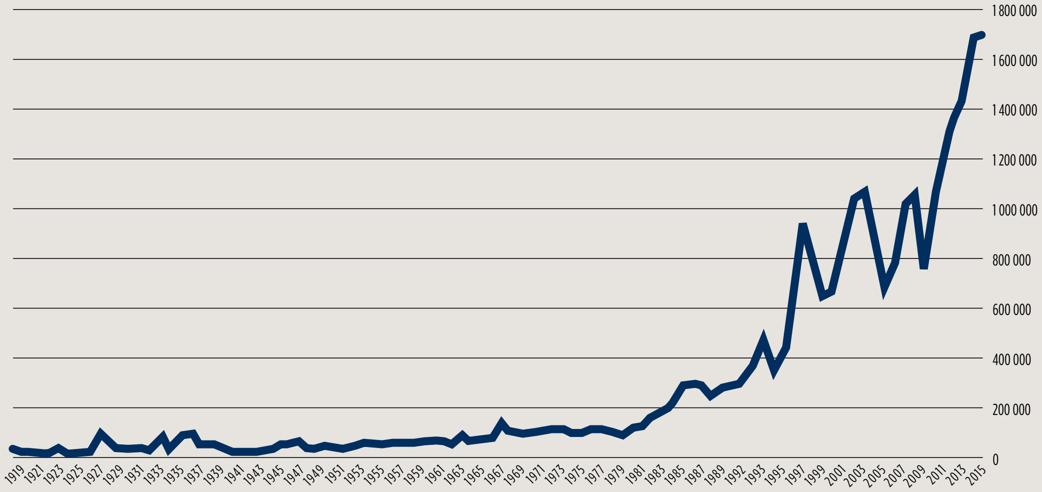
In 2000 the policy was revised again, to focus on providing support for: (1) high-end scientific equipment; (2) conference facilities and housing for visiting researchers; (3) a scholarship program; (4) new initiatives; and (5) national museums and science centers. Around that time, the pressure of applications on the Foundation had increased significantly, in terms of both the number and size of

ALICE WALLENBERG

After Knut's death in 1938, Alice took on a more active role in the Foundation's work, although she never sat on the Board of Directors. She made a number of proposals concerning causes she thought the Foundation should support.

GRANTS AWARDED ANNUALLY

1918–2015, adjusted for inflation (in thousands of SEK). Base 2015 = 100



Source: The Foundation's own summary, 2016.

Knut and Alice Wallenberg in the garden of their summer home, Villa Täcka Udden.

BASIC RESEARCH

Today, the Foundation focuses mainly on basic research in medicine, technology, the natural sciences, and other disciplines addressing issues linked to these domains.

applications for increasingly expensive equipment. That prompted the Foundation to take out more frequent "mortgages" of up to 20 percent of future budget frameworks to meet the increased demand for funding from the scientific community.

To make it easier for the Foundation to predict the size of potential future grants, the grant framework was restructured in 1987, the key amendment being that dividends from one year would form the pool of grants to be awarded the following year. Previously, it had been difficult to get an overview of the available resources because no one knew exactly what dividends could be expected from the Foundation's investments. This change also created greater room for maneuver if there were above-average increases or reductions in dividends.

Today, the Foundation focuses mainly on basic research in medicine, technology, the natural sciences, and other disciplines that address issues associated with those domains. There is a tendency to support more multidisciplinary research, and the Foundation welcomes projects involving collaboration among universities and other educational institutions or similar research and education bodies. The results of funded research must be published through Open Access channels.

Even with all the modernization and formalization of the Foundation's grant-awarding process, this activity still retains a number of characteristics from its founders' era. Indeed, that's the key point of setting up a foundation. The Knut and Alice Wallenberg Foundation's particular focus on funding outstanding individual researchers is still present, as are other forms of support such as scholarships, which were first granted in 1921. Today, scholarships are often awarded following calls for applications issued by major scholarship programs with particular objectives, such as supporting underdeveloped areas. The previous emphasis on large-scale facilities and expensive equipment has been toned down in favor of comprehensive investments with national significance.

The Foundation continues to listen to its founders' voices and maintains its focus on benefiting the kingdom of Sweden ∎

1967
Mainframe computer for electron synchrotron, Lund University

1967
50th anniversary donation, annual travel grants for individual researchers

1968
Wallenberg Laboratory, Lund University 300th anniversary

1969
Equipment for marine water chemical component analysis, University of Gothenburg

1970
MAX Lab: first storage ring for nuclear physics experiments, Lund University

1971
Incidence spectrograph, atomic physics, Lund University

1972
Principals' Council established within the Foundation
—
Underground particle accelerator, KTH Royal Institute of Technology

1973
Radio telescope equipment for Råö Observatory, Chalmers University of Technology

1974
Arne Tiselius research vessel, Royal Swedish Academy of Sciences

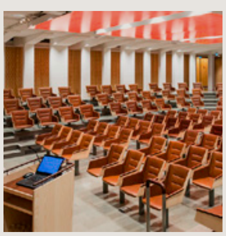
1975
Equipment for EISCAT project, Swedish Institute of Space Physics

1976
Minicomputer, pet hygiene department at Skara, Swedish University of Agricultural Sciences

1977
Visiting scholars' housing, Uppsala University's 500th anniversary

1978
Hospital cyclotron, PET camera, Karolinska Institutet

1979
Wallenberg Hall, Royal Swedish Academy of Engineering Sciences



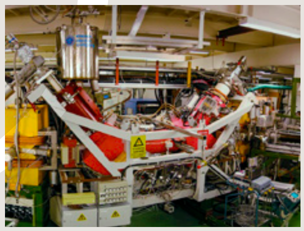
1980
La Palma solar telescope, Royal Swedish Academy of Sciences

1981
Equipment for 1982 Nobel laureate in Medicine Bengt Samuelsson, Karolinska Institutet

1982
Equipment for 2000 Nobel laureate in Medicine Arvid Carlsson, University of Gothenburg

1983
Three climate stations used in a Swedish plant nutrition research project, Royal Swedish Academy of Agriculture and Forestry

1984
CRYRING, accelerator and storage ring, Manne Siegbahn Institute, Stockholm University



1985
Center for Genetics, Swedish University of Agricultural Sciences, Uppsala

1986
Electron microscope and laser equipment, Umeå University

1987
Glaciology research at Tarfala Station, and in Antarctica, Stockholm University

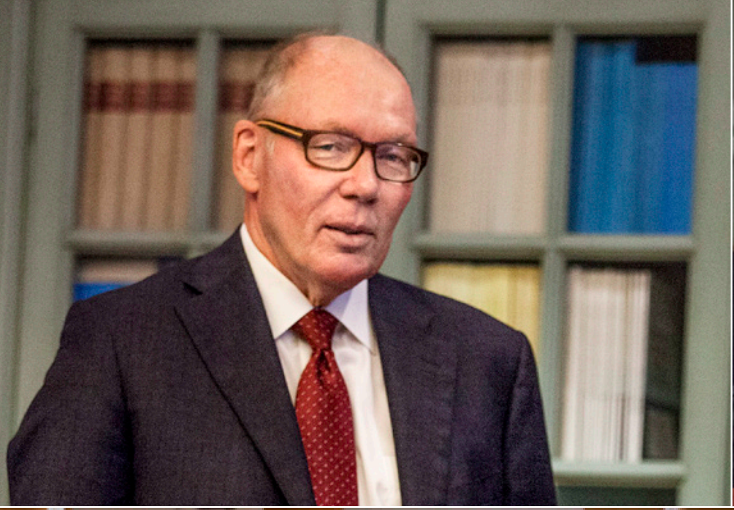
1988
Supercomputer, National Supercomputer Center, Linköping University

1989
Biomedical research laboratory, Umeå University

1990
Genetics and developmental biology laboratory, Stockholm University

1991
Materials research center, Ångström Laboratory, Uppsala University

GRANTS AWARDED 1967—1991, SEK 1.683 BILLION
GRANTS AWARDED 1917—1991, SEK 1.798 BILLION




Knut and Alice
Wallenberg
Foundation
100 YEARS IN SUPPORT OF EXCELLENT
SWEDISH RESEARCH AND EDUCATION

THE BOARD OF DIRECTORS' STRATEGIC WORK

One of the most important duties of the Foundation's Board of Directors is developing the Foundation's long-term strategy. The Board maintains an ongoing discussion of strategic challenges and potential opportunities for Swedish research. There are also regular meetings with the presidents of Swedish research universities and the Foundation's own international Scientific Advisory Board.

Through its major grants, the Foundation is an established part of Sweden's research funding system. Thanks to its flexibility, the Foundation can serve as a supplement to public-sector investments. It also has open channels of communication with representatives of research funding bodies in the public sector.

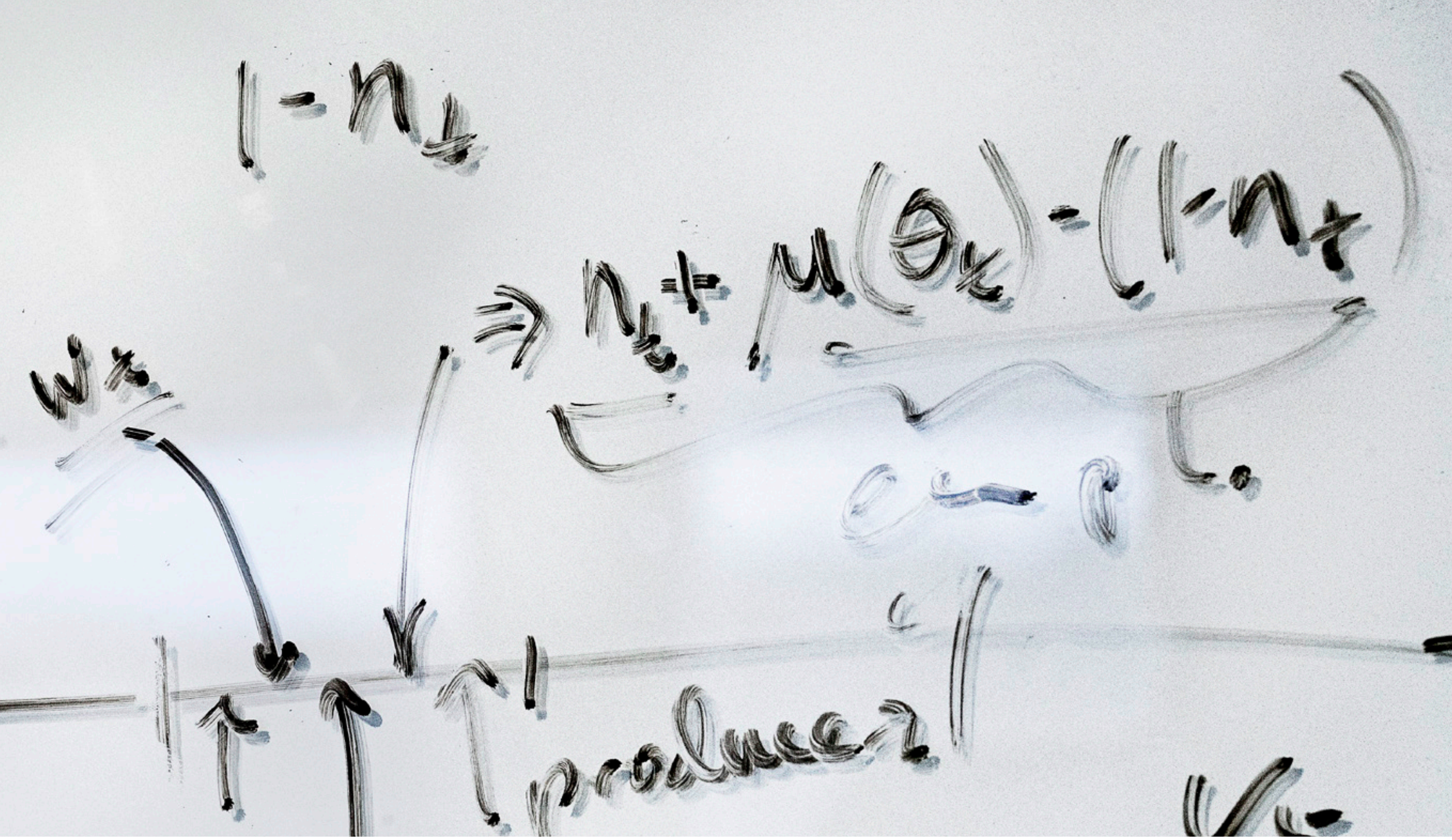
For many years, the Foundation was one of the major external funders of university construction projects, later turning to infrastructure and equipment, primarily for experimental disciplines.

At the start of the new millennium, the Foundation's Executive Director Erna Möller initiated the concept of supporting outstanding senior researchers. Her successor Göran Sandberg continued to build on that work with initiatives such as long-term individual grants to young researchers and individual research projects by research teams submitting competitive applications.

In addition, in the last 20 years, large-scale, long-term programs have been established to support research in life sciences, forestry and forest products, IT and automated systems, and mathematics.

It's important for the Foundation to move with the times to make sure that its support for Swedish research and education has the greatest possible positive impact. The Board of Directors is strongly committed to this process ∎

"The Board's strategic discussions are a cornerstone of our work to make sure the Foundation supports fields of major importance to Swedish research at every given stage."
—Peter Wallenberg Jr, Chairman of the Foundation.



For many years, the Wallenberg family has developed and refined an administrative model that incorporates a long-term, active ownership approach. In support of this approach, significant time is dedicated to managing the Wallenberg brand and continuing to expand the national and international network surrounding the family and the businesses linked to the family. This means the family can open almost any door.

“The 1.7 billion kronor the Foundation can distribute in grants each year is certainly a legacy of the original endowment, but it is primarily a result of the successful efforts to build up the assets over 100 years using a well-planned management model. Without this successful expansion of the endowment, the Knut and Alice Wallenberg Foundation would have had a much smaller, less influential role in the Swedish research and education community.” —Jan Holmgren, Board member 1995–2016.

CAPITAL MANAGEMENT

The Knut and Alice Wallenberg Foundation's assets are managed through a policy of active ownership, a Wallenberg family tradition that stretches back to the establishment of Stockholms Enskilda Bank in 1856. All the Wallenberg Foundations' assets are managed primarily through long-term direct or indirect investments in companies based mainly in the Nordic countries with world-leading market positions.

The key word has always been stable growth in assets and dividend levels over time. It is important to the Foundation to maintain predictable grant pools for distribution and to achieve steady growth.

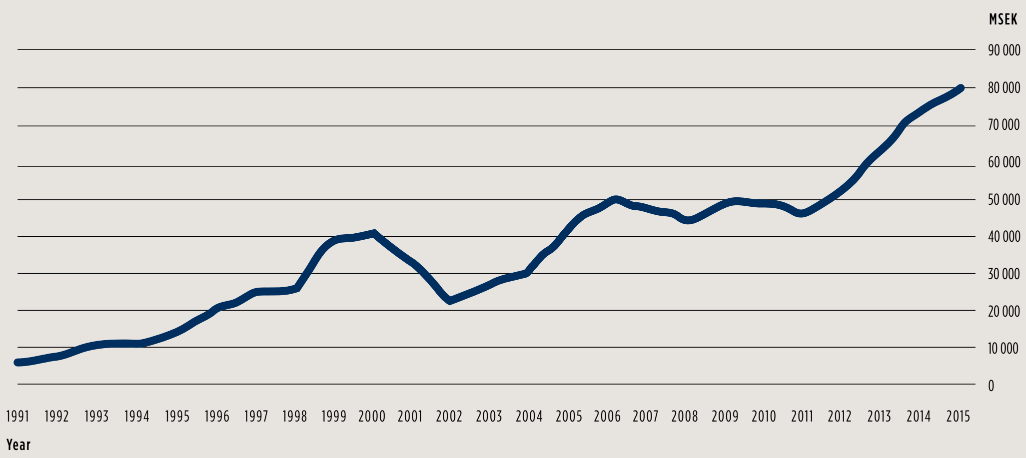
THE CAPITAL MANAGEMENT ORGANIZATION

The Foundations' capital management organization has developed over the years in efforts to secure the best possible long-term endowment growth.

The Foundation continues to focus on evaluating grant applications and research activity. All the Wallenberg Foundations' assets—as well as the grants awarded—must be managed as efficiently and professionally as possible. To that end, the responsibility for capital management and ownership has been delegated to the Foundations' Investment Committee, while the administration of grants and foundation activities is the responsibility of Wallenberg Foundations AB, a wholly owned company.

The Investment Committee's duties include overall long-term and strategic decision-making concerning management of the Foundations' assets and the management and development of holdings over time. Its prime responsibility is to see that the Foundations' asset management enables a continual increase in grants.

The Investment Committee is also responsible for making sure the right people are recruited to the boards and senior positions in the businesses. Another duty is management of cash flows and assets not currently invested in long-term holdings. Individual decisions made within the Investor and FAM holding companies are the responsibility of their respective boards, while the Investment Committee focuses on larger-scale issues concerning the Wallenberg Foundations' assets. Meanwhile, the Foundations' ownership vision for Investor and FAM is shaped within the Investment Committee ∎



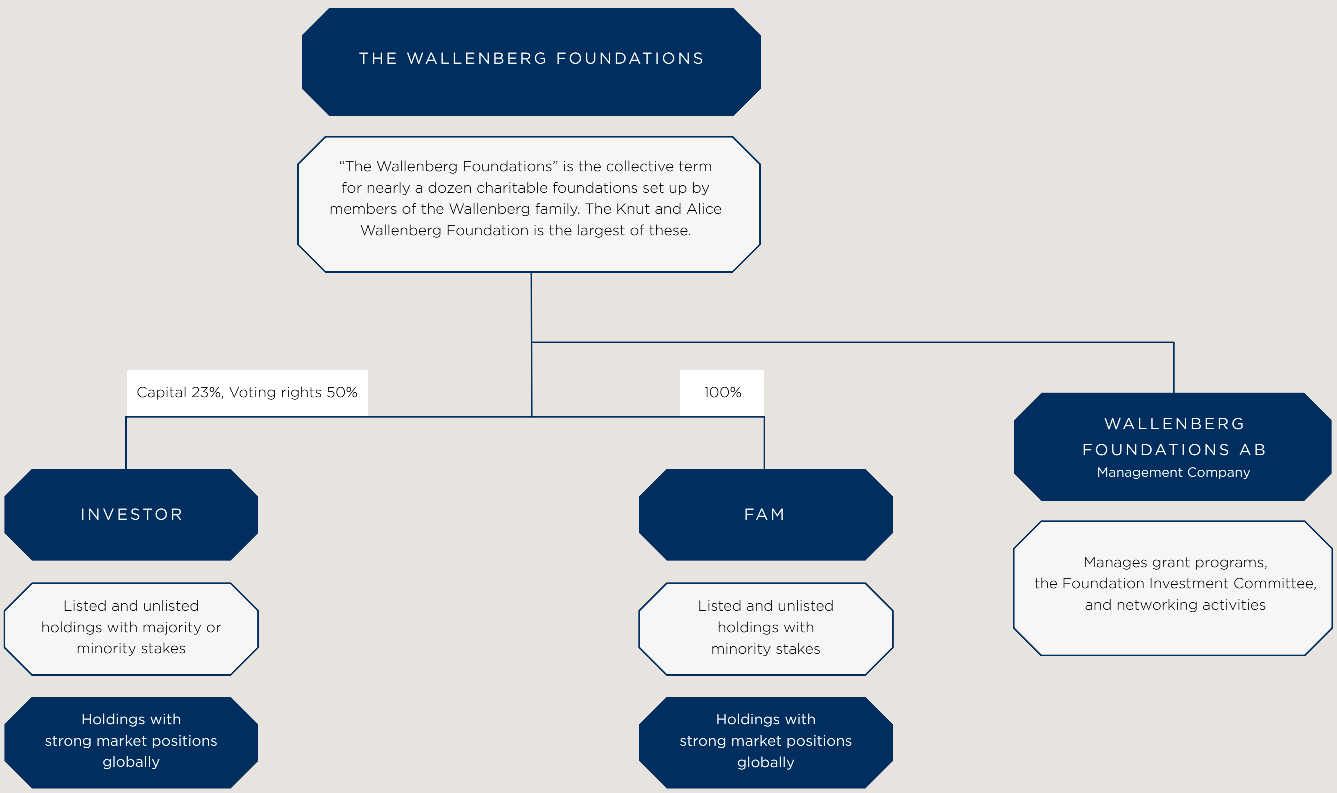
CAPITAL ENDOWMENT

The original endowment of the Knut and Alice Wallenberg Foundation consisted of SEK 20 million worth of shares in SEB and Investor. In accordance with Swedish legislation on foundations and the Foundation's bylaws, the grants awarded have equaled 80% of dividends received from assets/holdings. The remaining 20% has been reinvested in existing or new assets to generate increases in grants over time. So, the level of the Foundation's grants directly reflects the success of the Foundation's capital management.

CAPITAL EXPANSION

Since the launch of the Foundation, its assets have grown from SEK 20 million to 90 billion as of fall 2016, while nearly SEK 24 billion has been granted to Swedish research and education.

OWNERSHIP STRUCTURE



FOUNDATION INVESTMENT COMMITTEE

The Investment Committee takes overall responsibility for existing capital investments and corporate governance, not just for the stake it represents. As the representative for a responsible, long-term owner, the Committee works to secure growth that strengthens each individual company and benefits all its shareholders.

This role entails huge responsibility. Responsibility for managing the Knut and Alice Wallenberg Foundation's funds as well as the smaller foundations' capital has been delegated to an operational subcommittee, the Investment Council.

The Investment Committee's duty, in addition to generating returns, is to make sure funds are available to invest and to make the Foundations' ongoing grants. The Investment Council keeps a close eye on the market and provides information to the Investment Committee on capital markets.

The Investment Committee is responsible for assets totaling approx. SEK 110 billion.

Current members of the Investment Committee are Michael Treschow (Chairman), Claes Dahlbäck, Jacob Wallenberg, Marcus Wallenberg, Peter Wallenberg Jr, and Hans Wibom.

THE FOUNDATION AND SCIENTIFIC ACADEMIES

Following a resolution by the Foundation's Board of Directors, a Principals' Council was formed in 1972, consisting of representatives from universities, institutions of higher education, and scientific academies. The Principals' Council was given the opportunity to observe the Foundation's activities and submit requests and proposals to improve coordination between the Foundation's activities and Swedish science research and education. Over the years, this collaboration has expanded, and the Principals' Council has become an important dialogue partner for the Foundation's management and Board of Directors in strategic matters, including research issues and the grant-awarding process.

The Principals' Council consists of representatives from the Swedish Academy; the Royal Swedish Academy of Sciences; the Royal Swedish Academy of Letters, History and Antiquities; the Royal Swedish Academy of Agriculture and Forestry; the Royal Swedish Academy of Engineering Sciences (IVA); the universities of Uppsala, Lund, Gothenburg, Stockholm, Umeå, Luleå, and Linköping; the Swedish University of Agricultural Sciences; Karolinska Institutet; KTH Royal Institute of Technology; Chalmers University of Technology; and the Stockholm School of Economics.

The main duty of the Principals' Council is to appoint a member to serve on the Foundation's Board of Directors and the Foundation's auditors.

COLLABORATION WITH ACADEMIES AND EDUCATIONAL INSTITUTIONS

The Foundation has well-established links with Swedish scientific academies and educational institutions. In addition to their work within the Principals' Council, universities prioritize their applications to the Foundation to make sure their projects fall within their priority areas and they have the resources required to run the projects.

Collaboration with the scientific academies mainly entails the academies overseeing evaluation of several programs, including the Wallenberg Scholars, Wallenberg Academy Fellows, and Wallenberg Clinical Scholars. In addition, the Royal Swedish Academy of Sciences and the Royal Swedish Academy of Engineering Sciences (IVA) are in charge of mentoring programs for promising young researchers who have been designated Wallenberg Academy Fellows. For many years, the Foundation also funded Academy postdoctoral positions, which were announced and evaluated by the Royal Swedish Academy of Sciences, the Swedish Academy, and the Royal Swedish Academy of Letters, History and Antiquities.

SCIENTIFIC COMMITTEE

To support its evaluation process, the Foundation set up a Scientific Committee, consisting of eminent members of the research community. This group performs an initial scientific assessment of the applications received before they are sent out for international peer review.

SCIENTIFIC ADVISORY BOARD

An advisory committee consisting of 10 Nobel laureates produces an annual evaluation of the Foundation's work, the quality of its internal processes, and the Foundation's strategic orientation. They also evaluate the researchers used by the Foundation for peer reviews ■

The Ångström Building at Linköping University was dedicated in 2011. The Foundation donated SEK 46 million for the specially designed electron microscope in it.

THE PRINCIPALS' COUNCIL

The Principals' Council consists of twelve presidents of research universities and five representatives of the scientific academies in Sweden. The Council appoints auditors and nominates one of its members to serve on the Knut and Alice Wallenberg Foundation's Board of Directors. The Principals' Council is also an important dialogue partner for the Foundation's senior management in strategic matters concerning research and the grant-awarding process.

APPLICATION

Universities submit nominations for researchers and projects to the Foundation.

EVALUATION

The Foundation has a Scientific Committee composed of highly experienced, respected researchers. This committee performs an initial scientific assessment of the applications received.

PEER REVIEWS

The Foundation sends applications recommended by the Scientific Committee out to between five and eight international experts for peer review.

RECOMMENDATION

The Scientific Committee assesses the evaluations received. Then they give the Foundation their recommendations for projects that have major international scientific potential and are good candidates for grants.

DECISION

Based on expert evaluations and the Scientific Committee's recommendations, the Foundation selects projects to receive funding. The entire process is based on standardized evaluation criteria.

GRANT TO RESEARCHERS OR RESEARCH PROJECTS

SCIENTIFIC ADVISORY BOARD

An advisory committee consisting of 10 Nobel laureates produces an annual evaluation of the Foundation's work, the quality of its internal processes and the Foundation's strategic approach. They also evaluate the selection of researchers the Foundation uses for peer reviews.

THE GRANT PROCESS

Focusing on excellent researchers and projects

Over the years, a strict procedure has been developed to make sure grants are awarded to the best researchers and research projects. The fundamental objective is to maintain excellent standards in those receiving funding and in the Foundation's work, through securing resources for world-class individuals to perform independent research based on thorough international peer review.

GRANT POLICY

The Foundation's Board of Directors has established a grant policy to provide support mainly for basic research in medicine, technology, and the natural sciences. Projects in other disciplines may receive grants, provided they have some link to issues relevant to these scientific fields.

Because difficult research problems often require collaboration across disciplines, the Foundation willingly supports multidisciplinary research.

Universities, other higher education institutions, and similar research and education institutions may be awarded the following types of support:

1. Grants for research projects with high scientific potential; researcher-initiated projects of the highest international standards focusing on a coherent scientific issue.

2. Individual grants for outstanding researchers. The Foundation supports outstanding researchers through its Wallenberg Scholars, Wallenberg Academy Fellows, and Wallenberg Clinical Scholars programs.

3. Strategic grants, which are initiated by the Foundation or through discussion with representatives of the research community.

4. Scholarship programs, announced occasionally in various subject areas ■

1992
MAX II, Lund University

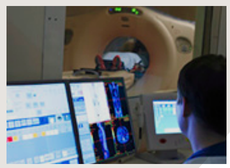
1993
Aula Magna,
Stockholm University

1994
Scientific equipment for the
Swedish "Odin" research satellite,
Swedish National Space Board

1995
400 MHz wide bore
NMR spectrometer,
Umeå University

1996
Microelectronics,
photonics, and micro-
mechanics equipment,
KTH Electrum

1997
Alternative biotechnological uses for Swedish wood raw
materials, KTH Royal Institute of Technology
—
Full-body imaging camera, PET centrum,
Uppsala University

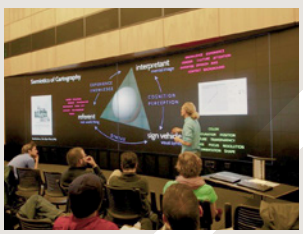


1998
Program for pharma-
ceutical chemistry,
Uppsala University and
University of Gothenburg

1999
WITAS project,
Linköping University

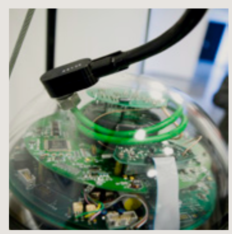
2000
5-year genome project,
WCN, Swegene
—
10-year program: Academy researchers
in the natural sciences,
Royal Swedish Academy of Sciences
—
Linnaeus Center for Bioinformatics,
Uppsala University

2000
Learning Labs collaborative project,
Swedish institutions and Stanford University

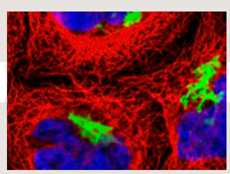


2001
National project,
Universeum, Gothenburg

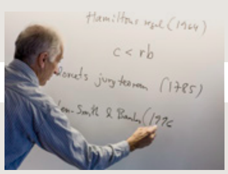
2001
Participation in ICECUBE,
Stockholm University



2002
MAX III, Lund University
—
10-year project:
Human Protein Atlas



2003
Kidney Research Center,
Karolinska Institutet
—
Endowed chair of Macroeconomics,
Stockholm School of Economics



2004
High-resolution
transmitting electron
microscope, materials research,
Chalmers University
of Technology
—
Experimental study in
distributed engineering work,
Luleå University of Technology

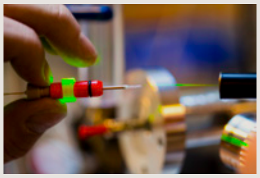
2005
Six-year program: Academy researchers in the humanities, Royal Swedish Academy of Letters, History and Antiquities and the Swedish Academy
—
Grant for nanoscience, Stockholm, Linköping, Lund, and Uppsala Universities and KTH Royal Institute of Technology

Solar cell research at Lund and Uppsala Universities and KTH Royal Institute of Technology
—
"Strength and Unity in Mathematics," KTH Royal Institute of Technology

2007
Stockholm School of Economics, remodeling, 100th anniversary
—
10-year project, Wallenberg Wood Science Center

2008
High-resolution electron microscope, Luleå University of Technology
—
MRI equipment for Lund University and Karolinska Institutet

2011
Foundation grants for research projects, 26 project grants, 10 Wallenberg Scholars



2010
10 Wallenberg Scholars
—
MAX IV accelerator and postdoc program

2009
Wallenberg Institute for Regenerative Medicine, Karolinska Institutet
—
Foundation program for outstanding senior scientists, 10 Wallenberg Scholars
—
Brain Power, Karolinska Institutet

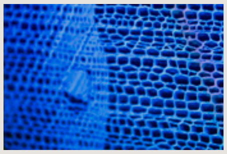
2009
Spruce tree genome, Swedish University of Agricultural Sciences

2012
25 research projects and 16 Wallenberg Scholars
—
Visiting professorships in green nutrition, Royal Swedish Academy of Agriculture and Forestry's 200th anniversary

2012
Foundation program for outstanding young scientists, 25 Wallenberg Academy Fellows

2013
28 research projects, 33 Wallenberg Academy Fellows, Grants for mathematics

2014
25 research projects, 29 Wallenberg Academy Fellows
—
Science activities at Nobel Prize Center

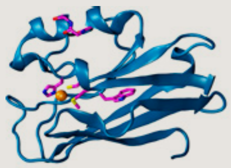


2016
Wallenberg Foundations grants to reduce exclusion

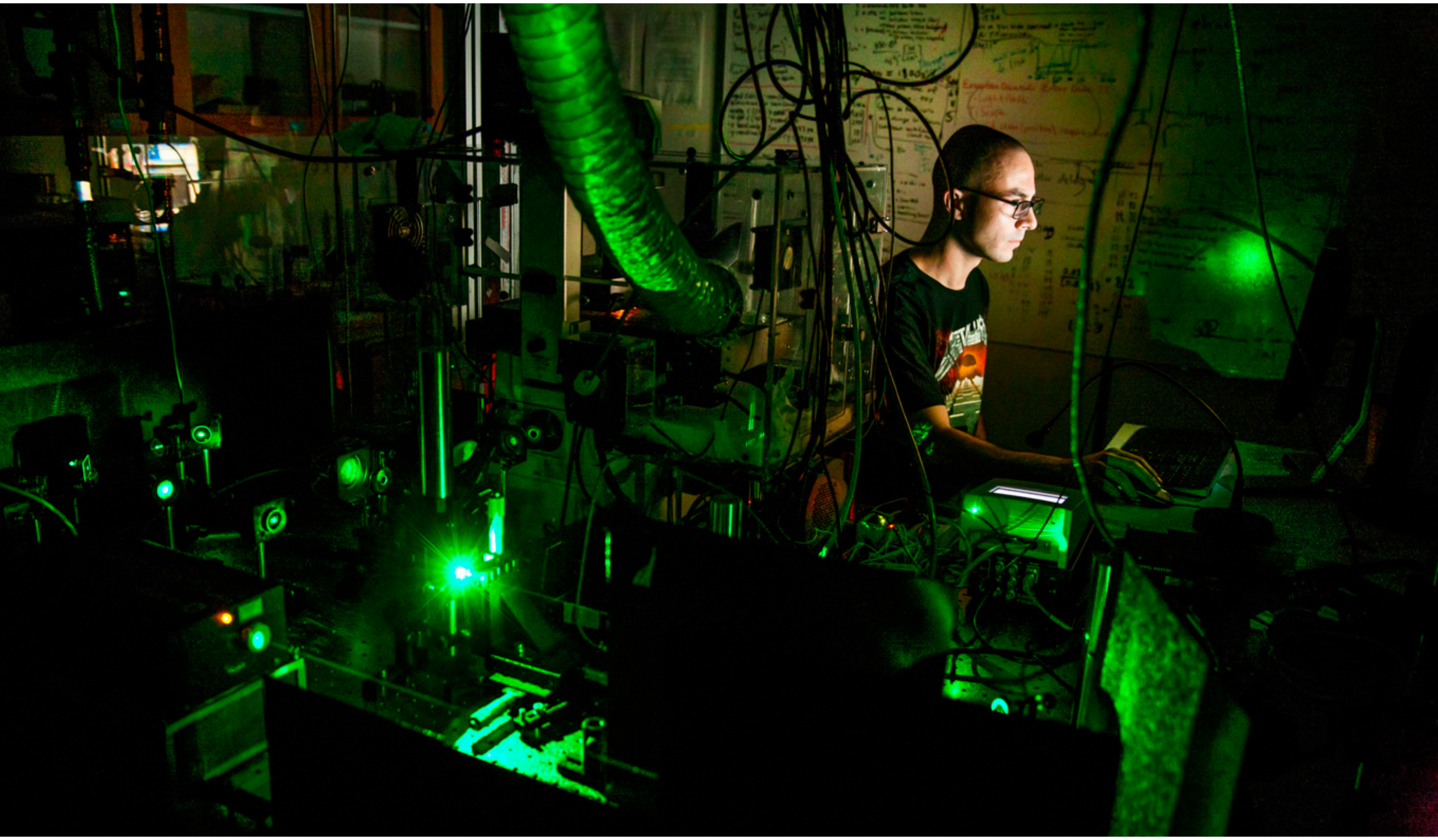
2016
22 research grants, 29 Wallenberg Academy Fellows, 5 Wallenberg Clinical Scholars

2015
27 project grants, 29 Wallenberg Academy Fellows, 4 Wallenberg Clinical Scholars

2015
Foundation grants for life sciences, autonomous systems, proteins, and biomedicines



GRANTS AWARDED 1992—2016, SEK 22 BILLION
GRANTS AWARDED 1917—2016, SEK 24 BILLION



At Johan Elf's laboratory at Uppsala University, researchers including Özden Baltekin study the physics of living cells.

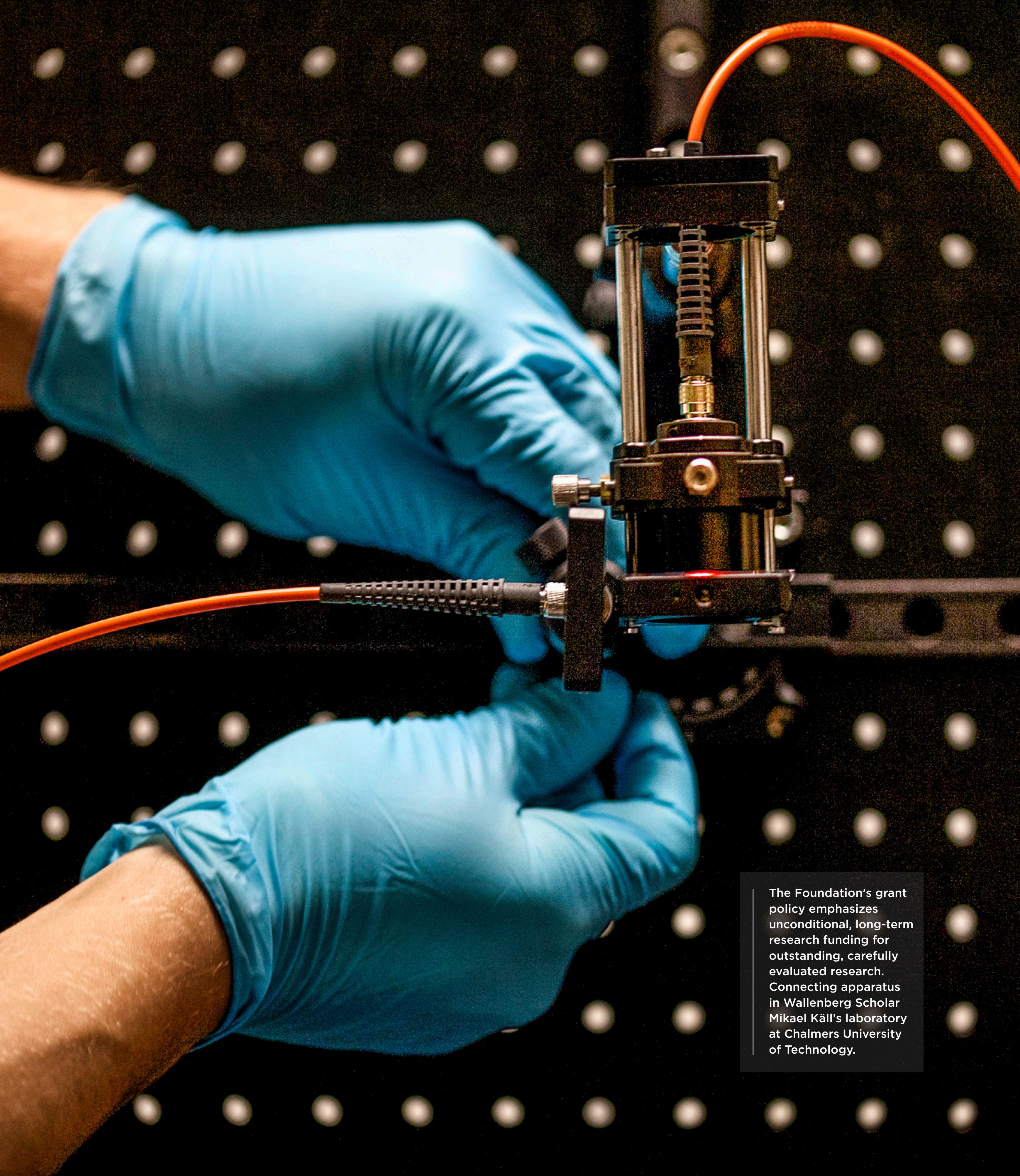
RESEARCH AND SUPPORT AREAS

Over the years, the Foundation has supported research in most major scientific domains, particularly medicine, technology, and the natural sciences. In the Foundation's early days, grants were awarded to support many types of activities, but soon a strategy emerged of providing construction grants to improve facilities for Swedish research and education. Later, the main policy was to provide grants for costly equipment, and since 2010 the focus has been on grants for specific projects and individual researchers. The types of grants awarded in recent years can be classified as support for outstanding researchers, project grants, infrastructure grants, strategic grants, and scholarship programs.

Yenan Bryceson of Karolinska Institutet and Lisa Hultman of Uppsala University attending a mentoring program meeting for 2014 Wallenberg Academy Fellows.

Project grants are researcher-initiated, and they must meet the highest international standards. Each project must address a coherent scientific issue, and the Foundation has chosen to prioritize projects within new research fields, particularly interdisciplinary areas where Swedish researchers are engaged in world-leading research. The Foundation has provided funds for outstanding scientists throughout its history, in the form of research and scholarship programs, project grants, and programs that support individual researchers. In recent years, however, providing individual grants—through the Wallenberg Scholars, Wallenberg Clinical Scholars, and Wallenberg Academy Fellows programs—has become one of the Foundation's top priorities. For many years, the Foundation has funded infrastructure in cases where universities have singly or jointly demonstrated that a certain technology is crucial to the progress of a scientific field. Two of the basic requirements for the infrastructure financed by the Foundation are that it must be open to all and must apply strict scientific criteria for access. A great deal of equipment has been financed in recent years through depreciation costs rather than direct investments, so those costs comprise a portion of a project or individual grant.

Strategic grants supplement the overriding principle for researcher-initiated projects. The areas for strategic grants have always been first identified internally within the Foundation and then passed along to the Foundation's Scientific Committee. The Foundation's Board of Directors then selects the strategic objectives to be pursued. Besides the strategic relevance requirement, the strategic areas must be of the highest scientific standard. The basis for determining a project's strategic relevance is that it must promote progress of Sweden's national research efforts and/or industry. Strategic projects are subject to expert evaluation according to the same principles as researcher-initiated projects ∎



The Foundation's grant policy emphasizes unconditional, long-term research funding for outstanding, carefully evaluated research. Connecting apparatus in Wallenberg Scholar Mikael Käll's laboratory at Chalmers University of Technology.

Arabidopsis thaliana is a model organism used in plant science.

LIFE SCIENCES

The science of all living things

The life sciences can be defined as the science of all living things. They deal with research into how living organisms function, interact, and affect their surroundings.

Biology and medicine are two major disciplines, but research within the life sciences is highly interdisciplinary, involving scientists from various fields such as technology, chemistry, physics, materials sciences, and pharmacology.

Research results have applications particularly in healthcare—in the development of pharmaceuticals, medical diagnostics, disease prevention, and therapeutic treatments—but also in veterinary medicine, plant science, and biotechnology. The life sciences also play increasingly sophisticated roles in industries such as forestry, paper and pulp manufacturing, and the food industry.

In basic life science research, various model organisms—such as fruit flies, worms, and yeast—are used together with exploratory technologies like genomics, proteomics, and metabolomics, integrated with advanced methods for analyzing massive datasets, to understand how organisms function on molecular to systemic levels.

Researchers have justified hopes that their studies of model organisms will provide foundations for understanding how other organisms function.

MORE, FASTER, CHEAPER

Today's rapid technological progress enables basic science to study complex biological processes increasingly efficiently. For example, both the costs of sequencing organisms' genomes and the time requirements are shrinking with each passing year.

The ever larger quantities of data generated by research in the life sciences provide new opportunities to extract information, but they also demand substantial resources and new expertise in statistics, bioinformatics, and large-scale data analysis—often referred to as "big data." These developments bring increasing demands for national and even international laboratories with access to advanced computing power.

MAJOR INVESTMENT

In 2014, the Foundation made a strategic decision to target additional major investment toward the life sciences.

Sweden has long been a world leader in this field, but a number of countries have made huge investments, enabling them to catch up with or even surpass Swedish research.

The Foundation has reserved a total of over SEK 2.5 billion for life science research for the period 2014–26. This is a direct continuation of the investment made in the early 2000s, when the Foundation contributed SEK 1 billion to enable Sweden to achieve leading-edge standards in life sciences within two frameworks: the Wallenberg Consortium North and Swegene.

One aspect of the new commitment to the life sciences is the Wallenberg Clinical Scholars program, a five-year initiative that enables 25 of Sweden's leading clinical researchers to focus on research and disseminate their results to other practitioners, while maintaining contact with patients in their role as clinicians.

Another part of the program provides support for career positions in the newly established centers for molecular medicine at Gothenburg, Lund, Umeå, and Linköping universities. These centers are being set up as counterparts to the government-run SciLifeLab, which has sites in Stockholm and Uppsala. Together with the Swedish government, the Foundation is the largest funder of SciLifeLab, which will serve as a source of technical support for Swedish researchers in the field.

The Knut and Alice Wallenberg Foundation has a long-term perspective, which is evident in the life sciences domain. When the targeted campaign finishes in 2026, the Foundation will have been active in the field's development for 25 years, through its grants for equipment, national infrastructure, projects, and individual researchers. A quarter-century is the kind of time needed to establish broad research competence in the field ∎

NMR—A VITAL TOOL

Nuclear magnetic resonance (NMR) imaging technology was initially developed in the mid-1940s. It has been crucial in many research breakthroughs in chemistry, biology, and medicine.

The technology is the same as that employed in MRI scans in healthcare. NMR technology has a wide range of applications and enables analyses to be carried out under natural conditions, with no need to modify or destroy samples. For example, it can be used to test new materials and to examine bacterial cultures and soil samples.

In chemistry, NMR has enabled determinations of the three-dimensional structure and movement of molecules, paving the way (with some refinements) for studies of proteins and protein complexes in natural settings.

Medical researchers use NMR technology to study tissue samples, proteins, and metabolite profiles. Samples of tissues can be taken during surgery, and their metabolite profiles can be immediately examined and compared to others previously characterized in healthy, abnormal, or diseased states. Researchers can even observe changes in individual proteins, and associated metabolic shifts, resulting from genetic mutations.

In molecular biology, NMR technology can provide crucial insights into the molecular-level organization of cell components and fundamental information about the mechanisms that govern functions of living cells. Thus, it has increasingly important roles in cellular and organobiological research.

NMR technology is indispensable in the life sciences because it enables studies of proteins in environments resembling those in living cells. Perhaps the most important applications for NMR are in the pharmaceutical industry. Researchers can investigate how all kinds of pharmaceutical molecules interact with the body's proteins. So, large numbers of molecules can be tested in early stages of pharmaceutical product development, which is vital for the development of "personalized medicine"—tailor-made pharmaceuticals for individual patients.

THE SWEDISH NMR CENTER

The Swedish NMR Center is a national, inter-university research framework located at the University of Gothenburg that has received several million kronor in grants from the Foundation. Originally, the facility was sited in Stockholm following a donation from the Swedish Tobacco Company. After a proposal from the University of Gothenburg and a donation from the Hasselblad Foundation, the Hasselblad Laboratory was opened in 1997. At the time of the relocation, the Knut and Alice Wallenberg Foundation provided a grant of SEK 25 million for a new spectrometer. That also marked the start of efforts to centralize the most expensive types of NMR technology in national centers.

THE NOBEL PRIZE IN CHEMISTRY

In the 1980s, Kurt Wüthrich developed NMR techniques for analyzing proteins. One of the advantages of these techniques is that they can be used to characterize proteins' structures and interactions in solutions that resemble cellular environments.

Changes in proteins' molecular shape often play key functional roles. Prof. Wüthrich was awarded the 2002 Nobel Prize in Chemistry for his work.

The Swedish NMR Center is located in the Hasselblad Laboratory on the University of Gothenburg campus.

NMR

The abbreviation NMR stands for *nuclear magnetic resonance*. It is used to analyze the composition and other properties of molecules.

NMR FOR LIFE

The Foundation's support of NMR technology continued in 2012 in the form of a grant for the NMR for Life infrastructure, which combines the expertise of Sweden's two leading NMR labs in Gothenburg and Umeå. Its current focus is on life sciences, primarily structural biology, metabolomics, and chemical biology. NMR for Life is an important resource for research in medical, plant, and other life sciences, as well as for materials sciences. The investment is supplemented by the two participating universities and a grant from the Kempe Foundations for the Umeå site. In 2015, the facilities in Gothenburg and Umeå also became nodes in the SciLifeLab network.

NMR technology has led to the development of new methods for studying changes in plant physiology over the past century. For example, in 2015 researchers at Umeå University and the Swedish University of Agricultural Sciences (SLU) used it to demonstrate that increases in atmospheric carbon dioxide levels in the 20th century had altered plants' metabolism.

The Foundation has also funded several hundred million kronor worth of NMR equipment at other sites in addition to the centers mentioned above ∎

TECHNOLOGY THAT CAN LOOK INSIDE THE BRAIN

MRT, fMRI, PET, and MEG: a mass of different abbreviations. A shared feature is that they are all technologies used in research and healthcare to view functional activities in the brain or to detect harmful changes.

These technologies have revolutionized brain and memory research. But the equipment places great demands on facilities and budgets. It is another example of a research infrastructure that has benefited from several sizable grants from the Foundation over the years.

The development of magnetic imaging cameras and fMRI technology in the early 1990s enabled breakthroughs in brain research. At last, it was possible to see which parts of the brain were activated during different types of tasks. In turn, those findings generated new knowledge about brain functions. This technology is indispensable in healthcare, making it possible to identify, locate, and treat tumors and other harmful conditions. It also paves the way for new treatment methods and enhanced understanding of many neurological and mental disorders.

MRT (magnetic resonance tomography) utilizes knowledge about magnetic resonance, which led to an imaging technology that earned a Nobel Prize in medicine. It is used to identify and classify certain disorders and injuries.

fMRI (functional magnetic resonance imaging) is used to measure brain activity. It allows us to see what is happening inside the brain as it works. In places where the brain is more active, the blood contains more oxygen. Because oxygen-rich blood has different magnetic properties than oxygen-poor blood, a magnetic imaging camera can be used to see which parts of the brain are active. The advantage of fMRI is that it does not require radioactive tracers. This method has been used to identify areas of the brain associated with particular activities, such as movements. MR imaging cameras, which can generate strong magnetic fields, make it possible to identify pathological changes associated with impairments of brain functions, such as dyslexia, ADHD, or degenerative conditions such as Alzheimer's disease.

PET (positron emission tomography) is a type of imaging involving use of isotopic (radioactive) markers or tracers to generate three-dimensional images of metabolic processes in the brain or to show how various substances move through the body.

MR: TECHNOLOGY THAT GOES BY SEVERAL NAMES

MR, MRT, or MRI—magnetic resonance tomography or imaging is based on the phenomenon of nuclear spin resonance, which has been studied since the 1940s.

The technology underlying the imaging technique was developed in the early 1970s by the chemist Paul Lauterbur and the physicist Sir Peter Mansfield, who were jointly awarded the Nobel Prize in Physiology or Medicine in 2003. In the 1980s, MR technology began to be used in healthcare.

MEG (magnetoencephalography) is an advanced method for measuring nerve activity in various parts of the brain. This technique is used to ascertain (among other things) how different areas are involved in regulating anxiety, placebo effects, memory and learning, self-awareness, proprioception, language, and motor skills.

In the 1990s, the Foundation made grants of almost SEK 80 million to Karolinska Institutet and Uppsala University for PET equipment and another nearly SEK 140 million to Karolinska Institutet, Lund University, Linköping University, and Umeå University for MRT and MEG equipment.

NATMEG, the Swedish National Facility for Magnetoencephalography, was opened in 2013.

The facility is a national infrastructure within Karolinska Institutet dedicated to the study of cognitive and emotional processes in the brain. Its MEG equipment was financed through a grant from the Foundation. The center's main focus is on advanced basic research, along with some clinical projects. Some examples of the center's studies include investigations of exercise effects on mobility in stroke patients, MEG-based identification of biomarkers for the progress of Alzheimer's disease, and pre-surgery localization of epileptic foci.

One of the Foundation's major funding initiatives in this area is the Center for Medical Image Science and Visualization (CMIV), a cross-disciplinary research initiative based at Linköping University. Working with the Visualization Center C in Norrköping, CMIV has coordinated clinical practice and research in techniques and medicine to generate new solutions to future clinical issues.

The Foundation has provided over SEK 200 million to support the development and use of these imaging technologies ■

DEVELOPING MEG TECHNOLOGY

MEG equipment is very costly.

There is just one MEG instrument in Sweden. Researchers from Chalmers, the University of Gothenburg, and Karolinska Institutet received a project grant from the Foundation to develop a cheaper, simpler version of the technology. The sensors used in MEG are based on a component called a SQUID (superconducting quantum interference device).

The new method uses nanothread sensors that are superconducting in liquid nitrogen—known as high-temperature SQUID.

MRI equipment in Umeå, which is used by researchers including Lars Nyberg.

Elisabet Carlsohn of the Sahlgrenska Academy at the University of Gothenburg uses equipment financed through Swegene.

STRONG NATIONWIDE COLLABORATION IN FUNCTIONAL GENOMICS

The Wallenberg Consortium North and Swegene

The Human Genome Project was an international research project launched in 1990 to establish the exact sequence of the approximately 3 billion base pairs that make up human DNA. When the draft of the human genome was published in 2000, the Foundation moved to finance a five-year research project in functional genomics. That project was a continuation of the analysis of the human genome and basic research to understand its functions.

Advances in the late 20th century had brought about a scientific revolution, and expectations were high for further research to revolutionize pharmaceutical research, healthcare, food research, plant breeding, and other fields.

Aware of the strength being assembled internationally in the field of genomics and its potential significance for Sweden's industrial development, the Foundation conducted discussions with some of the leading figures in the field concerning a possible initiative to secure the position of Swedish research.

With access to major biobanks at Swedish university hospitals and other facilities, along with Swedish demographic records, the nation's researchers have a resource unique in the Nordic countries that greatly facilitates analysis of genes' functions. Scientists at Swedish institutions had a clear competitive advantage that was there for the taking. To do that would require a supreme combination of experts, including not just structural biologists, medical practitioners, molecular biologists, and biochemists, but also mathematicians, computer scientists, physicists, and engineers. The field also touched on sensitive ethical issues that had to be addressed.

TWO CONSORTIA

The Swedish research teams formed two consortia: the Wallenberg Consortium North (WCN), centered in the Mälardalen region near Stockholm, and Swegene, located in southwest Sweden. WCN linked the universities of Linköping, Stockholm, Umeå, and Uppsala along with Karolinska Institutet, KTH Royal Institute of Technology, and the Swedish University of Agricultural Sciences (SLU). Swegene included the University of Gothenburg, Lund University, and Chalmers University of Technology.

FUNCTIONAL GENOMICS
is a field within molecular biology that involves analysis of activities of thousands of genes to understand the genetic interactions in a cell or organism.

The consortia were tasked with setting up technical platforms and resource centers to be shared by the researchers, because the equipment and other necessary infrastructure was so costly. The project also entailed the introduction of new working methods and forms of collaboration. The universities began to cooperate to apply for grants for high-tech equipment, and scientists started working in networks. Several hundred researchers were involved in the project overall. It was the largest single biomedical research project launched in Sweden to date.

The Foundation invested a total of nearly SEK 900 million in the consortia, and universities contributed a further SEK 165 million. Both consortia formally ceased operations in 2005, but collaborative efforts continued in various forms, notably the newly established SciLifeLab and the new centers for molecular medicine in Lund, Gothenburg, Linköping, and Umeå.

WHAT CAME AFTER WCN? REFLECTIONS BY PROF. LARS TERENIUS

WCN had a thematic objective to cluster activities in strong environments. These were largely centered around "strong" team leaders, in order to maximize exploitation of the new technologies. The key areas were:

- Genotyping, primarily through investment in Uppsala, which was developed into a world-class unit that forms the basis of SciLifeLab along with investment from Karolinska Institutet.
- Investigatory studies in gene duplication, epigenetics, and mitochondrial DNA, which have since been picked up by sites including SciLifeLab.
- Proteomics, a fundamental component of Mathias Uhlén's Human Protein Atlas initiative.
- Bioinformatics, with major investment in increasing expertise, later picked up by SciLifeLab and other sites.
- Targeted investments in Umeå, the Umeå Plant Science Centre (UPSC), genetics, and plant biology at global cutting-edge levels.

THE LEGACY OF SWEGENE: REFLECTIONS BY PROF. STURE FORSÉN

Within Swegene, a new organization was formed at Lund University called SCIBLU (the Swegene Center for Integrative Biology at Lund University), which brought together the most successful Swedish infrastructure platforms in proteomics and genomics. These continue to serve as "core facilities," with financing coming jointly from Lund University and other stakeholders. The Foundation's investment in functional genomics resulted in the establishment of CREATE Health, a translational cancer center within Lund University, in 2005. CREATE Health focuses on patient-centered cancer research and has attracted hundreds of millions of kronor in external funding since its establishment, along with several hundred jobs and five companies, some of which are listed on the stock exchange.

At the University of Gothenburg, several "core facilities" have been established within the Sahlgrenska Academy. These facilities are rooted in infrastructures built up in the Swegene program. One highly respected center is the Mammalian Protein Expression (MPE) lab producing recombinant mammalian proteins. Its specialties include production of proteins with post-translational modifications, such as glycosylation. Another unique facility with excellent equipment is the Center for Cellular Imaging, which offers all the instruments required for advanced optical studies, including time-resolved analyses of biological phenomena at cellular and molecular levels ■

SWEDEN'S NATIONAL BIOBANK PROGRAM

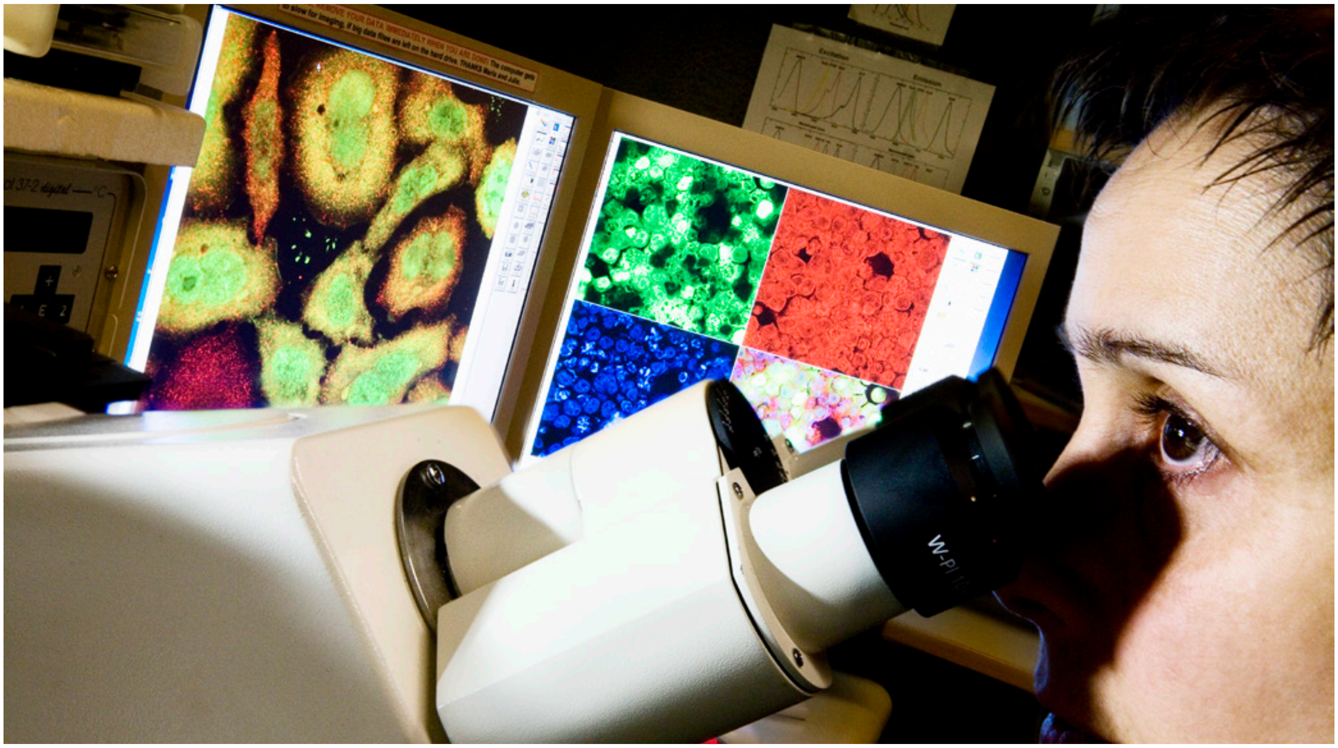
WCN and Swegene also jointly funded a national program to coordinate the bulk of Sweden's most significant biobanks.

The aim was to obtain a better overview of the holdings and enhance the usability and quality of the samples and tissues collected for research or routine hospital examinations and treatments. Protecting the donors' anonymity was another important consideration.

At the time, many biobanks served mainly as regional resources, and relatively few research studies were based on biobank samples.

The program focused on developing biobanks into national resources and prioritizing the use of samples only where scientifically justified. The program supported collection as well as distribution of samples, and training in appropriate use and compilation of biobanks.

One clear outcome was an increase in the number of published studies that utilized samples from Swedish biobanks. Several of the findings also helped to increase the visibility of biobanks as a health resource.



Julia Fernandez-Rodriguez at the Center for Cellular Imaging, a Swegene-supported core facility at the Sahlgrenska Academy.

Large biobanks, combined with Sweden's demographic databases, provide unique resources for analyzing functions of genes.

PROTEIN RESEARCH

Hopes for new drugs

Many diseases are linked to changes in proteins, so there is great hope that increasing our understanding of proteins will also lead to more effective treatments and new medicines for diseases that are currently untreatable.

Notably, accumulations of proteins or disturbances in the body's production of proteins play significant roles in the development of neurodegenerative illnesses such as Alzheimer's disease, dementia, Parkinson's disease, and ALS, as well as diseases like Type 2 diabetes and cancer.

Proteins are the body's building blocks. They are used for repairing and building new cells and tissues. Proteins are vital because they have myriads of functions, linked to unique three-dimensional conformations and properties.

All drugs essentially work by activating or deactivating proteins in the body. Understanding the structure, shape, function, and location of different proteins in the body is therefore crucial for creating effective medicines.

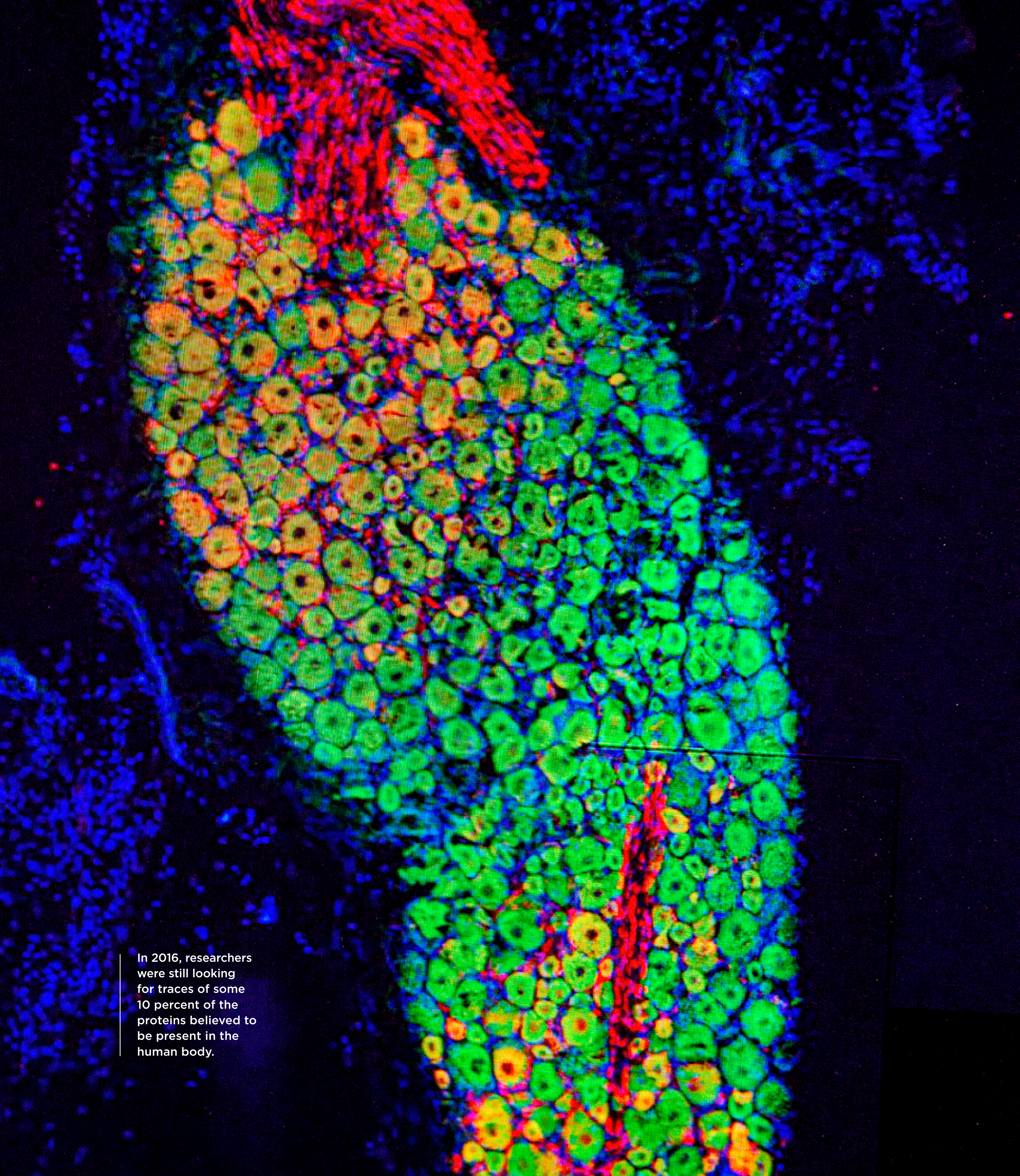
The mapping of the human genome in the early 2000s laid the foundations for another major biological initiative: systematic mapping of the human proteome, i.e. all the proteins encoded by our genes. This was carried out in the largest scientific project ever undertaken in Sweden: the Human Protein Atlas Project. The project, which was awarded SEK 900 million in grants by the Foundation, in turn formed the basis for the Wallenberg Centre for Protein Research (WCPR), an international protein research center focusing on studies of human proteins and production of biopharmaceuticals.

CRYO-ELECTRON MICROSCOPES

As part of its multi-billion-kronor investment in the life sciences, in 2014 the Foundation awarded around SEK 100 million for two new cryo-electron microscopes with high-resolution detectors. The microscopes were installed at Umeå University and SciLifeLab in Stockholm, but they are available for use by scientists from anywhere in Sweden. For certain types of proteins, these microscopes are a simpler alternative to X-ray crystallography, previously the main approach for determining the structure of proteins.

These microscopes are equipped with a new kind of electron detector that makes it quicker and easier to determine the structure of large proteins and protein complexes, including the types of proteins found in cells' protective membranes (which typically contain about a third of cells' proteins). Membrane proteins have many functions, and understanding their structures and characteristics is vital for the development of new drugs. In fact, just over half of all current drugs target membrane proteins ■

Proteins have numerous essential functions, which are often used to classify them. Some examples are transport proteins, structural proteins, and defense proteins.



In 2016, researchers were still looking for traces of some 10 percent of the proteins believed to be present in the human body.

A GIANT ATLAS OF MANKIND'S MACHINERY

Major headlines were made all over the world in 2001 when researchers announced they had mapped our genome—deciphering the blueprint for the human race. Swedish researchers are now taking this knowledge one step further. They have mapped every protein, all of the cogs in the human machinery that converts the genetic blueprint into a real, functioning body.

Sweden has a proud tradition of analyzing systems that are fundamental to science. In the 18th century, Carl Linnaeus categorized all living creatures, plants, and animals by dividing them into orders, genera, and species. In the 19th century, the chemists took over. Spearheaded by Jöns Jacob Berzelius, they searched for new elements. A total of 19 of the periodic table's 118 elements were identified by Swedish researchers.

Researchers from KTH Royal Institute of Technology in Stockholm and the Science for Life Laboratory (SciLifeLab) in Solna and Uppsala will soon join those illustrious ranks. In what is known as the Human Protein Atlas Project, they are mapping every cog in the human machinery—all of the proteins that build and control our bodies.

"After the equivalent of 1,000 person-years of work, our analysis is now complete," said Mathias Uhlén, Professor of Microbiology at KTH and head of the project that has been underway since 2003.

The key results were announced in November 2014, with a more detailed presentation published in an article in the journal *Science* in January 2015.

MATHIAS UHLÉN

Professor of Microbiology, KTH Royal Institute of Technology and scientific director of the project.

Researchers from KTH, Uppsala University, and SciLifeLab, a joint venture between Karolinska Institutet, KTH, Stockholm University, and Uppsala University, have mapped proteins encoded by about 20,000 genes in the human body.

The HPA project has been awarded a total of SEK 900 million in grants.

The protein atlas, which is actually in the form of a database, is accessible to everyone. Users might include pharmaceutical companies working on new drugs, doctors looking to improve their diagnoses of illnesses, or researchers who need a reference to compare tissues in healthy and sick people. The atlas will serve as a powerful tool in the fight against cancer, cardiovascular disease, and disorders of the nervous system.

PROTEINS ARE THE TOOLS OF LIFE

In the 1990s, Prof. Uhlén was involved in the mapping of the human genome in the "Human Genome Project." In that project, researchers identified the complete set of human genes, some 20,000 in total. However, this is only the blueprint for constructing a human being. Most genes contain a code for a specific sequence of amino acids to form a specific protein, which carries out the encoding gene's role, as specified in the blueprint. Some proteins function as building blocks, such as myosin and actin in the muscles. Other proteins, called enzymes, catalyze chemical reactions. Still others work as hormones or signaling substances, or sit in our sense organs and detect flavors and odors.

"I want to transform all the data in the Protein Atlas project into knowledge." —Mathias Uhlén.

To fully understand how the human body works, we need to know how all of these proteins cooperate. In the 1990s, Prof. Uhlén began to wonder if it would be possible to map the human proteins in the same way that people had begun to map all of our genes.

"We began to do some pilot studies, and in 2002 we presented our ideas to the Knut and Alice Wallenberg Foundation," he explained.

They received some initial funding, which was followed by additional grants. Eleven years and a total of SEK 900 million in grants from the Foundation later, all the proteins had been mapped. The Atlas includes 13 million images of proteins. One unexpected discovery during the project was that around half of our 20,000 proteins are fundamental components of all the body's cells.

"When we started the project, we thought we'd find what kinds of renal proteins enable our kidneys to filter blood, and which proteins in the brain enable us to think. But what we've found is a kind of Lego system, with relatively few building blocks that are used everywhere in differing quantities," he said.

WORLDWIDE COOPERATION

While the project is run from Sweden, many countries are involved. The entire process begins with researchers at KTH inserting parts of a human gene into the genetic material of a bacterium; in most cases, this gene has never been studied before. The bacterium is then converted into a protein factory. With the gene as a blueprint, it produces the unknown protein. This is then sent off to South Korea or China. There, rabbits are vaccinated with the protein. The rabbits then produce antibodies that specifically recognize and attach to the unknown human protein.

These antibodies are keys in the project. The researchers use them like molecular fishing rods. They connect fluorescent molecules to the antibodies so they can be traced, and then they go "fishing" for the unknown protein in tissue samples. Is the protein in the brain? In the heart? Or maybe in the kidneys? And what part of the cells is the protein in? In the nucleus? On the surface? Or a little here and there?

The research is done in three places in Sweden: Solna, Uppsala, and Lund. Using the fluorescence from the antibodies, the researchers can take pictures showing locations of the targeted proteins in the tissues.

So far, they have amassed 13 million images, all of which have been manually reviewed by a pathologist in India.

A DATABASE WITH HEALTHY AND DISEASED TISSUE SAMPLES

All the information about the various proteins is compiled and saved in an open-access database, freely accessible at www.proteinatlas.org.

"We send off around 150 antibodies a day, and every day about five articles are published in scientific journals based on antibodies from here," Prof. Uhlén noted.

The Human Protein Atlas Project has also been supplemented with a number of side projects. These include searches for proteins linked to various kinds of cancer, Alzheimer's disease, rheumatoid arthritis, multiple sclerosis, and numerous other diseases. The researchers use these discoveries for future studies that can lead to new understanding of how the building blocks in human machinery work together. When researchers know which piece has failed, it is easier to find ways to get the machinery working smoothly again ■

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PERCENT OF PROTEINS ARE MISSING

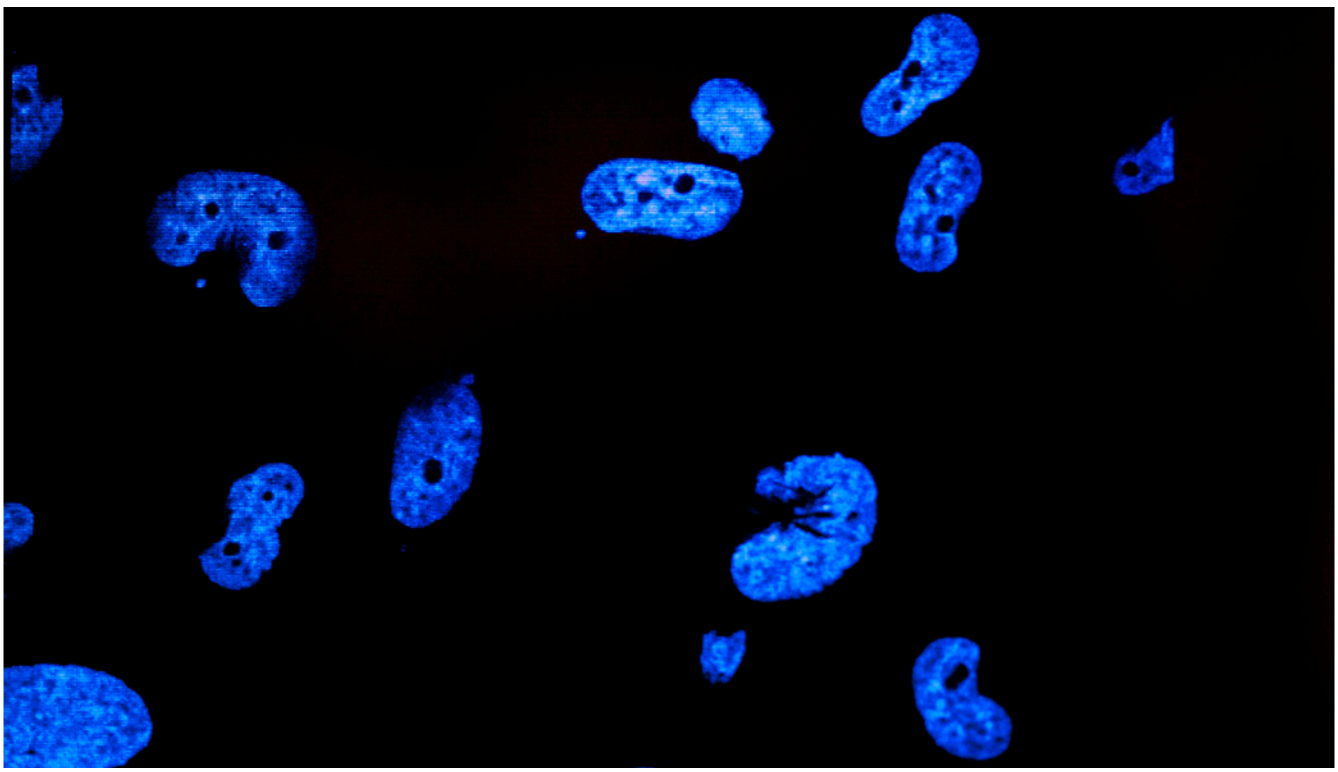
The Atlas provides an overview, showing why our bodies' tissues differ so much although our cells contain the same genetic material.

Researchers were surprised that the different tissues did not contain many different types of proteins. Of the approx. 20,000 proteins studied, 44% were present at varying levels in all tissues examined. This is believed to show that most proteins are needed to maintain basic functions in the body such as cell division, energy production, and metabolism.

Of the remaining proteins, 32% were present in several tissues but not all, while 12% were found in only a single tissue type. The testicles stood out as the organs with the biggest share of unique proteins.

Researchers have still not found 10% of the proteins believed to be present in our bodies. Finding them is one of their future challenges.

There is plenty of activity at the SciLifeLab. Around 1,000 person-years of work went into mapping all the proteins.



JOINING FORCES IN PROTEIN RESEARCH AND BIOPHARMACEUTICALS

The Wallenberg Centre for Protein Research (WCPR) focuses on studies of human proteins and production of biopharmaceuticals.

The WCPR combines basic research with the development of practical applications, particularly techniques to produce biopharmaceuticals. Biopharmaceuticals, which are produced from the body's own proteins, have revolutionized medicine, creating new ways to treat illnesses. One of the most widely known is insulin for the treatment of diabetes, and in recent years several biological treatments for arthritis have been created.

There are numerous types of proteins, including hormones and enzymes, but the most relevant in this context are antibodies. Rapid advances are currently being made in the development of antibodies for treating cancer and autoimmune disorders. In the future, many more illnesses are expected to be treatable with biopharmaceuticals, based primarily on antibodies. This is the focus of one of the WCPR's five programs.

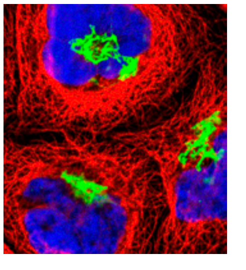
The WCPR has sites at the AlbaNova University Center at KTH Royal Institute of Technology, SciLifeLab in Stockholm, Uppsala University, and Chalmers University of Technology in Gothenburg.

Some small research companies and major pharmaceutical companies are also involved in the development of new production techniques for biopharmaceuticals.

FIVE PROGRAMS

The Foundation's new investment in the WCPR can be regarded as an extension of its previous support for the life sciences. The center is largely based on the infrastructure and knowledge built up in the course of the Human Protein Atlas (HPA) project.

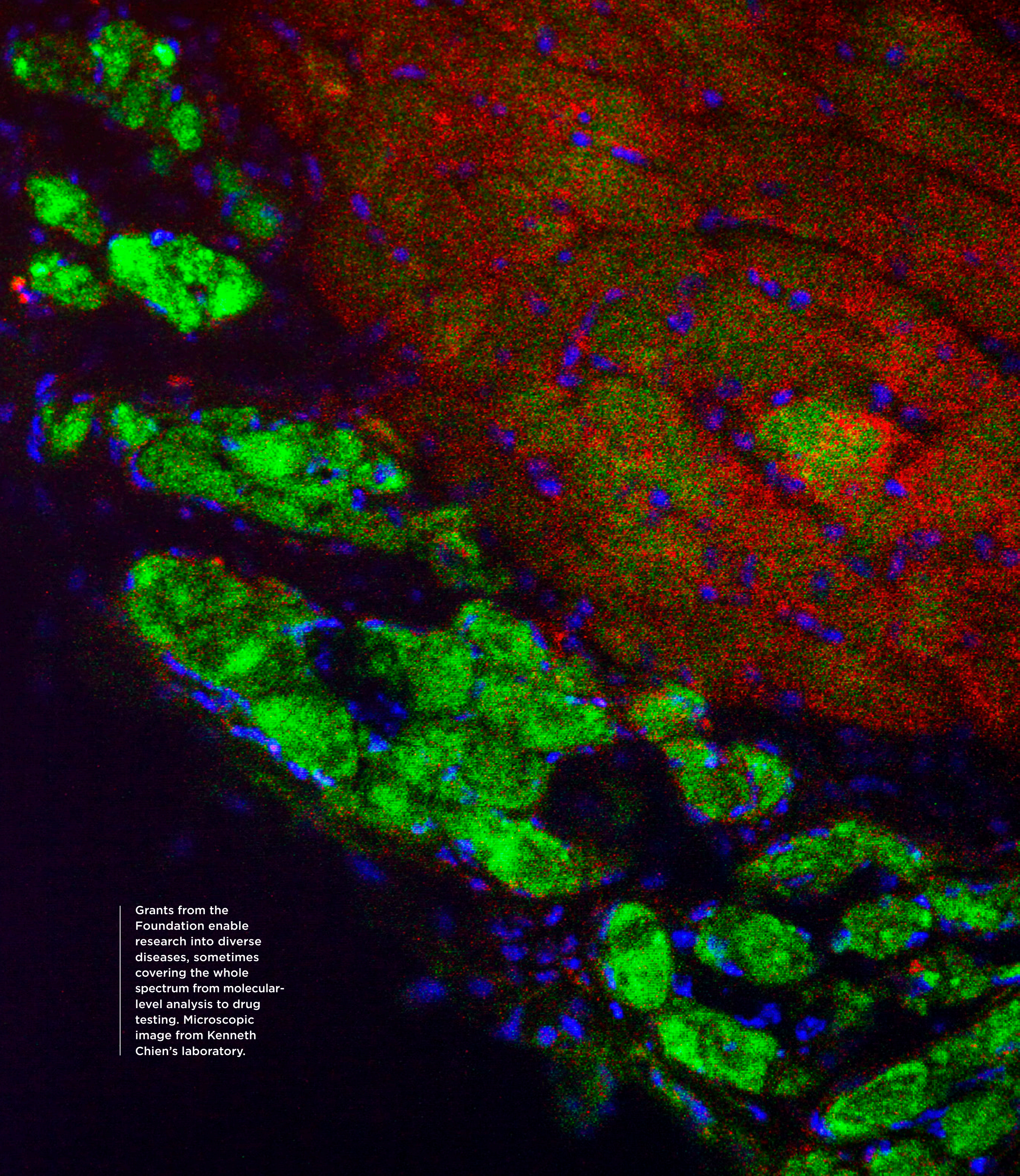
The WCPR is continuing the HPA's mapping of the human proteome—all the proteins in the human body—and it includes research programs to develop cellular factories for producing biopharmaceuticals; that is, bioproduction of all the proteins made by the human body as well as new concepts for antibody therapy and systemic biology studies of proteins relevant to pharmaceutical development. In 2015, the Foundation resolved to award the WCPR a grant of SEK 320 million ■



WCPR'S OPERATIONAL OBJECTIVES:

- Create new proteins
- Produce proteins at large scale by building platforms for new cellular factories
- Develop new biopharmaceuticals

The HPR laboratory in 2006. Sophia Hober, project leader, with Henrik Wernérus.



Grants from the Foundation enable research into diverse diseases, sometimes covering the whole spectrum from molecular-level analysis to drug testing. Microscopic image from Kenneth Chien's laboratory.

MEDICINE— FROM MOLECULES TO PATIENTS

Public health problems like diabetes, cardiovascular disease, and cancer; widespread illnesses like Alzheimer's and Parkinson's diseases; infectious diseases; and rarer illnesses such as ALS (Lou Gehrig's disease) and congenital metabolic disorders... a long list of diverse diseases. A shared feature is that the Foundation is providing support to study them at the molecular level—in some cases, all the way up to the drug-testing stage.

The Knut and Alice Wallenberg Foundation's primary area of support is for basic research—all the unconditional research that leads to new knowledge, thereby laying foundations for the development of new drugs and treatments.

In addition to its Wallenberg Scholars and Wallenberg Academy Fellows programs, and project grants, in 2014 the Foundation joined with the Royal Swedish Academy of Sciences to launch the Wallenberg Clinical Scholars program for clinical researchers. Its aim is to provide a decade-long boost for clinical research by supporting the 25 leading clinical researchers in Sweden, enabling them to dedicate efforts to research while seeing patients in clinical settings.

Clinical research links patient care and basic research. Taking a sample in Bo Angelin's laboratory at Karolinska Institutet.

BUILDING BRIDGES

Clinical research serves as a bridge between patients and basic research. It rapidly brings new knowledge to bear in healthcare, while the knowledge gained through physicians' interactions with patients feeds back into basic research.

The Wallenberg Clinical Scholars program is part of the Foundation's SEK 1.7 billion in targeted investment to improve medical and life science research—in addition to the approximately SEK 6 billion the Foundation is estimated to grant to the medical field in general—from 2014 to 2025.

Medical research requires increasingly advanced, complex and costly research equipment. Over the years, the Foundation has provided grants for all kinds of vital equipment necessary for globally elite medical research ■

THE KEY TO UNDERSTANDING AND TREATING CHILDHOOD OBESITY

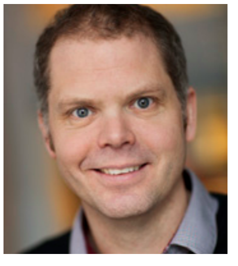
Prof. Fredrik Bäckhed and his research team at the University of Gothenburg are investigating a hypothesis that lean and overweight individuals have different intestinal microbiota. If they succeed in identifying bacteria that protect against obesity, it would also be possible to develop probiotics that prevent development of childhood obesity.

"The dream scenario is to develop a probiotic—a bacterial culture—that can be given to children who lack the protective bacteria. It could be administered as drops, like a vitamin supplement, or in capsules or yogurt," said Prof. Bäckhed, director of the Wallenberg Laboratory for Cardiovascular and Metabolic Research in Gothenburg.

The intestinal microbiota develops in the first years of life from birth, providing a window of opportunity when it can be manipulated—an opportunity not available in adults.

Excess weight and obesity are huge health problems in large parts of the world. Sedentary behavior and junk food are the most common explanations. But since the early 2000s, researchers have started to direct their attention to the role of intestinal bacteria in the development of obesity and other "lifestyle diseases," as well as allergies.

It was when Prof. Bäckhed worked with Jeff Gordon, a U.S. researcher, and discovered that germ-free mice did not develop obesity that this field really took off. At the same time, new sequencing techniques enabled scientists to map genomes and sequence bacteria in fecal samples.



FREDRIK BÄCKHED

Professor of Molecular Medicine, University of Gothenburg.

Principal investigator of the project "The gut metagenome as a novel target to treat childhood obesity."

Co-investigator: Jovanna Dahlgren.

Project grant in 2012
Grant awarded:
SEK 30.8 million over five years.

MAPPING THE DEVELOPMENT OF INTESTINAL MICROBIOTA

The intestines contain 10 times more bacteria than there are cells in the human body. Some bacteria are beneficial, while others can cause disease if their numbers grow out of control. Together, they form an internal ecosystem.

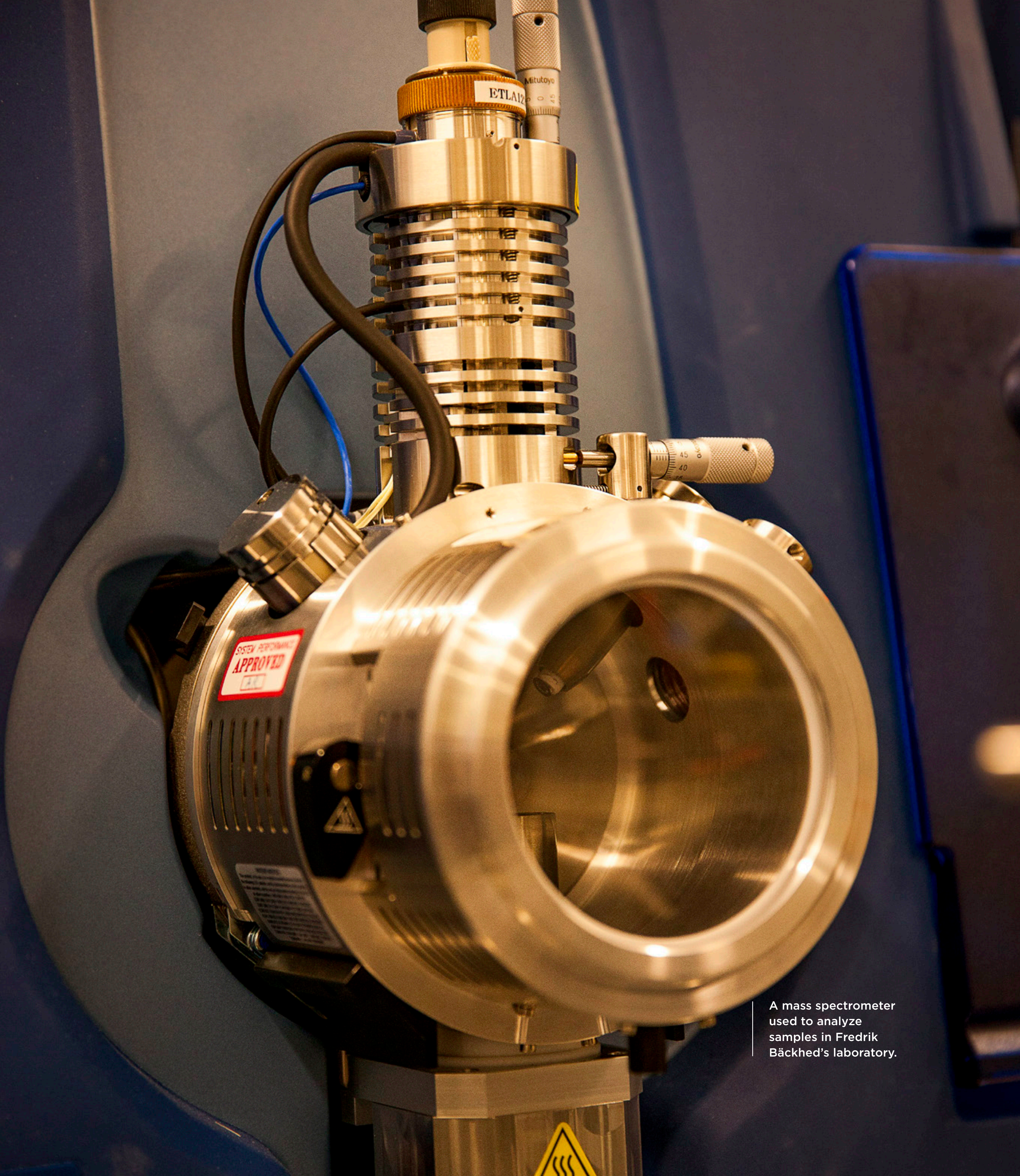
"The significance of the normal intestinal microbiota has been forgotten. It was a popular subject of study in Pasteur's era. However, it is also much more difficult to study than pathogenic bacteria—the kinds that cause diseases such as *Salmonella*," Prof. Bäckhed explained.

His interest in the link between intestinal bacteria and obesity was inspired by Jovanna Dahlgren and Josefin Rosvall, physicians and researchers at Queen Silvia's Children's Hospital, who conducted a study of childhood obesity in Halmstad, Sweden.

"They studied 3,000 children born the same year and concluded that the intestinal microbiota was a factor of interest," he said.

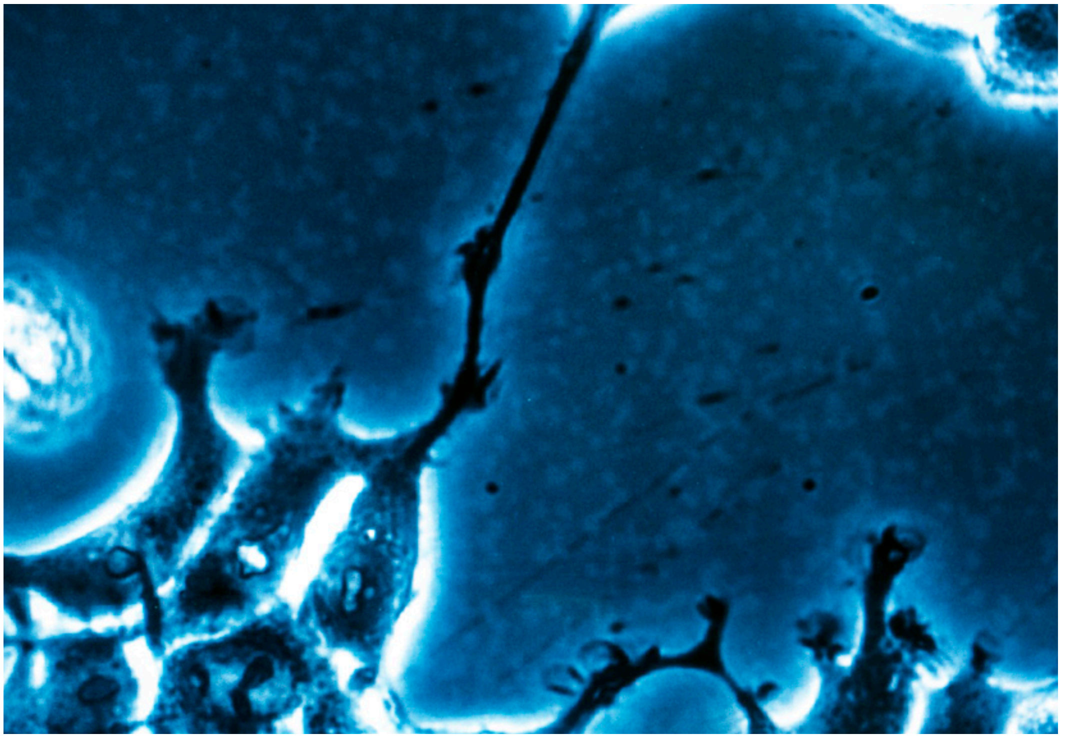
In 2008, a partial study was initiated with 620 children, 120 of whom were born by caesarian section. The mother's stool bacteria are transmitted to children born vaginally, while children born by caesarian ingest skin bacteria.

A database was set up with details of breastfeeding, formula feeding, and fecal samples from mothers and children at birth. Samples were also collected at regular intervals until the children reached five years of age.



A mass spectrometer used to analyze samples in Fredrik Bäckhed's laboratory.

Fredrik Bäckhed is working to develop probiotics—helpful bacteria—to combat childhood obesity.



The intestinal bacterial microbiota is attracting intense interest. Increasing numbers of illnesses are being linked to its composition.

"Because excess weight and obesity are relatively common, we expected that several of the children in the group would develop childhood obesity. The samples are helping us determine whether the intestinal microbiota are involved. We're mapping the development of intestinal bacteria from birth to age five," Prof. Bäckhed explained.

A LACK OF HELPFUL BACTERIA

These longitudinal studies take time, so to accelerate the investigation, experiments were also run with germ-free mice.

"The objective is to understand the development, composition, and function of the intestinal microbiota. We intend to do that by transferring microbiota from slim and overweight children into germ-free mice. That should enable us to identify bacteria associated with obesity and see whether they also increase fat storage in mice," Prof. Bäckhed summarized.

The researchers' hypothesis is that children who develop obesity lack certain bacteria that lean children have.

"In adults, current knowledge indicates that obese people have less complex intestinal microbiota than lean people. So, our hypothesis is that early disturbances in the intestinal microbiota may have consequences later in life," Prof. Bäckhed added.

WHICH IS THE CAUSE AND WHICH IS THE EFFECT?

So, the researchers know that people have different intestinal microbiota, but the question is, which comes first, the chicken or the egg?

"We still don't know whether the intestinal microbiota causes obesity, or if obesity affects the intestinal microbiota. Thus, we believe that our animal experiments and longitudinal studies of children—starting even before they develop obesity—can help us understand whether intestinal bacteria directly contribute to obesity," he said.

Cardiovascular disease and illnesses like asthma, allergies, Type 1 diabetes, celiac disease, gluten intolerance, and colic are also linked to intestinal microbiota ∎

2

KILOGRAMS OF BACTERIA

We have 1 to 2 kilograms (2.2–4.4 lbs.) of bacteria in our intestines. The number of bacteria is 10 times the number of cells in our body.

The intestinal tract is like a separate community in our body. The gut has its own nervous system and its own "population" of several billion intestinal bacteria.

Opinions are divided on numbers of bacterial strains that colonize our gut, but estimates range between 500 and 1,000 out of a total 6,500 recorded species.

DEFUSING PNEUMOCOCCAL BACTERIA

Infectious diseases are the second most common cause of death in the world. Among children under the age of five, lower respiratory infections claim the most lives. Researchers still cannot say for certain why some people get sick and others do not. One theory is that the early immune defense system plays a key role.

Birgitta Henriques Normark is the director of a research project that seeks to enhance our knowledge of infectious diseases' causes and to understand the connections between bacteria, their human hosts, and immune cells.

"Pneumococci, which can cause lower respiratory infections like pneumonia as well as blood poisoning and meningitis, are also found in the noses of many healthy children and some adults. We want to figure out why they sometimes cause fatal diseases," she explained.

This question is becoming ever more urgent, as increasing resistance to antibiotics can make it difficult to treat these diseases.

In Sweden, some 1,400 cases of severe pneumococcal infections are reported annually, but they claim most lives in developing countries. One solution is to create a vaccine that protects against all variants of pneumococcus. Today's vaccine only protects against a limited number that cause the most severe infections in the U.S. Another possibility is to find new antibiotics.

DIFFERENT BACTERIAL STRAINS

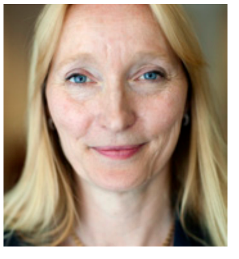
The team's research project is a "translational project," which means they are studying the whole chain—from molecule to patient. They are looking at the interplay between the bacteria, their human hosts, and immune cells. They examine bacterial strains from patients both *in vitro* (in test tubes) and *in vivo* (in living organisms) in efforts to understand what causes disease.

These bacterial strains include both those that lead to severe diseases and those that exist in humans without causing disease.

"Using various molecular techniques, we classify the strains to assess the significance of their genes in the development of disease, as well as other characteristics. We can then go on to create mutations that 'knock out' important genes to see what roles they play in the bacteria binding to cells in the mucous lining, for example, or their interactions with immune cells," explained Prof. Henriques Normark, Professor of Clinical Microbiology at Karolinska Institutet.

"BACTERIAL HAIR" PLAYS A ROLE

Prof. Henriques Normark is also trying to figure out what makes some people especially susceptible to infections. In the lab they are working with models for lung tissue. Immune cells and their helpers defuse the bacteria.



BIRGITTA HENRIQUES NORMARK

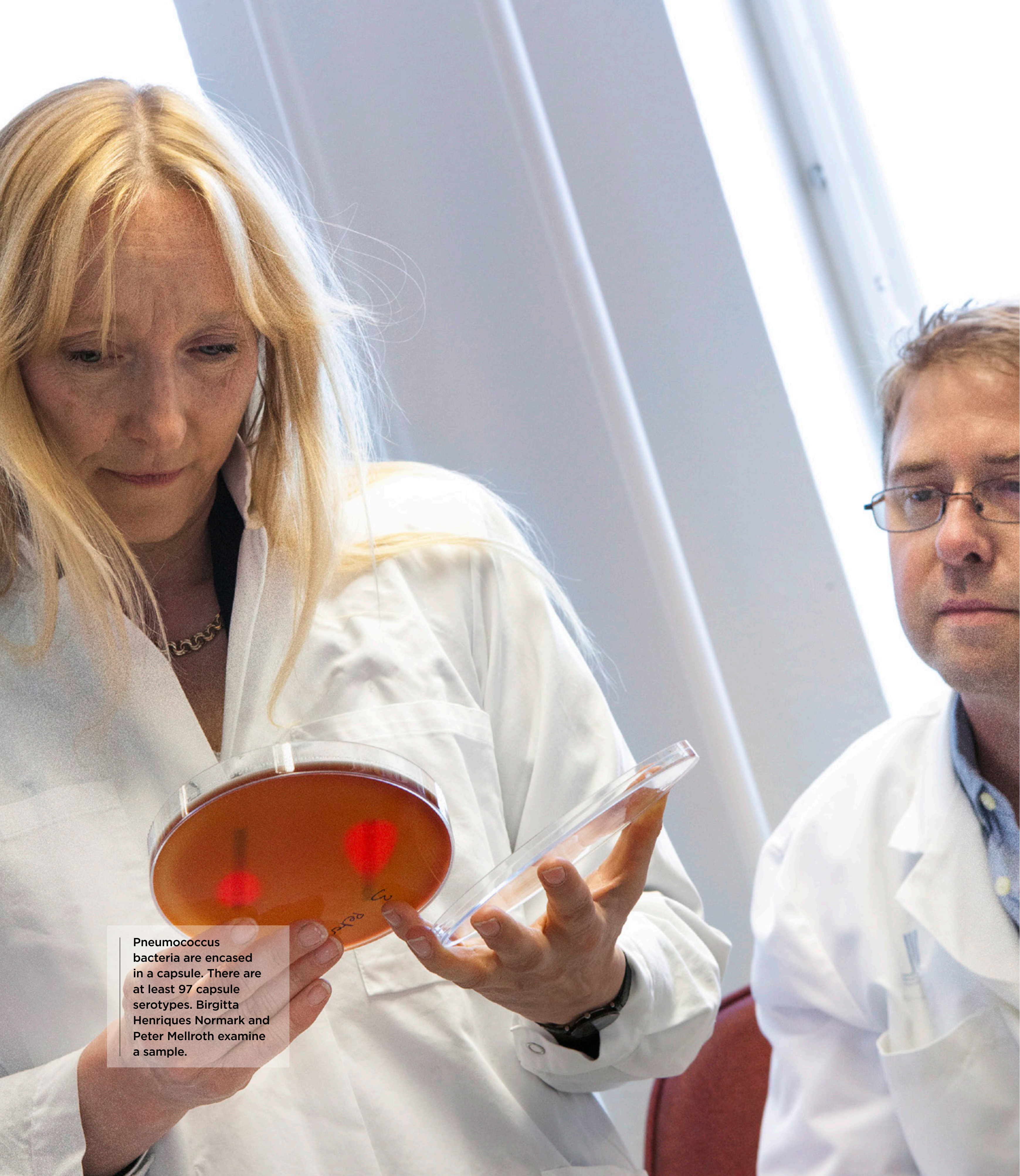
Professor of Clinical Microbiology, Karolinska Institutet.

Principal investigator of the project "Bacterial modulation of early clearing responses and its effect on infectious disease outcome."

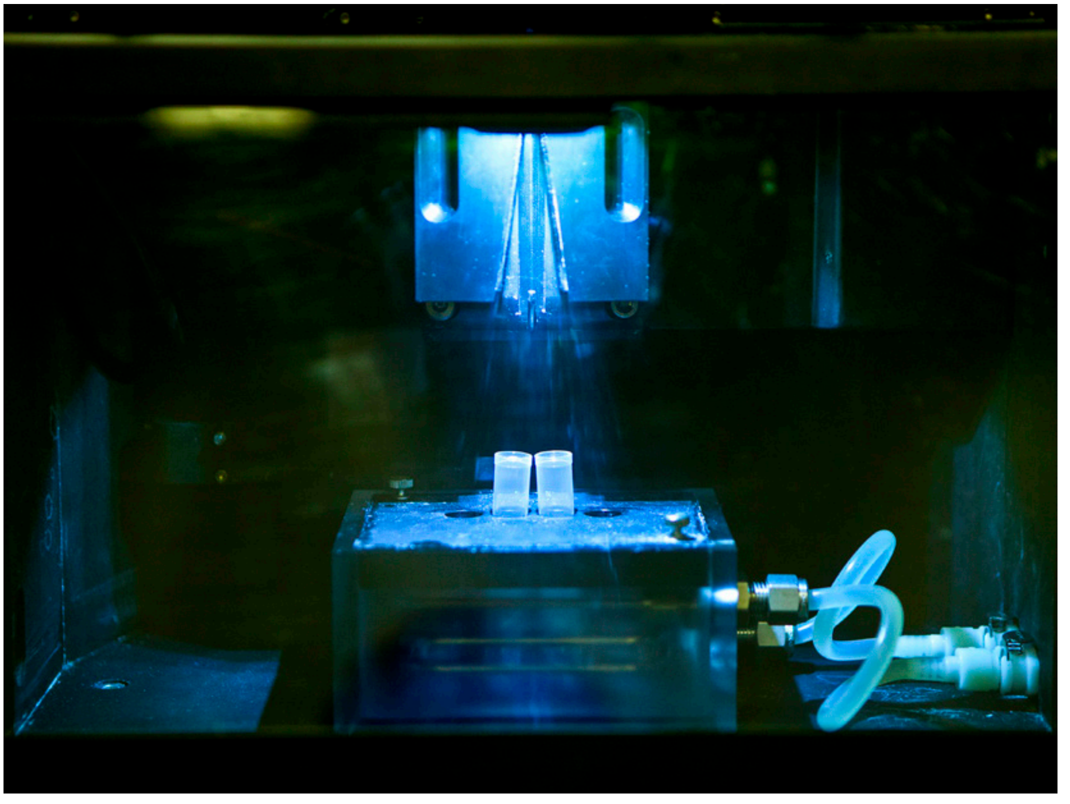
Co-investigators: Anna Norrby-Teglund, Juha Kere, Adnane Achour, Fredric Carlsson, Staffan Normark.

Project grant in 2011
Grant awarded:
SEK 25.8 million over five years.

Increased resistance to antibiotics means that illnesses caused by bacteria such as pneumococci are increasingly difficult to treat. A test tube in Birgitta Henriques Normark's laboratory.



Pneumococcus bacteria are encased in a capsule. There are at least 97 capsule serotypes. Birgitta Henriques Normark and Peter Mellroth examine a sample.



Bacterial samples being tested in Birgitta Henriques Normark's laboratory.

If they fail, the bacteria spread further and begin to destroy the tissue.

"We believe that early events in an infection are important and that the congenital immune defense system plays a significant role. Early elimination of bacteria is crucial," she said.

Among other things, her team is looking at complexes of proteins called inflammasomes that participate in activation of our built-in immune defenses. Differences in the appearance of the capsule surrounding the pneumococcal bacteria are also of great interest.

There are at least 97 different capsule serotypes. Some cause disease; others do not. But there are other distinguishing factors: some have a pilus—a hair-like structure that helps the bacteria to fasten to the mucous linings of the body. The researchers have a few candidate genes for vaccines on the bacterial side, along with a number of ideas regarding the receptivity of certain individuals.

CERTAIN GROUPS ARE MORE SUSCEPTIBLE

Prof. Henriques Normark's research team was the first to discover pili on pneumococci. They also found that several genes in a "pathogenicity islet" affect formation of the pilus.

"Some pneumococci have pili and others don't. The pilus seems to play a role in how pneumococci spread around the world," she noted.

The researchers also know that certain populations, such as indigenous populations in Australia and the Americas, are more susceptible than others to pneumococcal infections.

In 2009, a pneumococcus vaccine was added to the general children's vaccination program in Sweden, and Prof. Henriques Normark is monitoring the program at the Public Health Agency of Sweden.

The rationale behind the vaccination is to reduce illness rates, which could save many lives in developing countries ■

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MILLION PEOPLE
die of infectious diseases every year. Just six deadly infections—pneumonia, tuberculosis, diarrhea, malaria, measles, and HIV/AIDS—are responsible for most deaths of children and teenagers around the world, particularly in developing countries. Infectious diseases are caused by infectious agents (pathogens), including viruses, bacteria, parasites, fungi, and prions.

It was not until the mid-19th century that scientists made the connection between microscopic organisms and illness. The discovery is attributed to Louis Pasteur, who realized that particular bacteria cause particular illnesses.

Dopamine cells from mouse embryos being examined. In Parkinson's disease, dopamine cells lose their ability to produce dopamine.

CAUSES OF CELL IDENTITY LOSS

Mature cells in organs like the brain and heart should normally retain their characteristics for a lifetime. But sometimes mature cells lose their identity, resulting in serious diseases. Researchers at Karolinska Institutet are now trying to understand how mature cells normally retain their identity. The objective is to find clues that might eventually lead to new treatments for Parkinson's disease.

One important but largely unexplored question is how the mature, specialized cells in the body's various tissues behave so that they retain their identity for life. Some cells reproduce continuously throughout our life, while others, such as heart and nerve cells, ought to be able to preserve their characteristics as long as we humans live—for 100 years or more.

But no cells are carved in stone. In diseases like cancer, mature cells have trouble retaining their identity. What's more, researchers in a laboratory setting can reprogram mature cells and return them to the primitive "stem cell" stage. The discoverers were awarded with a Nobel Prize in medicine in 2012.

Thomas Perlmann is Professor of Molecular Developmental Biology at Karolinska Institutet. For many years, he has been interested in certain kinds of nerve cells in the brain that produce dopamine, a neurotransmitter. It is when these cells gradually die that Parkinson's disease develops.

But long before the cells die, they lose several functions, including the ability to produce dopamine. Some of the enzymes needed for producing and processing dopamine in the brain's synapses are scaled back and then disappear. This happens in parallel with a reduction in certain transcription factors —proteins that control the copying of information from DNA to RNA, a constant activity in living cells.

If transcription no longer works, a dramatic situation arises, as Prof. Perlmann explained. "This means a direct connection to disease, and we can now see that the loss of the transcriptional network's function could be a factor in Parkinson's disease," he said.

THE "ON" SWITCH FOR DOPAMINE CELLS

Back in 2006, Prof. Perlmann and Johan Ericson found two genes that control the development of dopamine-producing cells and function as the "on" switch for their formation. Subsequently, dopamine cells were successfully produced from immature stem cells.

Following these breakthroughs, research has continued to an even more detailed level. The new research project, financed by the Knut and Alice Wallenberg Foundation, focuses on mapping and understanding crucial processes for mature dopamine cells' stability. The project

THOMAS PERLMANN

Professor of Molecular Developmental Biology, Karolinska Institutet.

Principal investigator of the project: "Maintaining Neuronal Identity – Transcriptional control of the aging brain."

Co-investigators: Karima Chergui, Johan Holmberg, Nils-Göran Larsson, Rickard Sandberg, Per Svenningsson.

Project grant in 2013
Grant awarded:
SEK 40.4 million.

involves recreating disease conditions similar to Parkinson's in animal models to see how the transcription network is expressed.

"We want to understand the gene-regulating mechanisms that are important for the normal functioning of dopamine cells, even in the aging brain, so we're looking at dopamine cells from mice, healthy individuals, and patients with Parkinson's disease," Prof. Perlmann said.

Normal aging appears to be the main culprit in neurodegenerative diseases like Parkinson's and Alzheimer's. But the researchers still know very little about the aging process at the cellular level. They suspect that disturbance of mitochondrial functions may contribute to the aging process, because losses of energy supplies by the mitochondria—the cells' power plants—will results in cells' degradation and losses of functionality. To establish whether this is the case, an expert on mitochondria, Prof. Nils-Göran Larsson, is also involved in the project.

MANY DIFFERENT DOPAMINE CELLS

Dopamine cells cannot be lumped together as just one cell type. Instead, it turns out there are several sub-groups.

"In recent years, revolutionary methods have been developed that now allow us to analyze individual cells' characteristics and more effectively define various sub-groups of dopamine cells. We are also beginning to understand that certain sub-groups are more involved than others in Parkinson's disease," Prof. Perlmann explained.

This research is basic science and still far from clinical application. The main thrust is to understand how dopamine cells are formed and retain their characteristics. But, by elucidating the transcriptional controls, the team will gain understanding of the developmental principles of neurodegenerative diseases. It will be possible to find out what kinds of damage the cells' "identity crisis" can cause, and whether the cells' loss of their characteristics can be slowed or prevented ■

Thomas Perlmann and his research team—including Linda Dahl and Linda Gillberg, pictured here—believe their work will benefit Parkinson's patients in the future.

D

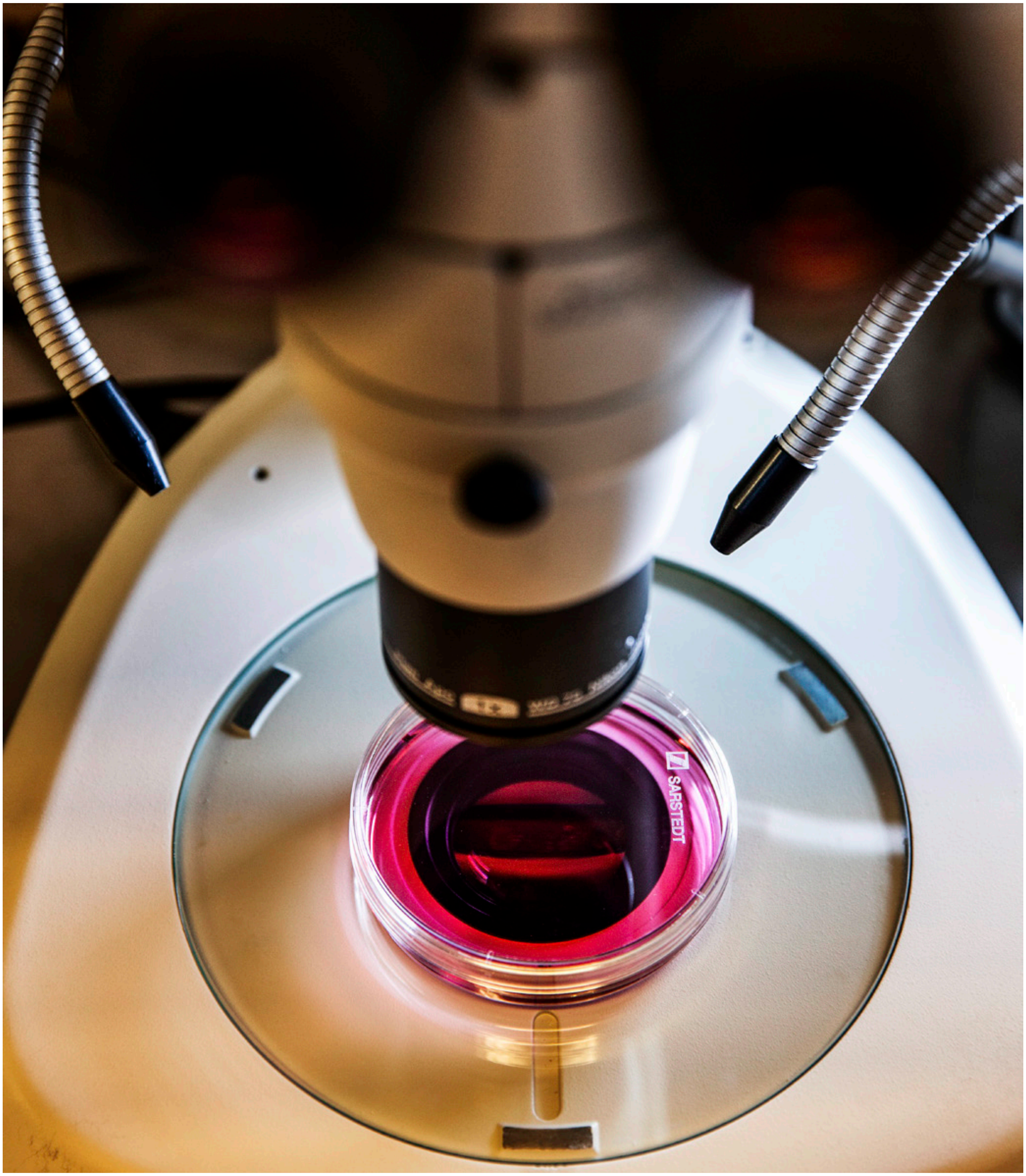
DOPAMINE

is a neurotransmitter in the brain. It plays an important role in controlling the body's movements.

Prof. Arvid Carlsson was awarded the Nobel Prize in Physiology or Medicine for his work on dopamine. In the 1960s, he showed that dopamine acts as a messenger molecule in the brain, and a lack of dopamine results in deterioration of movement, such as that in Parkinson's disease.

Clinical studies showed that administration of DOPA—a substance the body converts to dopamine—can dramatically improve movement in many severely debilitated patients.

This substance is still the most effective treatment available for Parkinson's disease.



Researchers have discovered several sub-groups of dopamine cells. Some are more involved than others in Parkinson's disease. Microscopic image from Prof. Perlmann's laboratory.

BRAIN POWER AGAINST DEMENTIA, ALS, AND PARKINSON'S DISEASE

In Europe, 7 million people are estimated to have dementia, including 160,000 in Sweden, and it strikes around 25,000 people in Sweden every year. So, Sweden's foremost brain researchers have joined forces in the Swedish Brain Power network to develop new drugs and treatments.

We currently have no medicines that can cure or slow the progress of Alzheimer's disease or other forms of dementia, although there are pharmaceuticals that alleviate the symptoms. Despite intensive research all over the world, breakthroughs have been elusive. The most recently developed medicine was launched back in 2002. Hopes have since hung on a few pharmaceutical candidates, but in the final phases they proved not to be viable.

"Unfortunately, investment in the pharmaceutical industry is tending to fall. Most research now takes place at universities. There are many ideas, but developing drugs is a long and expensive process," commented Prof. Bengt Winblad, head of the initiative.

Lars Lannfelt of Uppsala University, another Swedish Brain Power researcher, is leading one of the few studies on a possible pharmaceutical, an antibody treatment, which they hope can retard development of Alzheimer's. The antibody targets what is believed to be the root cause of the disease's development.

"Lars found a mutation, known as the 'arctic mutation,' which led to the disease in one family. He has since developed antibodies that are now being injected as part of a major clinical study on 650 people in Sweden," Prof. Winblad explained.

BENGT WINBLAD

Professor of Geriatrics at Karolinska Institutet and Director of Swedish Brain Power.

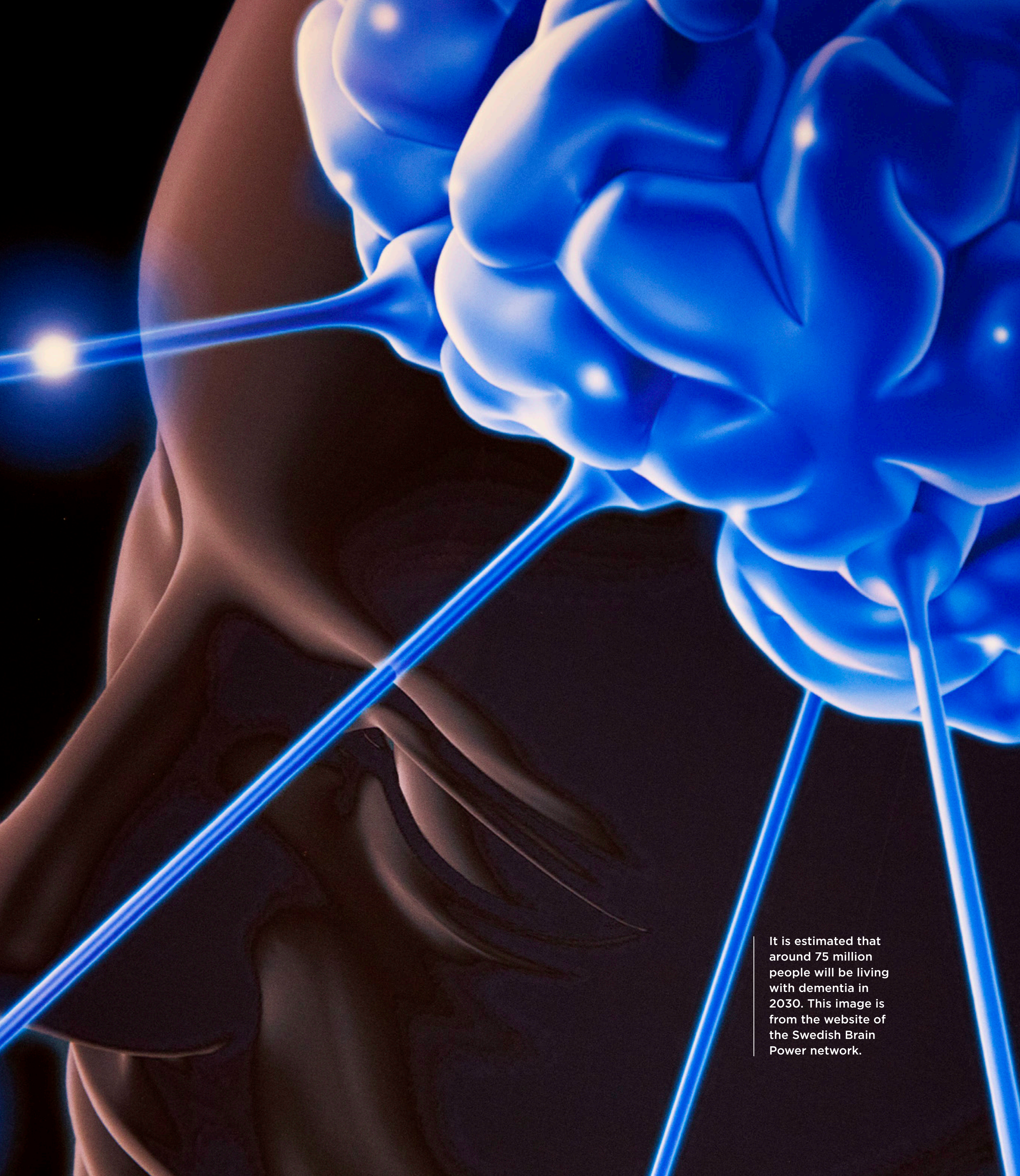
Swedish Brain Power is a network of leading Swedish brain researchers who work together to combat incurable neurodegenerative illnesses.

The network has received SEK 125 million in grants.

DIAGNOSIS, TREATMENT, AND CARE

Swedish Brain Power, a network of researchers working on dementia as well as other neuro-degenerative diseases such as Parkinson's and ALS (Lou Gehrig's disease), was established in 2005 with support from several funders. Between 2010 and 2015, the research network received SEK 100 million in grants from the Knut and Alice Wallenberg Foundation. The Foundation had previously provided over SEK 25 million to the network.

The aims are to improve early diagnosis, treatment, and care of patients with neuro-degenerative diseases; to develop, test, and evaluate new drugs and other new treatments that can be applied in early stages of the disease; and to maintain a leading international position to enable Swedish neuroscience to attract industrial cooperation from Sweden and abroad.



It is estimated that around 75 million people will be living with dementia in 2030. This image is from the website of the Swedish Brain Power network.

The two main goals of the research team at Karolinska Institutet—Pontus Forsell, Johan Sandin, Johan Lundkvist, and Märta Dahlström—are to improve methods for early diagnosis of dementia and enhance patient care and treatment.

SWEDISH BRAIN POWER is a network of Swedish researchers who study dementia, Parkinson's disease, and ALS.

In all of these neurodegenerative diseases, nerve cells die, but they differ in types of damage as different parts of the central nervous system are affected.

The network's research is divided into nine areas: basic pre-clinical studies; genetics; biomarkers; clinical diagnostics and treatment; epidemiology; neuropsychology; care and rehabilitation; health economics and primary care; and ethics.

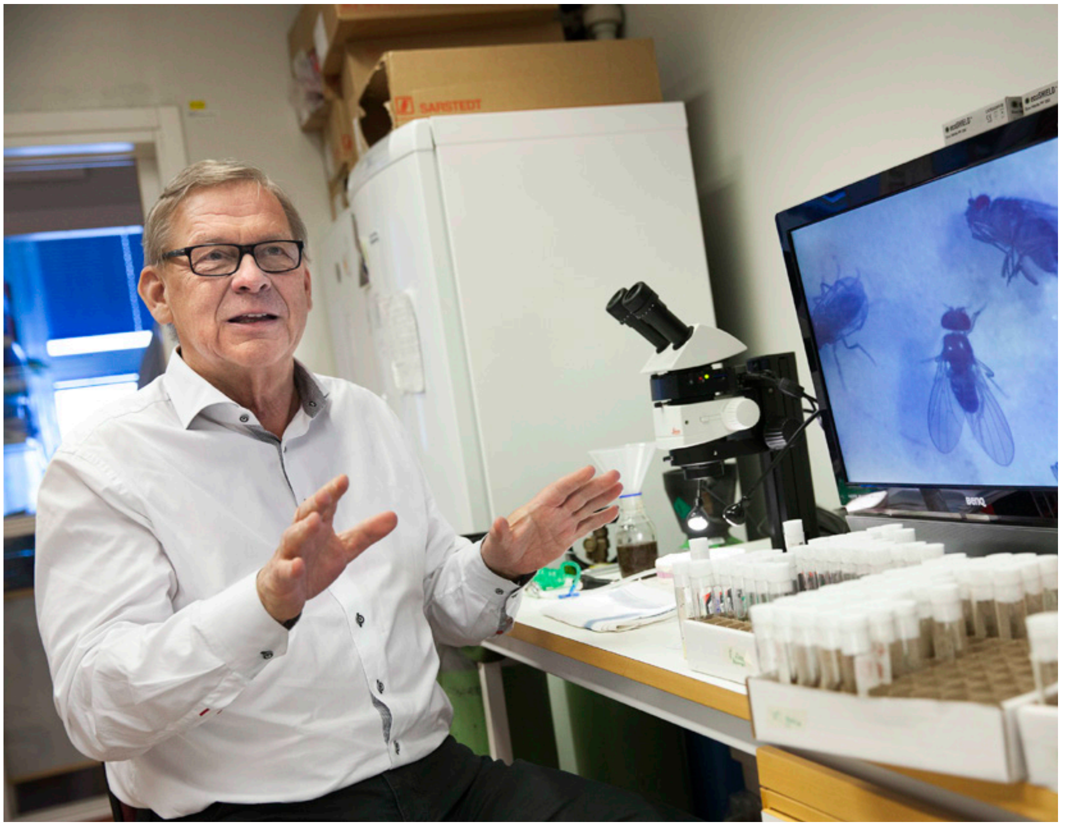
ROLE MODEL

The Swedish Brain Power network includes specialists from several research fields, such as medicine, genetics, care research, behavioral science, engineering, IT, and image analysis.

"For us, the most important aspect has been getting researchers and research teams to work together, both laboratory and care researchers, as well as research teams in Gothenburg and at Karolinska Institutet, who have always competed with each other," Prof. Winblad said.

The Swedish research network's successes include important discoveries for early diagnosis of dementia. They have developed new biomarkers that can be analyzed in spinal fluid and reflect what happens in the brains of patients with Alzheimer's disease. The researchers have also built up several databases, such as the Swedish dementia register, SveDem. New risk genes have been found for ALS and frontotemporal dementia. In addition, newly developed animal models offer novel research opportunities. Instruments have also been created to measure various factors in care and the functional capacity of older people—both healthy and those with cognitive problems ∎

"The most important aspect has been getting researchers and research teams to work together—groups who have always competed with each other." —Bengt Winblad



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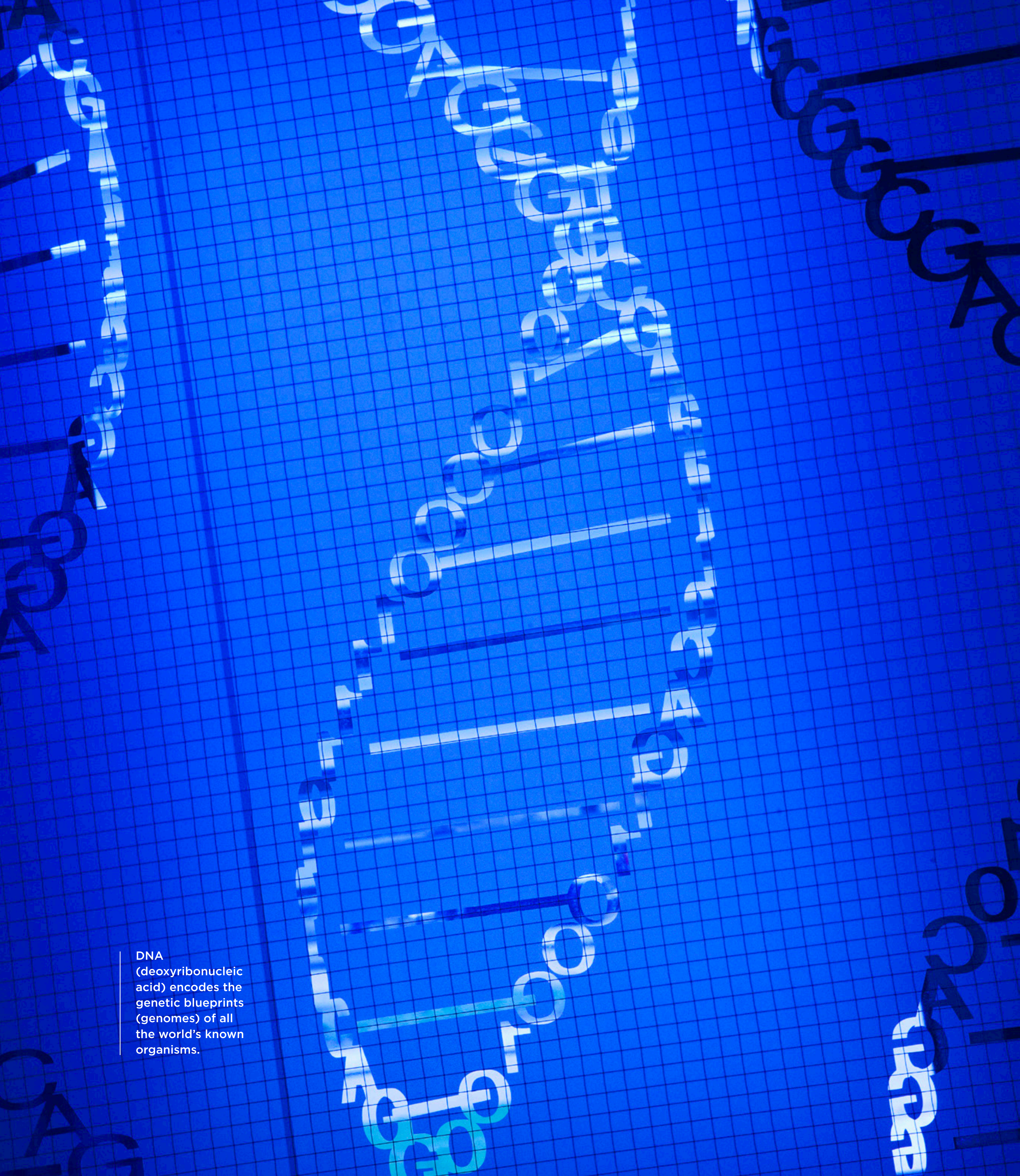
MILLION NEW CASES EACH YEAR

Around 47 million people around the world were estimated to be living with dementia in 2015. That number is expected to double every 20 years.

The number of sufferers is predicted to rise to 75 million by 2030 and 131.5 million by 2050.

The most common types of dementia are:
- Alzheimer's disease (60% of the dementia cases in Sweden)
- Vascular dementia
- Frontotemporal dementia
- Lewy body dementia
- Parkinson's disease with dementia
- Huntington's disease



DNA (deoxyribonucleic acid) encodes the genetic blueprints (genomes) of all the world's known organisms.

EVOLUTIONARY BIOLOGY

How life arises and develops

The process by which organisms change and develop is called evolution. This process also explains how there can be such a huge variety of species and organisms in the world today, even though they all share the same origin.

Evolutionary changes in organisms stem from changes in DNA molecules and consequent biochemical events. The appearance of new gene variants is essential for organisms' evolutionary adaptation to their environments, diversification, and—eventually—emergence of new species. Various mechanisms have led to the millions of different genes and proteins found in the organisms that exist today.

Throughout time, people have sought explanations for the origins and development of life on Earth. In 1859, Charles Darwin published *On the Origin of Species*, in which he set out the first scientific account.

Darwin's theory is based on the occurrence of variation within species and natural selection, whereby the individuals that are best adapted to their environment will generally contribute more to the next generation than those that are less well adapted—summarized as "survival of the fittest."

Mapping, or sequencing, of the genomes of various organisms including bacteria, humans, spruce trees, horses, pigs, titmice, rice—as the technology becomes increasingly efficient and costs decrease, the list grows almost daily—provides new pieces in the puzzle of the origins and development of life, as well as clues about what can go wrong and how diseases arise.

Most disease-causing mutations are similar in all mammals. For example, dogs have proven to be good model organisms for finding genes linked to diseases. Dogs can get cancer, diabetes, cardiovascular disease, and many other illnesses that also affect humans.

Genes in horses have provided clues about the development of malignant melanoma, and domestic pigs' muscles have taught us about mammals' development.

Bacteria also have genomes that have been mapped, potentially enabling scientists to design bacteria that can perform particular tasks. For example, researchers in Uppsala are studying whether bacteria in the body can be made to produce vaccines or vitamins.

The Foundation's investment in the life sciences includes SEK 200 million in grants to expand Sweden's capacity for human genome sequencing at SciLifeLab. The facility enables scientists to study humans' full genetic material, not just genes, and gain a better understanding of genetic illnesses, cancer, and other diseases ∎

BACTERIA—THE BODY'S OWN VACCINE FACTORIES

Sequencing bacterial genomes is now entering a new phase. Scientists aim to design bacteria for new tasks, such as serving as the body's own vaccine factories. If these efforts are successful, they will open up totally new ways to protect against infectious diseases

Siv Andersson is one of Sweden's pioneers in genome sequencing. She has been studying bacterial genomes for more than 15 years. Her work has led to a fundamental understanding of how nature sets up cooperation between bacteria and higher organisms such as insects, animals, and humans. This research has also contributed new insights into various well-known diseases, including typhus, and enhanced our understanding of how bacteria can become pathogenic from an interaction breaking down.

SIV ANDERSSON

Professor of Molecular Evolution, Uppsala University.

Wallenberg Scholar 2011

Main research field: DNA sequencing and studies of the mechanisms that control the development of alpha-proteobacteria.

HELPFUL AND HARMFUL BACTERIA

Each adult human's intestinal flora contains around two kilograms (4.4 lbs.) of bacteria that regulate the body's eco-balance.

"Bacteria can have a lot of helpful properties. They can produce amino acids and vitamins, and in many cases they are crucial to the survival of their hosts," Prof. Andersson explained.

Aphids, for example, contain bacterial "factories" that produce essential amino acids that are lacking in the leaf sap they consume. The bacteria enable the aphids to colonize new plants and thus spread. Bacteria can also produce toxins that protect insects against attack from other animals, and in extreme cases they can even change the gender of an insect from male to female, so a genetic male can start to produce eggs.

NATURE AS THE MODEL FOR A NEW DESIGN

The technology has made such advances that it is now possible to start designing new biological systems inspired by nature.

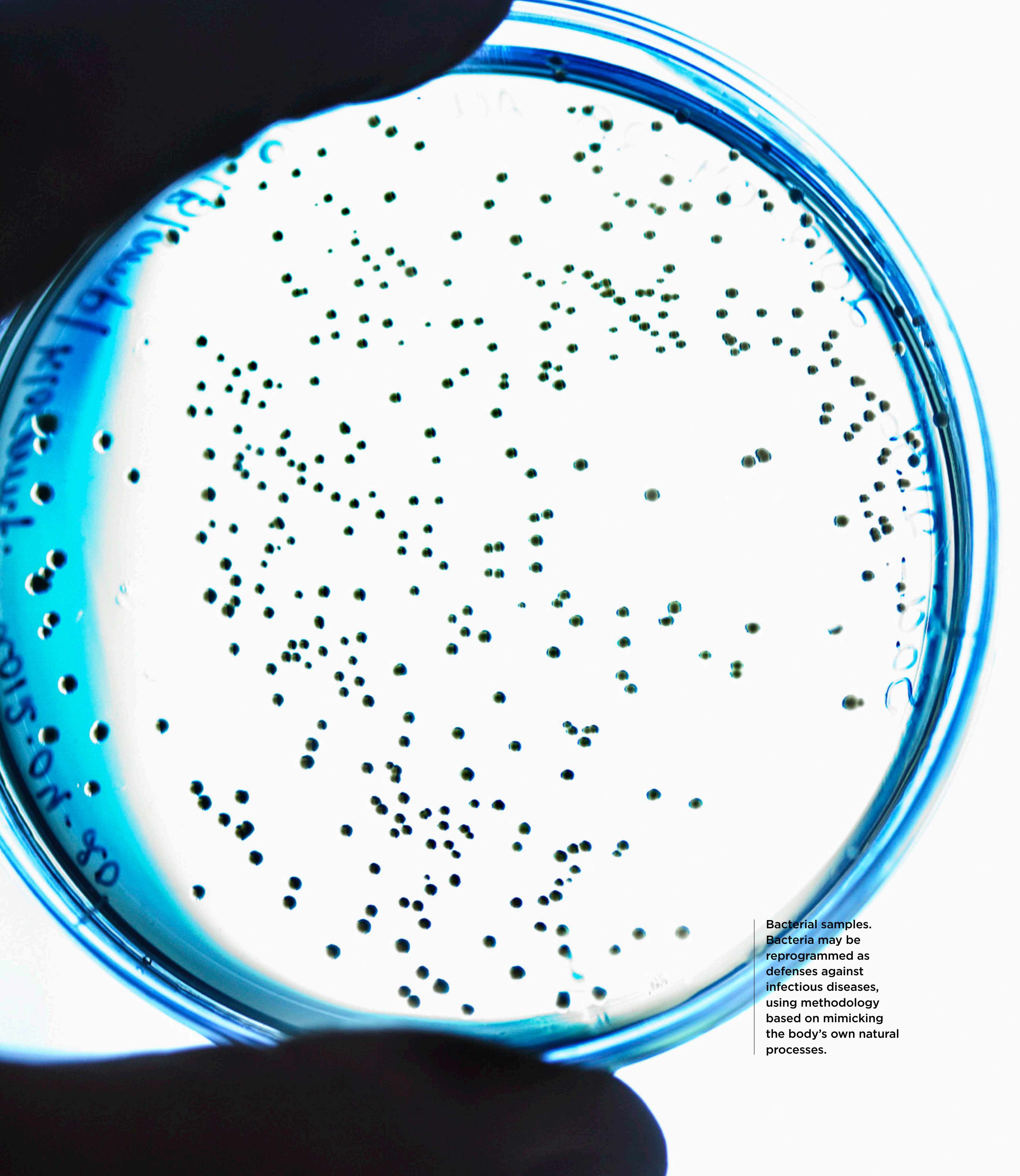
"Developments are going to proceed rapidly over the next five to 10 years," Prof. Andersson predicts. "We'll be able to construct new genetic material rather easily, so we had better get on our marks and be ready to exploit this technology."

One pilot project involves *Bartonella*, a common bacterium that spreads via ticks and insects. It makes its way into the circulatory system and attaches itself to red blood cells, where it lives without doing any harm, waiting to be picked up by another insect.

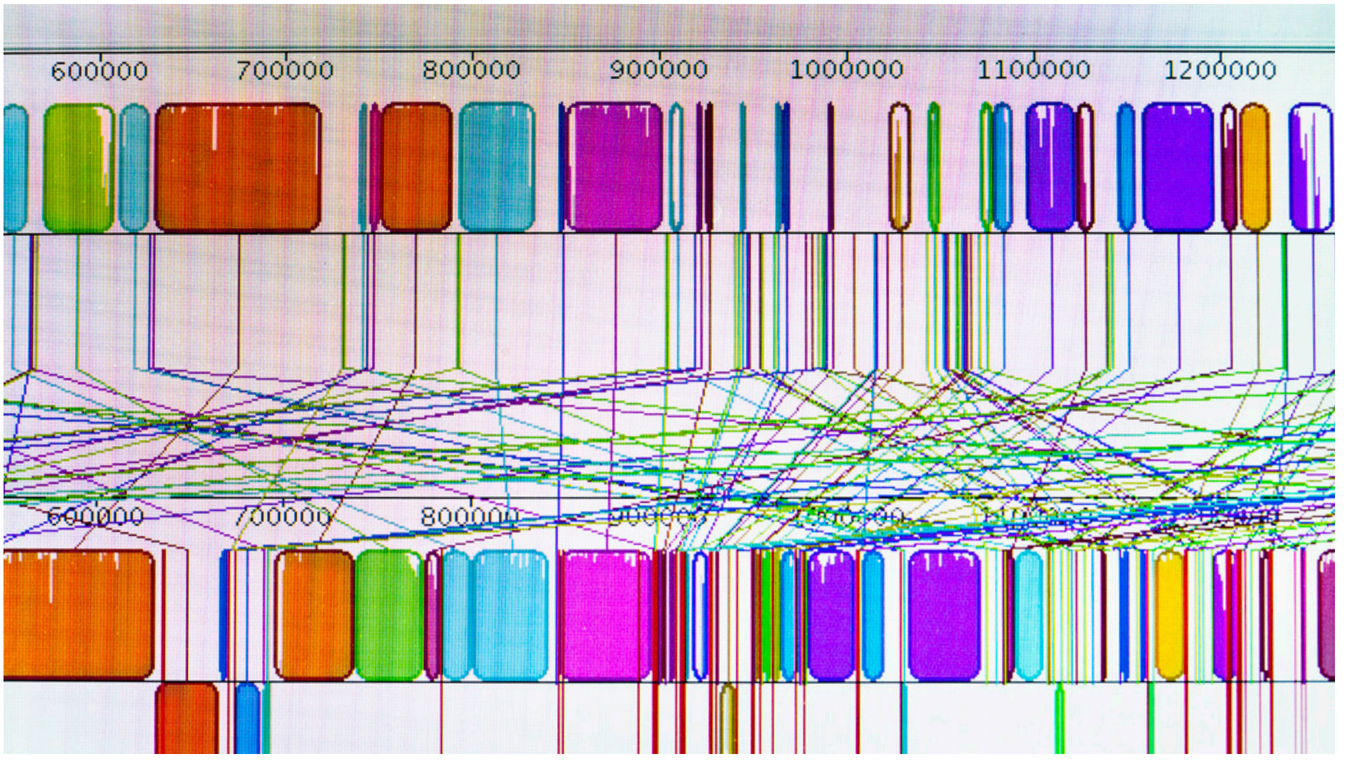
"Harmless bacteria like this could be utilized to produce something valuable," Prof. Andersson pointed out.

GENES FOR COLLABORATIVE TRAITS

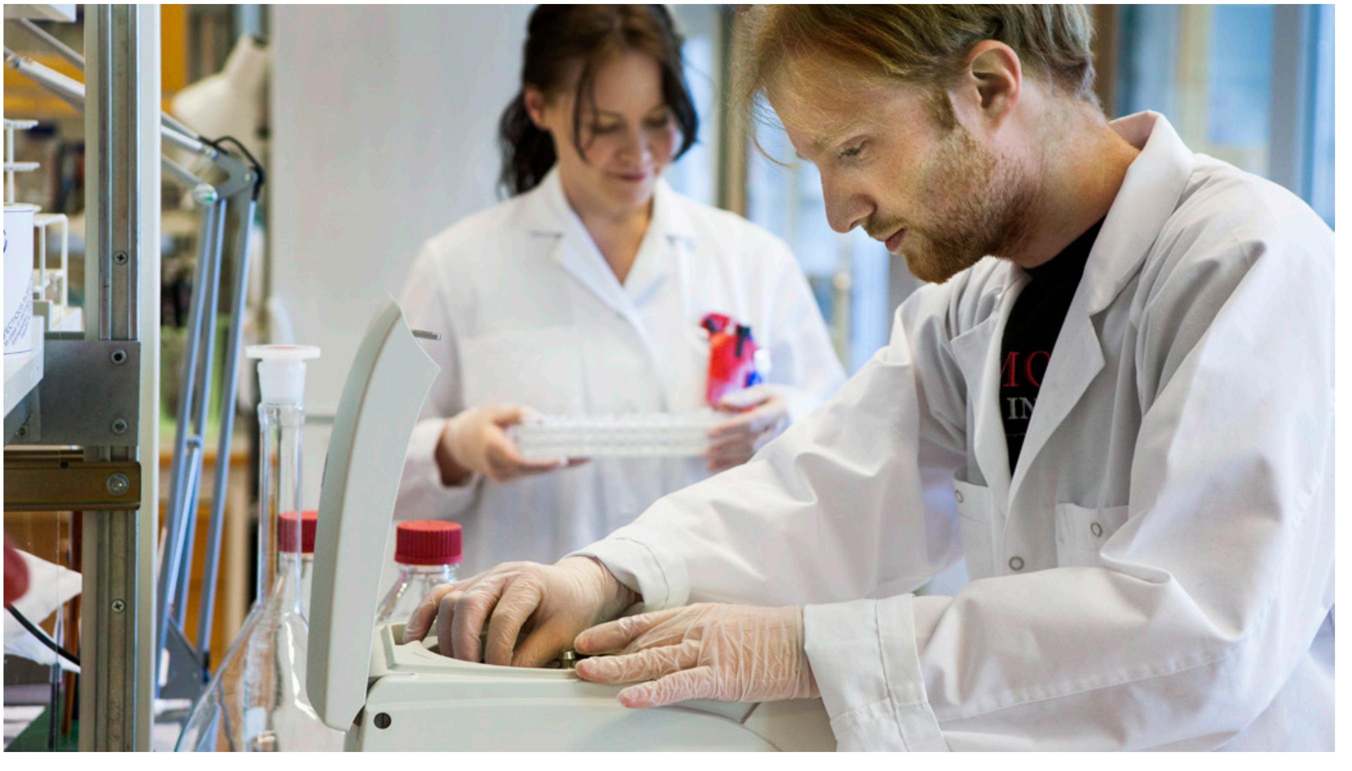
Like the aphid's bacteria, these bacteria would be able to produce amino acids and vitamins. They



Bacterial samples. Bacteria may be reprogrammed as defenses against infectious diseases, using methodology based on mimicking the body's own natural processes.



Because growth requirements for many bacteria are not known, they cannot be cultivated in the lab, so many types of bacteria are still unidentified. Minna-Maria Neuvonen and Daniel Tamarit, grad students supervised by Siv Andersson, perform an experiment in the lab.



would also be able to produce antigens, serving as a kind of living vaccine that the body could use to build up immune defenses. One challenge is to prevent the emergence of "selfish" cells that do not contribute to production of the desired compound and so may lead to collapse of the intended bacterial population.

In a project funded by the Foundation, researchers will now be able to study genes that code for collaborative traits, and ways to design "living" vitamins and vaccines. The first step is to use the new technologies to supplement the genome with genes for collaborative traits and study behaviors *in situ*.

"Medical applications are still far off, though. First we have to learn how to build with these genetic building blocks," Prof. Andersson noted.

ARTIFICIAL GENOMES

The scientists have learned from nature that the deeper the cooperation between bacteria and higher organisms, the smaller the bacteria's genomes become. Ultimately, the bacteria have so little DNA left that they can no longer reproduce without their host. Instead, most of the bacteria's genetic material is used to produce substances the higher organism needs. They have been turned into kinds of mini-bacteria whose own genes have been replaced by genes that are beneficial to the host organism.

"That's the kind of deep interaction we want to imitate. But since these mini-bacteria can't be cultivated outside their natural environment, they are very difficult to study. We want to use the new technology to recreate genomes that are just as small as those of mini-bacteria and get them to produce the desired proteins in the lab. Ultimately, we want to build mini-bacterial 'factories' that produce vaccines or other useful substances, just the way nature does," Prof. Andersson summarized.

MITOCHONDRIA WITH NEW FUNCTIONS

The most genetically reduced of all mini-bacteria are mitochondria, which are believed to have originated from normal bacteria that developed into a power plant for cells. The remaining genetic material is extremely small in most cases, such as in humans. Nevertheless, damage to the genomes of mitochondria can lead to extremely serious diseases.

"My dream discovery would be to identify the closest relative to our mitochondria and at the same time design new kinds of mitochondria for new functions," Prof. Andersson said ■

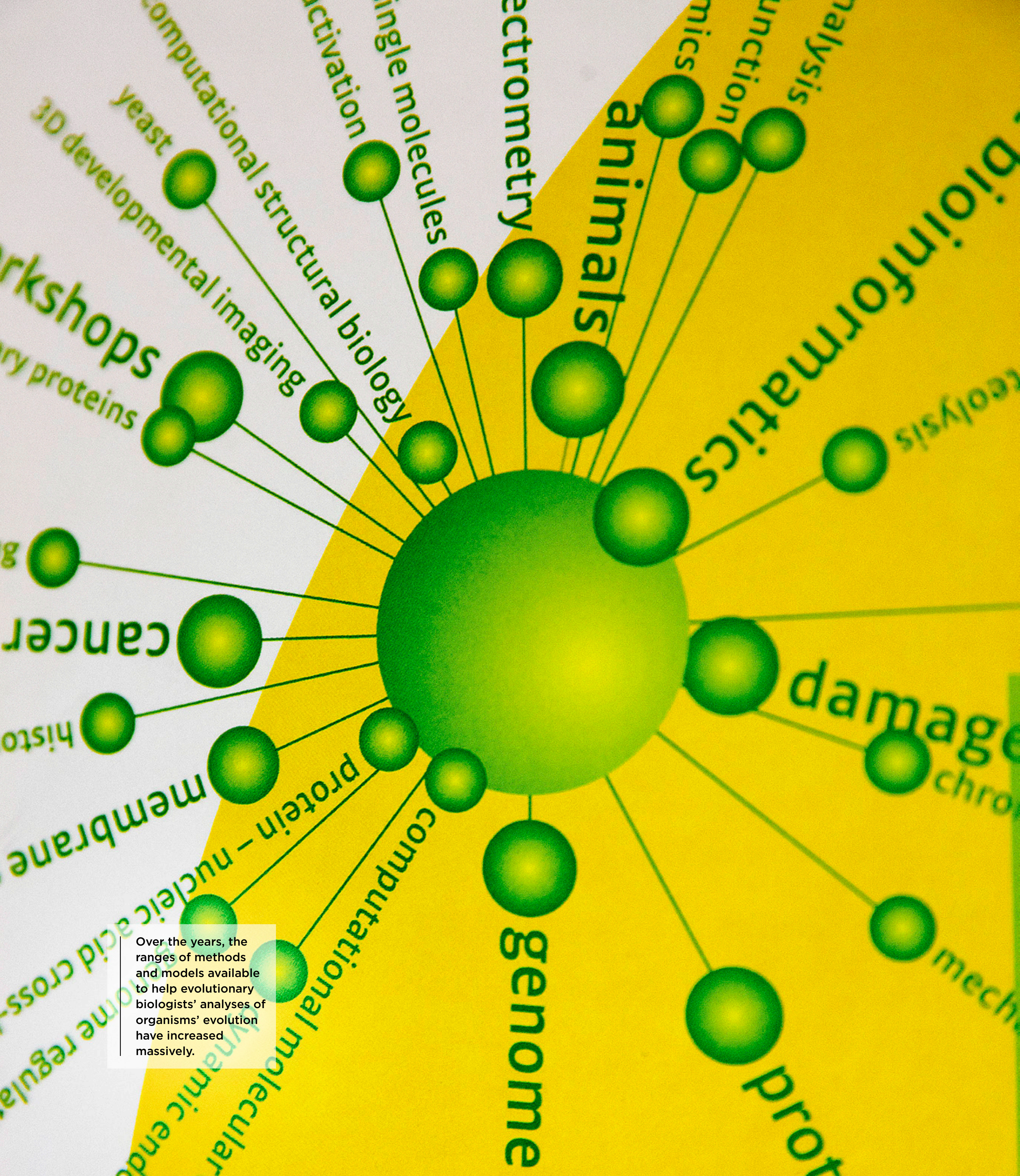
"The grant is a wonderful subsidy. It's rare for funding to be given with no strings attached, and this entails a unique opportunity to do exactly what I want. Without long-term funding, you have to go for the safe option. This gives me a chance to start high-risk projects with the potential for big pay-offs in the long run."
—Siv Andersson

THE FIRST VACCINE

In 1796, the English physician Edward Jenner produced a vaccine that virtually eliminated smallpox in Europe. Jenner knew nothing about viruses. He tested a hypothesis that people who had had cowpox were immune to smallpox. First, he inoculated a little boy with cowpox, then exposed him to smallpox six weeks later. The boy was immune and did not become ill.

At first, no one took Jenner's method seriously. The Royal Society in London rejected his scientific paper on the subject.

In attempts to acquire protection against smallpox, people had previously inoculated themselves with the live virus—including in China in the 11th century—but that was a risky method that sometimes resulted in epidemics. Jenner's cowpox inoculation was both harmless and highly effective. Once the initial skepticism subsided, the method was quickly adopted. Jenner's discovery also gave the practice its name. His inoculation was based on the cowpox virus, and he coined the word *vaccination* from *vacca*, the Latin word for cow.



Over the years, the ranges of methods and models available to help evolutionary biologists' analyses of organisms' evolution have increased massively.

DOMESTIC PIGS, HORSES, AND CHICKENS TELL US ABOUT MANKIND'S HERITAGE

Our domestic animals' genes are goldmines for inquisitive researchers. When Leif Andersson was investigating why domestic pigs build more muscle than their wild cousins, he found a gene that is unique to all mammals. Gray horses, which are born black and turn white as they grow older, have provided clues about how malignant melanoma may develop.

The idea that domestic animals might be good models for genetic studies was conceived in the early 1980s, on a train somewhere between Stockholm and Uppsala. Leif Andersson, now Professor of Functional Genomics at Uppsala University, was a newly graduated biologist and was working at the Swedish University of Agricultural Sciences. He was analyzing data on about 40,000 horses that had been collected for pedigree checks.

"I used to commute between Stockholm and Uppsala. There were no laptops in those days, so I read a great deal. One of the books I read was Darwin's *On the Origin of Species,*" he recalls.

The first chapter of the book describes how humans changed farm animals' characteristics through breeding. Darwin says that similar changes take place in nature based on natural selection. The young Leif Andersson began to wonder if it might be possible to take Darwin's ideas to a new level using modern genetic technology and study the links between genes and different characteristics. Domestic animals should be good models because certain characteristics have been bred so intensively in a relatively short time—the last 10,000 years.

LEIF ANDERSSON

Professor of Functional Genomics, Uppsala University.

Wallenberg Scholar 2012

Main research field: Evolution of domestic animals—A model to generate basic knowledge of genotype-phenotype relationships.

STRONG PIGMENTATION IN GRAY HORSES

One phenomenon that attracted Prof. Andersson's interest was the coloring of "gray" horses. These horses are born black, but their coats start to turn white during their first year of life.

Using the genetic tools available at the time, he began to compare these horses with others. There were 15 genetic markers to study. And not a single "hit" to be seen. He was quite simply before his time. He could only finish the project a few years ago.

"By then, the entire horse genome had been mapped. Today, we have millions of markers spread throughout the genome that we can study. A lot has happened in 30 years," he said.

His research team used genetic markers to identify the right part of the genome. They found a particular change that seemed to stimulate stem cells to mature into pigment cells in hair follicles.

"Our interpretation is that the mutation drives this process, causing an over-recruitment of stem cells," he explained.

An individual is born with a limited quantity of the stem cells that form pigment cells. Over-stimulation leads to the foals generally being born jet-black, but the stem cells are soon used up and their coat then turns white.

ACTIVE PIGMENT CELLS BEHIND MALIGNANT MELANOMA

One reason why Prof. Andersson wanted to find the gray horse mutation is that the horses run a serious risk of developing melanoma (skin cancer), although they have black skin—which gives good protection against the sun's rays—under their white coat.

"We think the genetic mutation causes more pigment cells to form in the skin. They reproduce more easily, and that increases the horses' predisposition to develop melanoma," he explained.

One of the things he plans to do as a Wallenberg Scholar is investigate how the same mutation affects mice. He also intends to see if there is a link to humans. People who readily form moles are most likely to suffer from malignant melanoma, so mechanisms responsible for melanoma in some people and gray horses may be similar.

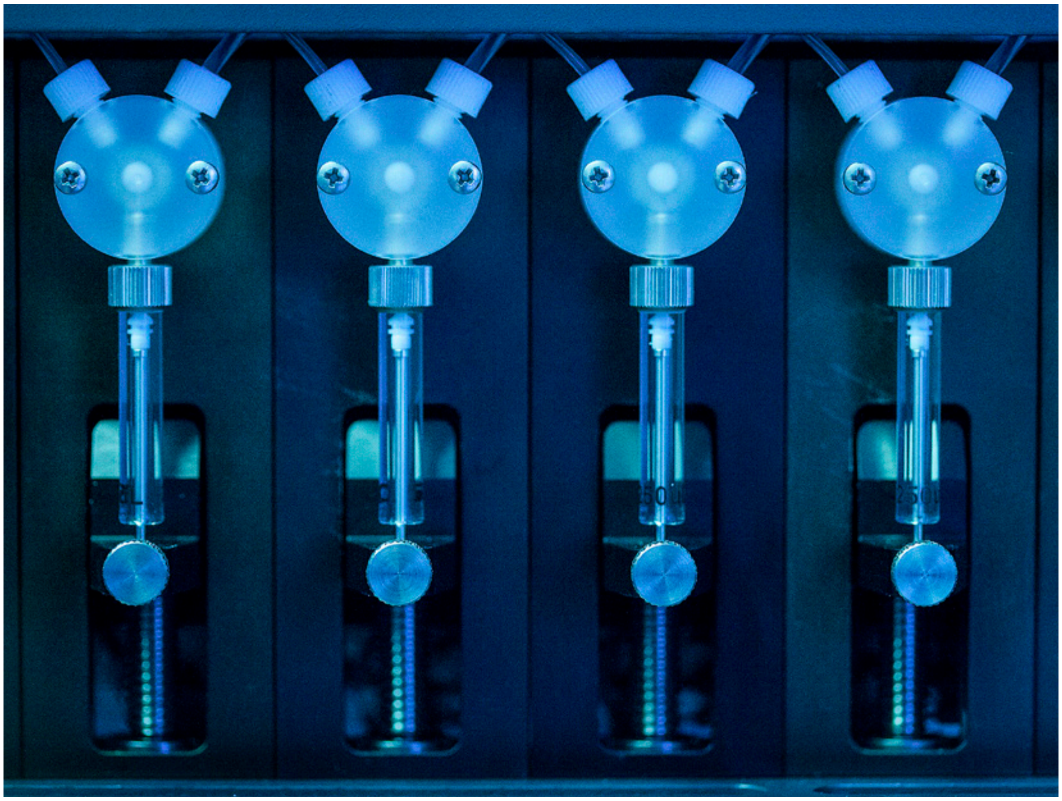
DOMESTIC PIGS' MUSCLES PROVIDE CLUES TO MAMMALS' EVOLUTION

Another avenue Prof. Andersson is pursuing is domestic pigs' ability to build muscle. Farmers have bred pigs that have less fat and more muscle than the parental breeds.

"We've identified a genetic change that causes pigs to develop four percent more muscle," he noted.

His research team has shown that the affected pigs have more of a particular growth factor in their muscles. At the same time as they made that discovery, they found a new "transcription factor," a kind of switch that turns certain genes on and off. This particular transcription factor, ZBED6, is unique to placental mammals (which have a placenta and give birth to live offspring).

"It seems to have entered the genome between 200 and 250 million years ago," he said. He now wonders whether ZBED6 may also determine the ability to form a placenta, in which case it was a crucial innovation in our evolution ∎



Instruments in Leif Andersson's laboratory.

17

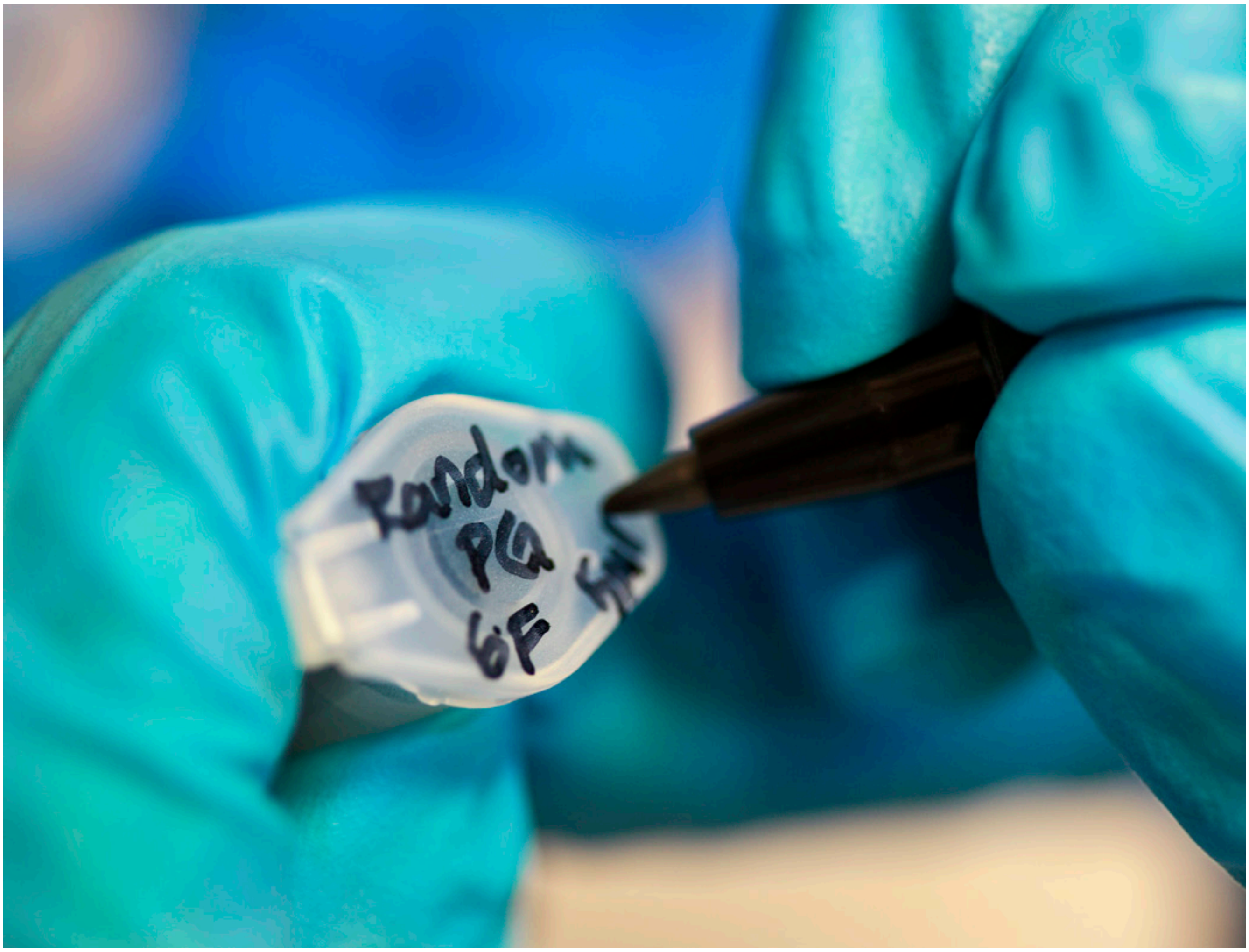
SYNTAXIN 17

"Gray" horses' white hair is linked to an increased risk of changes in skin cells and malignant melanoma (skin cancer).

Leif Andersson's research indicates that the mutation that causes horses' hair to turn white also stimulates growth of the cells that produce pigmentation, in both the follicles and skin.

But the end results depend on the pigment cells' locations. In the hair follicles, it is believed that the supply of pigment-producing stem cells is depleted.

When the stem cells have been used up and no new pigment cells can be formed, the horse's coat turns white. In the skin, the number of pigment cells keeps increasing, which causes tumors. This mutation causes overproduction of the protein syntaxin 17 and another protein that controls gene regulation.



A sample from Leif Andersson's laboratory.

"The generous grant from the Wallenberg Foundation provides a fantastic opportunity to freely choose the direction of our projects. We can also quickly seize new opportunities that arise. If we want to take up a new line of research, we would normally have to apply for a grant first, and then it might take a whole year to get any money." —Leif Andersson

A BIRD'S-EYE VIEW OF HOW SPECIES EVOLVE

Ever since Darwin wrote his book *On the Origin of Species* over 150 years ago, mechanisms involved in the evolution of species have raised major biological questions. Hans Ellegren and his colleagues have taken steps toward finding some of the answers. They hope to find more clues by studying changes in the genetic codes of the flycatcher and the crow.

Hans Ellegren and his research team at Uppsala University were the first in the world to map the genome of a wild bird species: the collared flycatcher (*Ficedula albicollis*). Its genetic code was found to comprise just over a billion DNA building blocks (base pairs), and was sequenced using the latest technology, known as "next-generation sequencing."

They then thought they would try to discover which genes or regions in this long alphabetical code account for different characteristics in the flycatcher. But that turned out to be harder than expected. It is not simply a matter of a single gene being behind a given characteristic—it is much more complicated.

A NEW APPROACH

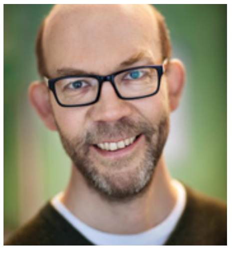
So instead of trying to find the genes that distinguish individuals, the researchers have focused more on studying how different species evolve and finding the genes that distinguish species. This is a very hot topic in the research community.

"We want to understand the processes when genetic material, or a genome as we say, evolves and a new species is created. What are the factors that result in differences in that genome, so that in the end individuals cannot mate?" Prof. Ellegren summarized.

His team has compared the genomes of about 10 pied flycatchers (*F. hypoleuca*) and the same number of collared flycatchers. Their findings were published in *Nature* in 2012. These two species co-exist on the Baltic islands of Öland and Gotland, where they sometimes hybridize. The researchers concluded that differing chromosomal structures, rather than differences in individual genes, are the reason behind the separation of the two species.

The team has now gone on to compare four species of flycatchers: the two in Sweden, one in northwest Africa, and one in southeast Europe.

So far, they have sequenced the genomes in blood samples from about 400 birds. They are using the material to find out how new species evolve. Do the differences arise from mutations in the genome, or is there some other reason, and the mutations appear later?



HANS ELLEGREN

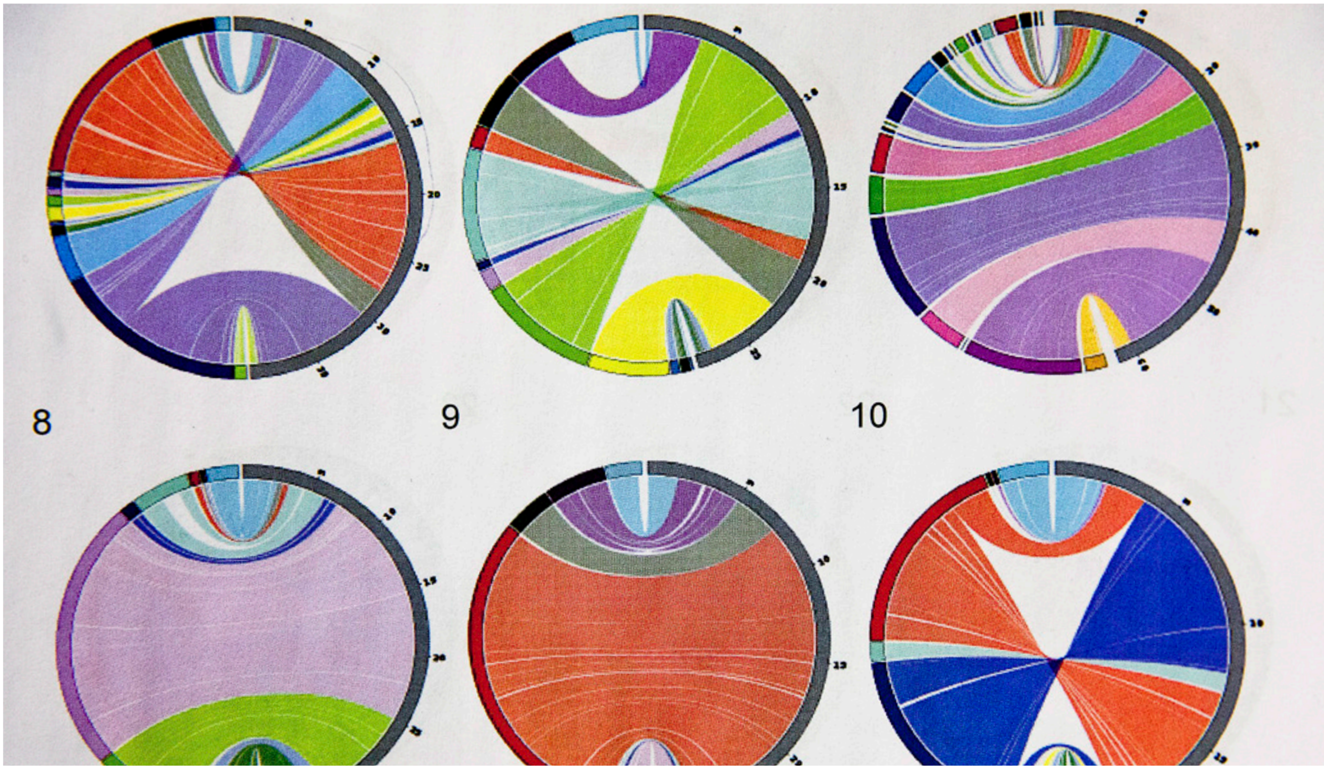
Professor of Evolutionary Biology, Uppsala University.

Principal investigator of the project "The genomics of species diversification."

Co-investigators:
Mattias Jakobsson,
Anna Qvarnström,
Jochen Wolf.

Project grant in 2014
Grant awarded:
SEK 42 million.

The collared fly-
catcher was the first
wild bird species in
the world to have its
DNA mapped.



Researchers in Hans Ellegren's laboratory want to understand how biodiversity arises and how to manage genetic variation.

"Our ability to carry out large-scale mapping of this kind is predicated on a strong research environment and long-term funding. The environment around the Evolutionary Biology Center here in Uppsala has turned out to be one of the most successful in the world, attracting gifted young researchers."
—Hans Ellegren

PAINSTAKING ANALYSES

In the rooms next to Prof. Ellegren's office, researchers sit at their computers, painstakingly analyzing genomes that have been sequenced. One thing they are trying to do is see how many new mutations occur during the long evolutionary process.

"It's like looking for a needle in a haystack. We're basing our study on family material from 11 flycatchers and going through their genetic code one item at a time. A completely new kind of biologist is needed to run this kind of analysis, someone who both understands the biological issues, and is a skilled bioinformatician," he said.

Genetic data are also used to understand the demography of the birds. It is possible to calculate backwards to work out how the four species' numbers and distributions have varied. Prof. Ellegren pointed to a graph on his computer.

"Here you can see how all the lines merge," he said. "They used to be a single species for 1–2 million years before it split. We can also see how they diverged purely in terms of number. This information is incredibly important to us, because differences in genetic material can also occur due to demographic changes. We need the whole picture."

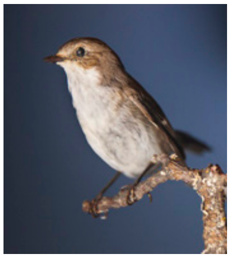
TWO MODEL SYSTEMS

Prof. Ellegren explained that the flycatcher is being subjected to such scrutiny because several generations of Uppsala researchers have studied the little black-and-white bird in various ways, and there is ample information, which makes it a practical subject for modeling.

Crows are also being studied in the project. Jochen Wolf, Professor of Evolutionary Biology, is leading a research team that mapped the genetic code of 60 hooded crows and carrion crows from different parts of Europe. Their findings were published in *Science* in 2014.

The project also includes two research teams led by Anna Qvarnström, Professor of Ecology, and Mattias Jakobsson, Professor of Genetics.

"Our ability to carry out large-scale mapping of this kind is predicated on a strong research environment and long-term funding. The environment around the Evolutionary Biology Center here in Uppsala has grown into one of the most successful in the world, attracting talented young researchers," Prof. Ellegren noted ■



ICE AGE

Scientists believe the European flycatchers' evolutionary divergence began after they were geographically isolated in an ice age.

The collared flycatcher is found mainly in southeast Europe and on the Baltic islands of Öland and Gotland.

The pied flycatcher dominates in northwestern Europe. The two species co-exist in an overlapping belt in central Europe.

A fossil of the early tetrapod *Acanthostega* from Greenland. Per Ahlberg was a member of the expedition that collected this specimen in 1987.

THE FIRST EVOLUTIONARY STEP ONTO LAND

The first step from water onto land was one of the most important events in vertebrate evolution. Per Ahlberg is shedding new light on this key step in our own ancestry, which took place considerably earlier than was previously believed.

A few years ago, some fossil tracks were discovered in a quarry in southeast Poland. Initially they were interpreted as traces made by a lobe-finned fish crawling through the mud, but Prof. Ahlberg spotted impressions of toes and quickly determined that they were footprints of animals with real feet: tetrapods, or the first land-based vertebrates.

The fossilized footprints are 395 million years old, making them the oldest fossil evidence of the move from water to land ever presented. The findings were published in the journal *Nature* in the winter of 2010 and attracted global attention.

"There were tetrapods at least as big as you and me at a time when we thought this group hadn't yet evolved. We thought we had a good picture of the emergence of tetrapods, but now we realize that there are huge gaps," he says.

The discovery casts light on a pivotal episode in the evolution of life. The first tetrapods later evolved into amphibians, reptiles, birds, and mammals, including humans. For decades, researchers largely agreed that tetrapods emerged within a brief period of time about 380 million years ago. But the Polish prints show that this happened considerably earlier.

PER AHLBERG

Professor of Evolutionary Organismal Biology, Uppsala University.

Wallenberg Scholar 2010

Main research field:
The evolution of tetrapods in the Devonian Period (416–359 million years ago).

LIVING ON THE COASTLINE

It was previously thought that tetrapods emerged at the same time as the first forests, and that the first steps from water to land were taken along forested riverbanks and marshes. But the new footprints are not only older than the first real trees, they also come from another environment: a shallow lagoon near the coast.

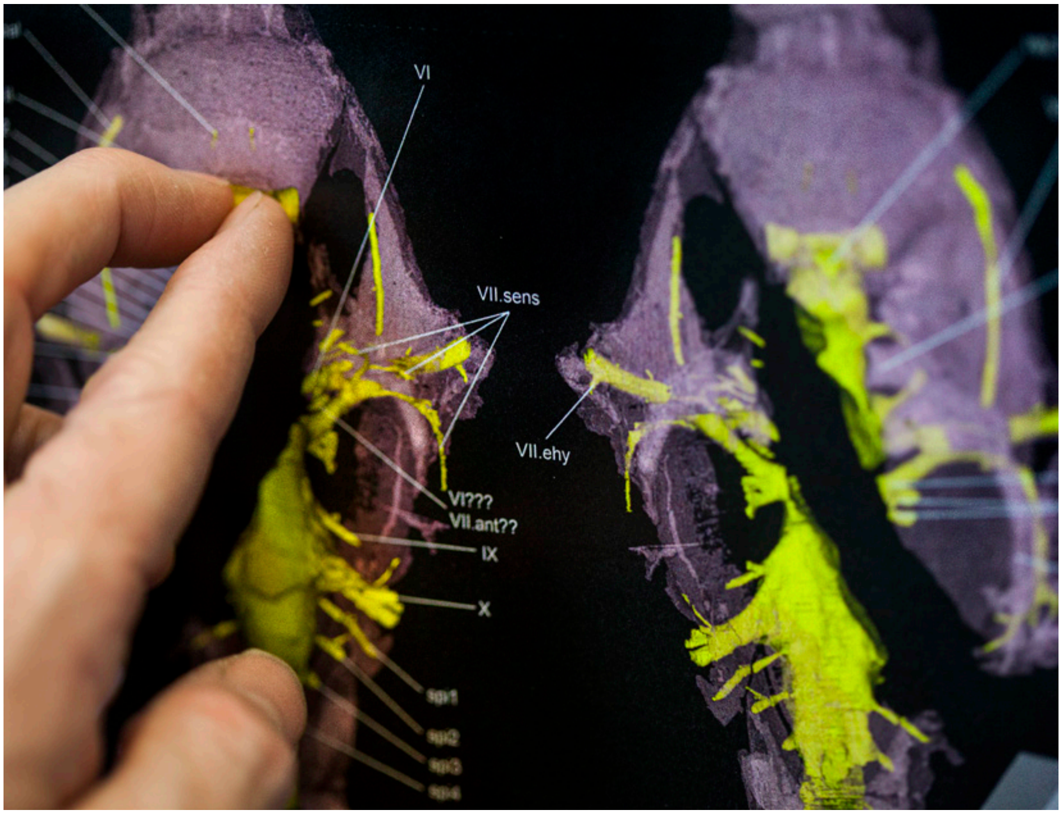
"What's cool about these footprints is not just that they're so old, but also that they show us the animals' behavior and patterns of movement," Prof. Ahlberg pointed out.

The first tetrapods probably looked like a cross between crocodiles and fish, and they seem to have lived on muddy banks on the coastline. They pulled themselves forward with their front legs.

"We don't know exactly what the tetrapods were doing along the seashore," he said.

CRAZY ABOUT DINOSAURS AS A CHILD

As a child, Per Ahlberg was crazy about dinosaurs, and his interest has lasted through the years. For many years, he worked as a paleontologist at the Natural History Museum in London. In 2003, he came to Uppsala University, where



Model of the skull of *Romundina*, a jawed fish.

he built a research environment in evolutionary organism biology from the ground up.

Being named a Wallenberg Scholar has enabled him to recruit new associates, including the Polish researcher Grzegorz Niedzwiedzki, who found the footprints of the oldest tetrapods.

One current project involves a well-preserved fossil of a previously unknown tetrapod from Sosnogorsk in northern Russia.

"Because we have separate bones that have been perfectly preserved in three dimensions, all we need to do is put them together like a puzzle to obtain the correct shape. For instance, we can see that the nose turned up, like the face of a pike," he said.

DETAILED IMAGES OF PREHISTORIC LIFE

This research is not being carried out only in the field, but also in a molecular biology laboratory that Prof. Ahlberg has built up. A team is at work there studying the relation between gene expression and embryonic development in zebra fish—a common model organism in developmental biology. In another room, some associates are busy at large computer screens, visualizing the three-dimensional structure of fossil bones.

The images are very high resolution, showing details smaller than one thousandth of a millimeter, with peppercorn-like holes that are traces of individual cells. By modeling blood vessels through the bones, it is possible to understand how the teeth grew in a jawbone that is 420 million years old.

"Our research is ultimately about the origins of human beings and the steps in evolutionary history without which we wouldn't exist. This gives it biomedical relevance because it looks at how the nose, pituitary, and jaw region were reshaped when we went from round mouths to vertebrates with jaws," Prof. Ahlberg explained ∎

TETRAPODS

All vertebrates with four limbs belong to the superclass Tetrapoda.

The name comes from the Greek *tetrapoda*, a compound of *tetra* (four) and *podes* (feet).

The superclass does not include fish, but does include snakes, whales, and other animals that lost their legs through evolution. The early tetrapods probably resembled a cross between fish and crocodiles. Later, they evolved in diverse ways to become today's amphibians, reptiles, birds, and mammals.

Per Ahlberg has discovered many tetrapods, which have names like *Elginerpeton*, *Obruchevichthys*, *Ventastega*, and *Sinostega*, as well as the transitional form Livoniana.

Three-dimensional modeling of the bone histology of an early fossil fish, *Lophosteus*, from Estonia using synchrotron scanning data.

Coniferous trees are called “living fossils” of the forest. All flowering plants have undergone huge evolutionary changes, while conifers have remained largely unchanged.

FORESTRY AND PLANT SCIENCE

Forests represent both the ancient and new. Although coniferous trees' genomes have remained practically unchanged, they have dominated Nordic forests for 200 million years. Researchers are now employing electronic tools in wood pulp and plants. The combination of modern technology and forests has revolutionized the opportunities for research.

Most Swedes have a very special bond with the forest. We use it for recreation and exercise, and as a source of foodstuffs like berries, mushrooms, and meat. Many people also earn their livelihood from the forest. Forestry is a cornerstone of the Swedish economy and one of Sweden's most important basic industries. It provides employment all over the country.

But competition from countries with faster-growing forests is increasing, while a rapid structural transformation is underway. For example, computerization is causing a major fall in demand for paper, while the importance of high-tech processes and products is rising, highlighting the need for research.

One avenue is to create new, renewable materials from nanocellulose; another is to create tailor-made trees for specific applications through genetic engineering—one type for products, another for lumber, and yet another for new plastic-like materials or fuel.

Wood-based materials have many benefits; two of the main ones are that they are renewable and environmentally friendly. There is huge demand for new materials with such properties for uses in automobiles, trains, and airplanes as well as packaging and construction. Research can also lead to new specialty products, such as fibers with magnetic, electroconducting, or antibacterial properties.

The first project the Foundation supported in experimental plant science was the Tree Genome program at the Umeå Plant Science Centre (UPSC). Researchers there studied the genetic material in tree cells and the effects of removing, modifying, and adding one or more genes. The project was carried out using mainly poplar (species of the genus *Populus*) trees as model plants. The first genome of a tree to be fully mapped—a major scientific achievement—was from a poplar (*P. trichocarpa*).

With new technologies and sequencing methods, basic research has made great strides. Working with SciLifeLab, researchers at the Umeå Plant Science Centre mapped the spruce tree genome in just three years. Having that understanding of trees' composition can help scientists breed trees that can grow faster or are more disease-resistant.

The Wallenberg Wood Science Center (WWSC) was established in 2009, when the Foundation provided funding for a research center focusing on new wood-based materials. Bioplastics and products made from nanocellulose are two examples of innovative materials that have emerged from the center's research. Scientists there are also working on identifying new applications for wood-based materials.

In addition, funding has been provided for a number of projects that focus on trees' unique biology and the role of forest ecosystems in the global climate. Project grants have been awarded for research including use of isotope techniques to study forest growth, investigation of the environmental factors that regulate flows of water, carbon, and energy in forest ecosystems, and studies of the effects of each individual process. Another high-profile project is focused on developing paper-based electronics at the Norrköping campus of Linköping University, where scientists have also created the world's first electronic plant ■

TRANSFORMING SWEDISH FORESTS INTO NEW ENVIRONMENTALLY FRIENDLY SUPERMATERIALS

Researchers at the Wallenberg Wood Science Center are working to develop new materials and technologies that will enable forestry to remain a significant industry both in terms of Sweden's economy and employment. Their goals include replacing oil with wood in the manufacture of plastics and creating stronger, non-flammable materials.

Forestry has always played a major role in Swedish industry. But as countries with forests that grow 10 times faster than Sweden's are developing their industry, the Swedish forestry and pulp sector has had a hard time keeping up.

"That's why it's crucial to move forward with research. The forestry industry has traditionally focused on improving methods for pulp and cardboard manufacturing. But now, research is needed to create conditions that will enable the development of new products," said Lars Berglund, Professor of Wood and Wood Composites at KTH Royal Institute of Technology and Director of the Wallenberg Wood Science Center (WWSC).

The WWSC, a joint venture between KTH Royal Institute of Technology and Chalmers University of Technology, was established in 2009 when the Foundation awarded a grant for a research center specializing in new wood-based materials. The Foundation has invested a total of SEK 450 million in the center.

GREAT HOPES FOR NANOCELLULOSE

The research program has two main objectives: to extract new components and develop different materials. One project involves extracting components from the wood that can be used as biocomposites or to replace oil to produce environmentally friendly plastics. You could say the scientists are "prospecting" in the wood for resources that haven't been used before.

In another project, researchers are working with tiny fibers—nanocellulose.

"We can use nanofibers to make materials that are stronger, water-resistant, non-flammable, and optically transparent," Prof. Berglund explained. Those properties are very useful in the manufacture of barrier layers in packaging, for example.

"Such layers prevent oxygen penetration, extending the expiration date. We have also worked with magnetic materials in cellulose. A strong argument for investing in wood fiber is that it is renewable and beneficial for the carbon dioxide balance," he added.

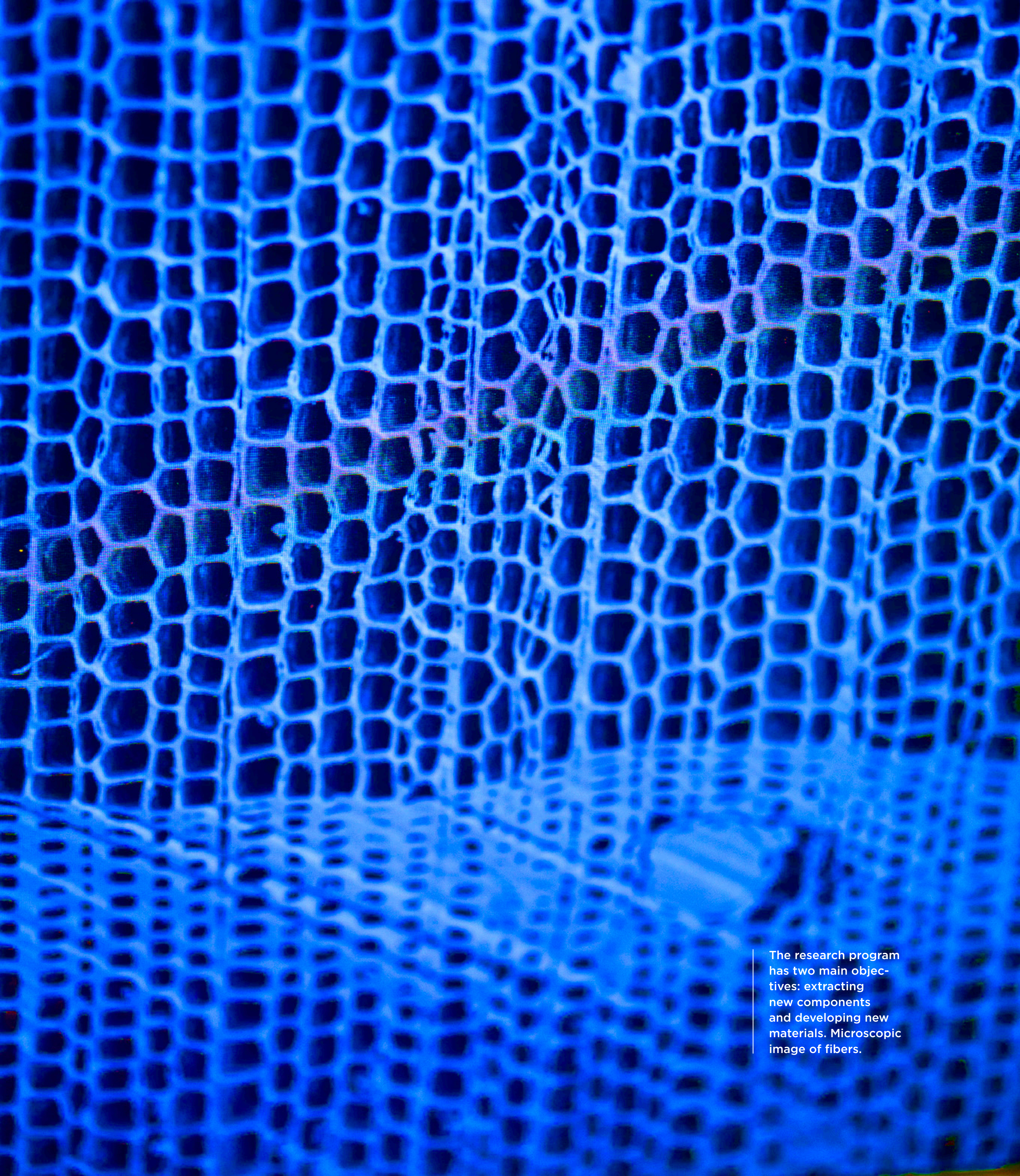
Besides developing wood polymers—that is, biological plastics—researchers also need to find methods for extracting components from the wood without destroying them.

LARS BERGLUND

Professor of Wood and Wood Composites at KTH Royal Institute of Technology and Chair of WWSC.

The research center is run jointly by KTH and Chalmers University of Technology. Emphasis is on basic research towards novel utilization of trees to make new materials from Swedish wood.

The center has been awarded SEK 450 million in grants.



The research program has two main objectives: extracting new components and developing new materials. Microscopic image of fibers.

The Wallenberg Wood Science Center is a joint venture between KTH Royal Institute of Technology and Chalmers University of Technology. One of its aims is to produce new materials from Swedish wood. Assya Boujemaoui analyzes wood fibers.

WOOD

Wood, the raw material from trees, contains cellulose, lignin, and hemicellulose. Currently, in most cases only the cellulose is utilized.

Lignin makes up around 30% of wood. Lignin is used in the production of cement, and it could also become an important component in bioplastics.

Researchers at the WWSC work with a biorefinery to make environmentally friendly materials. Between 20% and 30% of wood is hemicellulose, which has shorter molecular chains than pure cellulose and can be used for ethanol production. The WWSC's scientists are working to find new ways to use hemicellulose in materials such as bioplastics.

A BIO-REFINERY FOR MATERIALS

Nanocellulose is an exciting area. Nanotechnology is new to the forestry industry, and it has the potential to become very big. There is huge demand for packaging materials, construction materials, and composites.

Prof. Berglund believes that besides fibers, pulp mills will also extract nanofibers and chemicals in the future.

“We view trees as sources of materials, kind of like oil wells. Just like a refinery utilizes every component in crude oil, we want to utilize everything from trees. We envision small, specialized biorefineries for materials, scattered throughout the country, extracting wood components and maybe also producing bioplastics and other materials,” he said.

He drew a comparison with Domsjö Fabriker in the town of Örnsköldsvik, a facility that currently extracts cellulose for textile fibers.

RESEARCH FOR NEW APPLICATIONS

Although the applications take center stage, most of the WWSC’s research addresses fundamental issues.

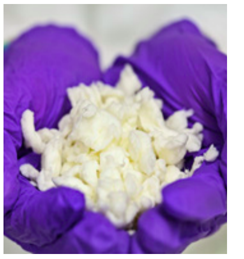
“If you want to extract new components from wood, you have to understand how it’s formed. So, we also have a fiber project involving both chemists and mechanical engineers. We take natural cellulose and make new fibers that are “better” than traditional wood fibers. Cellulose is a natural carbon fiber; it gives trees much of their strength, which is something we can exploit,” Prof. Berglund said.

In nanocellulose research, applications are envisioned for environmentally friendly packaging, as well as materials for building insulation and reinforced plastics.

“We’re trying to identify future areas of use, such as microelectronics and energy storage,” he added.

The scope of applications appears very wide. In another project, scientists are developing new plastics from lignin. The range of expertise at the WWSC is crucial for this breadth of innovation.

“We have cutting-edge expertise in chemistry, chemical engineering, materials science, mechanical engineering, and biotechnology. Around 60 people work here in total, including 20 professors and even more PhD students,” Prof. Berglund noted ∎



NANO-CELLULOSE

Nanocellulose, produced from wood fiber, has many attractive qualities.

It is as strong as Kevlar, lightweight, and completely renewable. A disadvantage—a very energy-intensive production process—has now been solved.

“It’s incredibly important to promote research. The forestry industry has traditionally been about improving methods for manufacturing pulp and cardboard. However, research is now needed to enable us to develop new products.” —Lars Berglund

Spruce DNA contains 20 billion base pairs. Its sequence was assembled from a "puzzle" consisting of 2 trillion fragments.

MAPPING THE SPRUCE GENOME

Conifers have dominated large parts of the world's forests for 200 million years and are sometimes called living fossils. The spruce is Sweden's most important plant in economic terms, and its genome —which is seven times larger than the human genome—has now been completely mapped by researchers at the Umeå Plant Science Centre and SciLifeLab in Stockholm.

The main purpose of the project was to map the spruce genome to understand the tree's biology and evolution.

"Way back before the dinosaurs wandered in the coniferous forest, conifers hit upon something that was so successful they still dominate. Since then, all flowering plants have undergone enormous changes, while the conifers have barely developed at all," said Ove Nilsson, Professor of Forest Genetics and Plant Physiology.

It is something of a mystery why the conifers have nevertheless retained their dominant position.

"In purely theoretical terms, it should be a disadvantage not to develop at the same rate as the other plants," he said.

TAILOR-MADE TREES

Another of the project's objectives has been to improve and accelerate the breeding and cultivation of spruce and pine.

"With the entire genome sequence, we have complete control of every gene so we can link them to various characteristics. For example, trees can be bred to grow faster and become more disease-resistant. We hope that all Swedish tree breeding and cultivation will change after this," Prof. Nilsson commented.

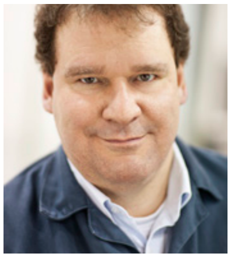
According to the researchers, this also opens up the possibility to tailor-make trees for various uses. There could be one type for paper pulp, another for lumber, and a third for new plastic materials or fuels.

The mapping of the spruce genome was a gigantic task in many ways. Its DNA consists of 20 billion base pairs, or nucleotides. There are four kinds of nucleotides (referred to by the abbreviations A, C, G, and T) in DNA, which could be called the alphabet of life, as their order in DNA sequences has almost infinite numbers of combinations and provides the blueprints for organisms' forms, capacities, development, and behaviors.

"The problem is that we can only read small parts at a time, which results in an enormous puzzle made up of random bits of DNA," Prof. Nilsson said.

The researchers' biggest challenge was to put all the pieces of the puzzle together so the letters were in the right sequence. In the case of the spruce, more than 2 trillion puzzle pieces had to be put together. To put the enormous amount of information involved into perspective, the scientists refer to the Bible.

"Think how many individual letters there are in the Bible. Then imagine how many Bibles you would have to line up to stretch from Stockholm to Uppsala, and the total number of letters they contain. That gives you an idea of the amount of data we're dealing with," Prof. Nilsson explained.



OVE NILSSON

Professor of Forest Genetics and Plant Physiology at the Swedish University of Agricultural Sciences and the Umeå Plant Science Centre.

The spruce genome was mapped by researchers at UPSC (a joint venture between Umeå University and the Swedish University of Agricultural Sciences) and at SciLifeLab (a joint venture between Karolinska Institutet, KTH Royal Institute of Technology, Stockholm University, and Uppsala University).

The spruce genome project has received SEK 75 million in grants.

Propagation of plant cells in sterile cultures in Ove Nilsson's laboratory.

THE RIGHT CONDITIONS FOR TECHNICAL PROGRESS

With the establishment of SciLifeLab, it became technically possible to sequence the genome. SciLifeLab is a collaborative venture between KTH Royal Institute of Technology, Stockholm University, Karolinska Institutet, and Uppsala University, which enables access to cutting-edge technology and new platforms for genomics and bioinformatics.

The project got underway in the summer of 2010, and the entire spruce genome was mapped by spring 2013.

THE KÖTTSJÖ SPRUCE

The material the DNA researchers sequenced originated from a spruce in Köttsjö in the county of Jämtland, north-central Sweden. A few sprigs were grafted from the Köttsjö spruce in 1959, and now it has millions of offspring in the Swedish forests. The sequencing shows that the spruce has at least 29,000 different genes. That's just a few more than humans have, yet the spruce's genome is seven times larger than ours. One of the project's aims is to find out why it is so large.

"We were fairly certain it was not because the spruce has more genes. However, the genome is full of short DNA sequences that are repeated. They are the remains of 'transposons,' pieces of DNA that can replicate themselves and jump around in the genome. Most plants have mechanisms to limit the spread of these transposons, but conifers appear to lack them," Prof. Nilsson explained ∎

A

C, G, AND T

All living cells contain a genome—genetic information coded in DNA. Even viruses have genomes, which consist of either DNA or RNA.

The genome contains all the information cells need to produce the primary components they require to function: different types of RNA and proteins.

Genes are the parts of a DNA molecule that contain genetic information, while the other parts have more structural roles or are involved in regulating the genes.

Each gene consists of a specific DNA sequence, i.e. a specific series of base pairs that encodes a particular protein (or RNA molecule). DNA sequencing is the process used to "read" the order of the four nitrogenous bases (designated A, C, G, and T).

The spruce DNA that the researchers sequenced originated in Köttsjö, north-central Sweden.

An image of electronic circuitry printed on paper, which originated in the late 1990s when Magnus Berggren's research team used ion-based electrochemistry.

CREATING RECYCLABLE PAPER ELECTRONICS IN NORRKÖPING

Imagine a sheet of paper with lighting woven into the very paper pulp. Or cardboard that folds into a box at the touch of a finger, or paper batteries. It sounds like something out of the magical world of Harry Potter, doesn't it? In a few years it may be a reality in Magnus Berggren's laboratory.

Today's electronics are manufactured with expensive materials that may also be difficult to recycle. They may soon be replaced by recyclable paper alternatives.

Electronics are already being printed on paper in Norrköping. Magnus Berggren (Professor of Organic Electronics at Linköping University) and all the researchers, designers, technicians, chemists, and mechanics working with him have converted an ordinary printing press into a press for printing electric components on paper. They simply pour electronic ink into the containers that were designed for printing ink.

"My colleagues and I started dreaming about this back in 1999, when our lab was completed. We were first in the world in the field of 'paper electronics' and initially worked with various plastic structures—polymers. Even back then, we talked about taking this down to the cellulose level, and with the grant from the Knut and Alice Wallenberg Foundation, we'll be able to do it," he said confidently.

SMART, ENVIRONMENTALLY FRIENDLY TECHNOLOGY

In 1999, the first sheet of paper with electronics was printed, and in 2011 production of the first simple commercial products started at the PEA facility, a project with seed funding from Vinnova, Sweden's innovation agency. The advertising and security industries were particularly quick to adopt this technology.

They are currently working with the construction company PEAB and the municipal housing corporation Hyresbostäder on a pilot project involving adhesive labels and sensors. The new sensors are being employed in efforts to avoid moisture and water damage in a new housing development. They consist of a thin foil label containing a tiny antenna that transmits information when the moisture level changes.

"This technology is also environmentally friendly. Our vision is to make everything we produce recyclable," Prof. Berggren noted.

Similar sensors could be used to monitor the temperature in food shipments or other sensitive production chains.

"I'm really excited about sensors. They are the future. They'll enable us to monitor various processes via our mobile phones, so we can find out immediately if something is wrong," he predicted.

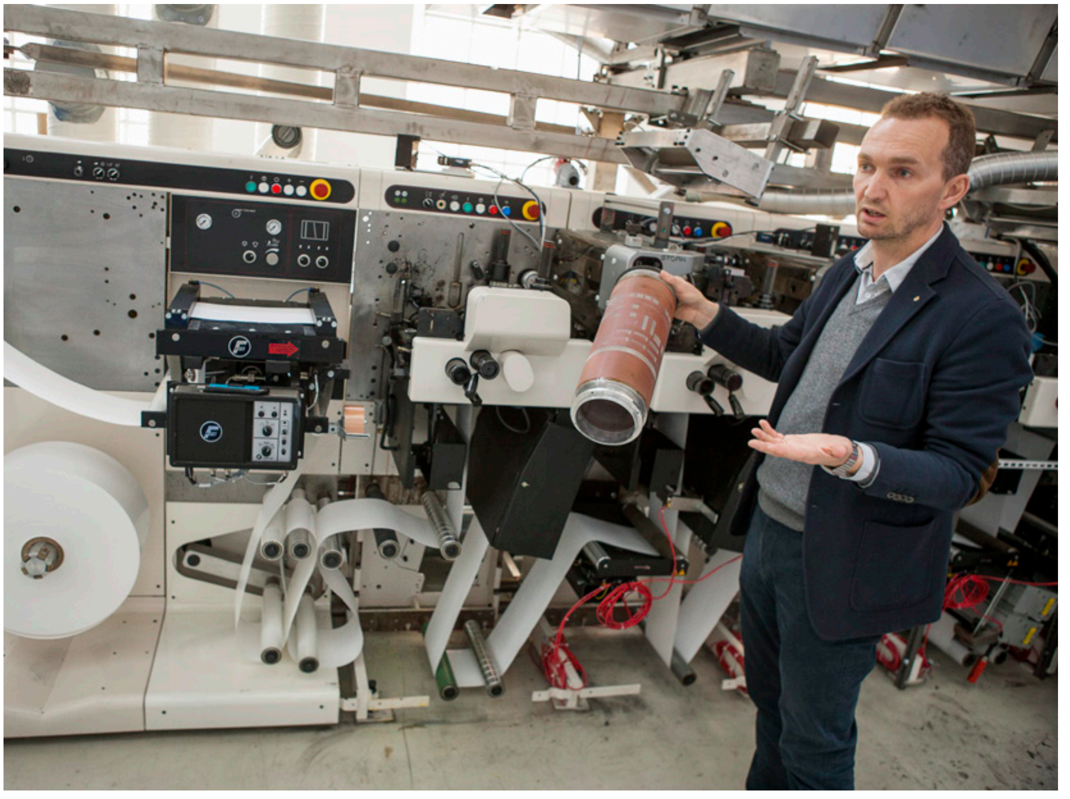
MAGNUS BERGGREN

Professor of Organic Electronics, Linköping University.

Principal investigator of the project "Power Papers."

Co-investigators:
Niclas Solin, Olle Inganäs, Thomas Ederth, Xavier Crispin, Lars Wågberg (KTH Royal Institute of Technology), Tom Lindström (Innventia AB).

Project grant in 2011
Grant awarded:
SEK 35 million.



An ordinary printing press has been repurposed to print electronic components on paper. Electronic ink is put into the containers that would normally hold printer's ink. Magnus Berggren demonstrates.

PAPER WITH MUSCLES

Now Prof. Berggren wants to take paper electronics to the next level and integrate electronics in paper pulp. In order to understand the process properly, he assembled around 30 people, including some researchers from KTH Royal Institute of Technology in Stockholm, for a basic course in making paper with electronic functions.

"We also did a brainstorming exercise. Of the 111 ideas that emerged, we have chosen to move forward with seven or eight," he said.

One of the ideas was to build a "muscle" function into the paper.

"The idea is that you'll be able to apply pressure to the paper or cardboard and change its shape or structure. It could fold itself into a box or dissolve into the structure of toilet paper so it can be flushed. I believe we can achieve this within five years," he predicted.

At the same time, he admits it was a huge step to be able to print electronics on paper, and this next step will be at least as big as that.

MANY AREAS OF APPLICATION

This technology could be incredibly valuable in identifying genuine or counterfeit currency, bank cards, and tickets.

"We've already tried introducing electronics in paper currency. In principle, we should be able to use a cell phone to make the picture of Greta Garbo on a Swedish 100-kronor bill blink, thus confirming the bill is genuine. We've also produced electronic tickets for a special conference. It's impossible to counterfeit bills if they have to light up," Prof. Berggren said with a smile ■

3

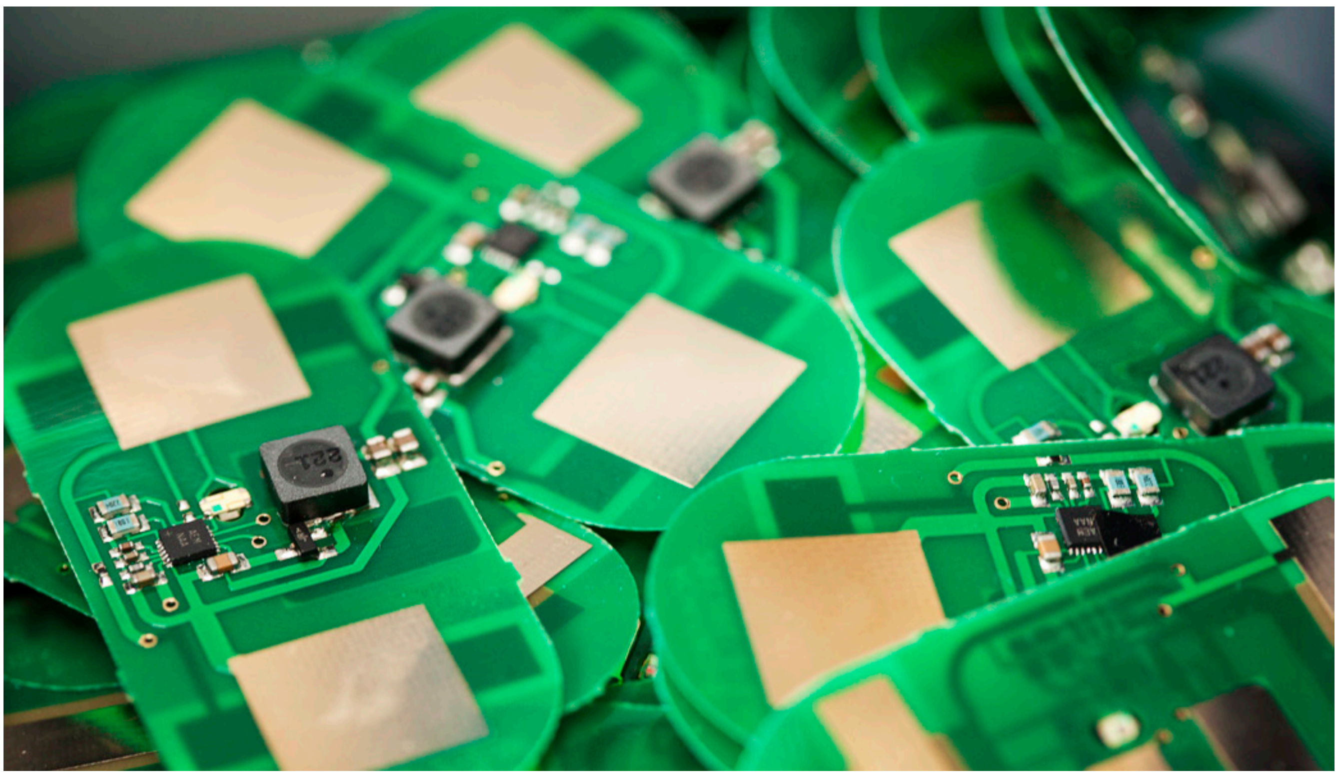
MORE EXAMPLES OF APPLICATIONS

Smart packaging – a sensor tells whether milk is sour or meat has gone bad, if food should be thrown out or if it's still edible. This will reduce food waste.

Printed solar cells – can be made from renewable materials, and even in new shapes, like roofing shingles that warm your house, or a window covering that shields against bright light and transforms the sun's rays into energy.

Authentication – barcodes that can be hidden under printed layers, e.g. to prove that a vaccine or medicine is genuine.

Dust-free cleanrooms are essential when manufacturing sensors and other sensitive electronics. Magnus Berggren's laboratory in Norrköping.



TREE GENOMICS

How—and why—does a tree grow? How do a tree's genes work? How is wood—the foundation of the forestry industry—formed? These are some of the questions researchers at the Umeå Plant Science Centre (UPSC) have grappled with.

UPSC is a center for experimental plant research, established in 1999 as a collaboration between the Swedish University of Agricultural Sciences (SLU) and Umeå University. It is one of Europe's preeminent research centers for plant science, and around 200 people from 40 countries work there.

In the period 2001–05, the Knut and Alice Wallenberg Foundation awarded SEK 54 million in grants to UPSC.

During that time, one of the main research topics was the thin layer of "meristematic" cells, just inside the bark, which determine how much wood is formed. By identifying and modifying these cells, wood formation can be influenced. Genetic modifications can also affect a tree's other characteristics, such as the length of its fibers or its growth rate.

Traditional tree and plant breeding has concentrated mainly on creating various kinds of new plants and seeds. In contrast, at UPSC researchers investigate the structure of tree cells, their genetic composition, and the effects of removing, modifying, or adding one or more genes. The scientists have access to hi-tech laboratory facilities and specially designed greenhouses containing thousands of saplings in different sizes.

Researchers at UPSC have developed the poplar as their "model tree," partly because the first fully mapped tree genome was from a poplar. While spruce might have been a more natural choice to study in Sweden, poplar has several other major advantages. Some experiments can be completed 10 times faster with poplars than with spruces, and many of the results can be applied to coniferous trees like spruces.

BERZELII CENTRE FOR FOREST BIOTECHNOLOGY

Today, most research at UPSC is conducted within two centers: the Berzelii Centre for Forest Biotechnology and FuncFiber.

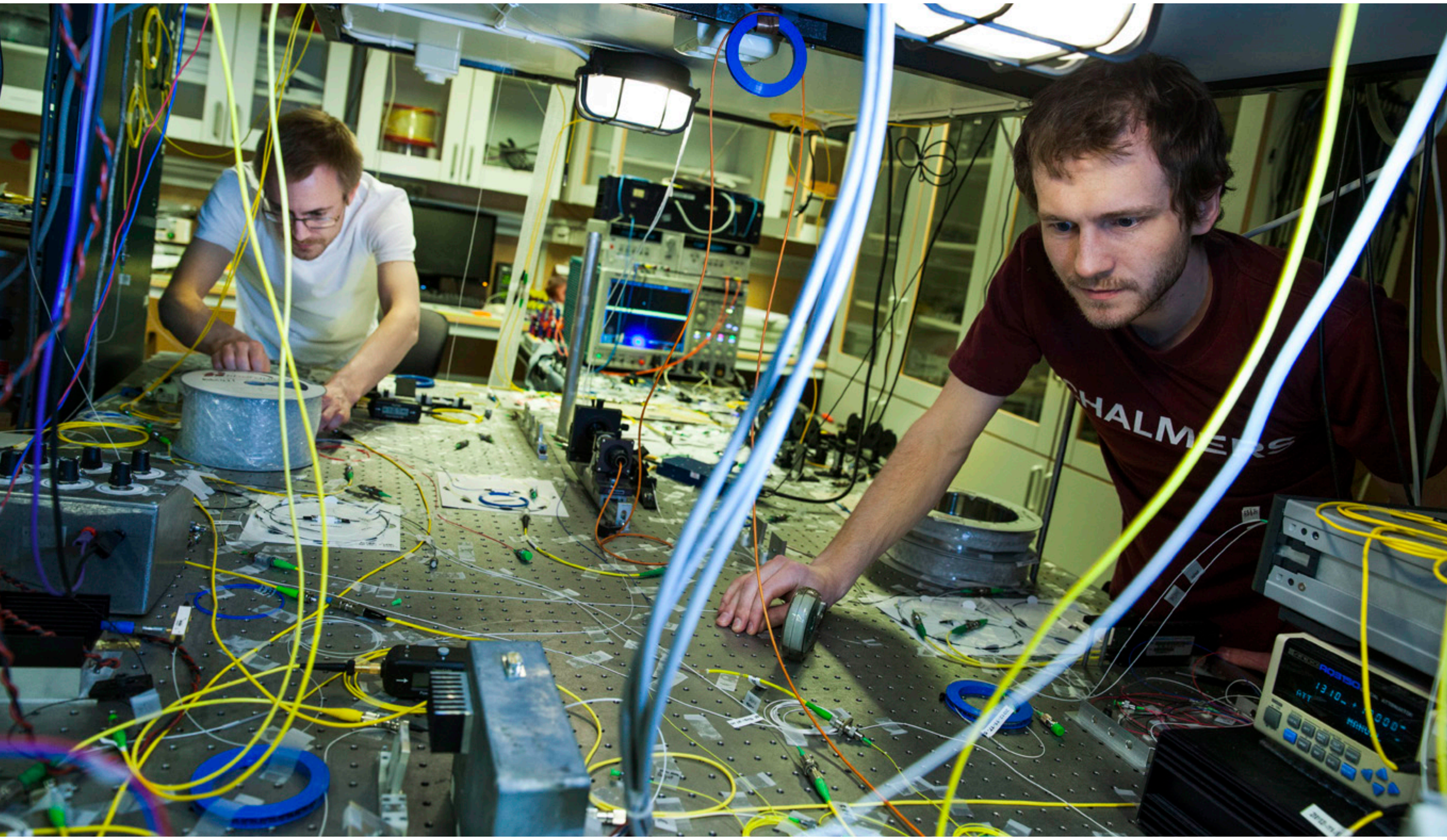
UPSC's Berzelii Centre for Forest Biotechnology is one of the world's strongest research centers in its field. Its research efforts focus on three aspects of the fundamental biology and chemistry accounting for trees' key properties: mechanisms controlling trees' growth and productivity, the formation and characteristics of wood, and trees' adaptive annual growth and dormancy cycles ■

FUNCFIBER

The FuncFiber network unites research teams from industry and several universities. Its aim is to promote collaboration among researchers with expertise in wood biology, chemistry, and mathematical analysis.

The research program can help to increase the efficiency and profitability of commercial forestry by analyzing effects of various genes on the production of wood biomass and wood properties. Natural genetic variations among trees are identified and can be utilized in tree breeding to improve growth rates and other targeted characteristics.

Poplar saplings in the hi-tech greenhouse at Umeå Plant Science Centre.



The team in Wallenberg Scholar Peter Andrekson's laboratory at Chalmers University of Technology made a discovery that can increase internet capacity and developed an optical amplifier. Samuel Olsson and Henrik Eliasson are two members of Andrekson's team.

In the future, more energy-efficient and environmentally friendly manufacturing methods for materials will be required, and materials will need to be stronger, lighter, and made from cheaper raw materials. Samples from Olle Inganäs' laboratory.

PHYSICS AND MATERIALS SCIENCES

From 1960 to 1990, Swedish public-sector funding bodies made a number of substantial investments in materials science at Swedish universities.

Physics and chemistry provided the foundations of what later came to be regarded as a separate academic discipline: materials science. Advances in materials science centered around improvements in instrumentation, such as the use of ultra-high vacuums for studying surfaces of materials. New spectroscopic and microscopic technologies like electron spectroscopy and electron microscopy were used to study material structures. Surface physics and chemistry, as well as thin-film technology, soon attracted attention.

More systematic national investment in materials science did not come until the 1980s, when programs in biomaterials and micronics were established. The largest grants went toward creating a future knowledge base for Swedish electronic manufacturing, at least partly for strategic policy reasons.

In the early 1990s, 11 "Materials Consortia" were set up with the intention of creating cross-scientific centers in various materials science disciplines, rooted in one institution but including researchers from several other institutions. The consortia served to organize Swedish materials science research, and the various institutions later assumed responsibility for different aspects of research, such as nanometer structures, theoretical expert systems for material structures, biomaterials, and thin-film processing. The consortia were the predecessors of today's distributed national centers.

EXPENSIVE INFRASTRUCTURE

Special lab facilities called cleanrooms are required to study properties of materials. Cleanrooms are free from dust particles and house the latest microscopes for studying structures at the atomic level. It was also necessary to create a theoretical basis to develop new materials.

It was extremely expensive to build the lab infrastructure, so grants from the Knut and Alice Wallenberg Foundation, along with support from public research bodies, played a major role in the development of materials science in Sweden.

In the late 1990s, investment in the Materials Consortia ceased. Around the turn of the millennium, the new equipment required for research was so costly that a national assessment was carried out, and the Myfab laboratory was set up with support from the Foundation, together with the Swedish Research Council.

Today, materials research is supported by several funders, with major support from the Foundation in the form of grants for individual researchers in the Wallenberg Scholars and Wallenberg Academy Fellows programs as well as comprehensive project grants.

The Foundation has also provided significant grants to two national facilities with major significance for taking Swedish materials research into the future: the Onsala Space Observatory and the MAX IV laboratory ■

MYFAB— A NETWORK OF CLEANROOMS

Cleanrooms have enabled research and development in miniaturization of electronics and mechanical components in fields such as communications, space technology, nanotechnology, and biosensors. These areas of research and development are often collectively referred to as micro- and nano-manufacturing.

As the name indicates, cleanroom technology requires extremely clean spaces to prevent damage to expensive equipment and interference with highly sensitive experiments.

Humans are the worst sources of contamination. Our cells are continuously renewed, with new skin cells produced as old ones are shed. We shake off 100,000 particles every minute, and in an ordinary room millions of particles can accumulate. Protective suits, face shields, and comprehensive purification equipment are necessary, as is thorough ventilation.

The Myfab network was set up in 2004 by Chalmers University of Technology, KTH Royal Institute of Technology, and Uppsala University to attain national and international synergies for researchers and commercial stakeholders. The reasons for establishing the Myfab network were to coordinate and improve utilization of Sweden's three national cleanrooms (micromanufacturing labs) at those three institutions. The overarching goal was to increase use and access to the facilities within academia and industry, while reducing risks of duplicating expensive equipment.

Support for building the network, which was initiated in 2004, came from the Knut and Alice Wallenberg Foundation together with the Swedish Research Council, the Swedish Foundation for Strategic Research, and Vinnova, Sweden's innovation agency.

Another of the network's aims was to develop more distinct roles for the three cleanrooms. The MC2 facility at Chalmers University of Technology began to focus mainly on new quantum components and products for microwave technology and photonics. The Uppsala unit was assigned to life sciences, materials research, and process engineering. The facility at KTH Royal Institute of Technology, operated in conjunction with the Acreo research institute, centers mainly on research and development in semiconductor physics and photonics.

In the cleanrooms, components of devices are downsized while the complexity of their potential functions is increased. The big question is how far we can go: What is the smallest material that can be manufactured, and how complex can the components become?

For many years before and since Myfab was established, the Knut and Alice Wallenberg Foundation has provided grants for research equipment at Sweden's three national micromanufacturing labs, located at Chalmers University of Technology (MC2), Uppsala University (the Ångström Laboratory), and KTH/Kista (the Electrum Laboratory). The Foundation has contributed over SEK 500 million in total to these three facilities.

PHOTONS

A photon is a single particle of light. It can carry all kinds of electromagnetic radiation, such as light, gamma rays, microwaves, and radio waves.

Photonics is a rapidly expanding field that combines modern electronics and optics. It has revolutionized information and communications technology. Today, large parts of the internet's infrastructure consist of optical fibers that transmit communications in conjunction with other photonic components.

Photonics can be divided into three main areas: light sources and light modulation; information and communications technology; and applications that exploit interactions between light and materials. Much of the latter sub-field is involved in medicine and biology.

A cleanroom in the MC2 laboratory at Chalmers University of Technology in Gothenburg. Cleanrooms are widely used in semiconductor manufacturing and in biotechnology, bioscience, and other fields that are highly sensitive to impurities.

Cleanrooms are indispensable parts of the infrastructure in the Swedish Graphene Initiative project, led by Mikael Fogelström at Chalmers University of Technology.

MICROTECHNOLOGY AND NANOSCIENCE

MC2, a network of over 200 researchers and grad students, conducts research into micro- and nanotechnology. This research focuses on future nano- and quantum mechanical electronics, photonics, biosystems, and nanosystems. The facility houses a cleanroom for micro-macro field microscopes with the latest equipment. Research is often conducted in close collaboration with Swedish and international partners from academia, industry, and the wider community.

ÅNGSTRÖM MICROSTRUCTURE LABORATORY (MSL)

MSL is a central resource at the Ångström Laboratory and a division within the Department of Engineering Sciences at Uppsala University. The key reason for building the first phase of the Ångström Laboratory was to concentrate all the general equipment for micro-profiling of nanoprocessing and materials in a shared cleanroom lab. The lab was opened in 1997, and since then it has hosted numerous students, researchers, and engineers working along the entire innovation chain, from basic research to product development.

ELECTRUM LABORATORY AND ALBANOVA NANOFABLAB

These two laboratories are run by Myfab in the KTH node. The Electrum Laboratory, located in the Stockholm suburb of Kista, focuses on nano- and microscale production and profiling. It supports the whole chain from education through R&D to prototypes and production. The AlbaNova NanoFabLab is located on the KTH campus in Stockholm. With particular strength in direct imaging technology, AlbaNova NanoFabLab is a flexible resource for basic research requiring nanomanufacturing and nanoprofiling of a range of materials and substrates. Both labs are meeting places for students, researchers, and businesses from various fields ranging from basic science to applied engineering ■

The MC2 lab at Chalmers University of Technology conducts micro- and nanotechnology research.

0.5

MICRON

Different classes of cleanrooms have different purity standards, according to the maximum numbers of particles of specified sizes they may contain per unit of air volume.

For example, the air in a city contains around 35,000,000 particles 0.5 micron or larger per cubic meter. That is equivalent to an ISO Class 9 cleanroom.

ISO Class 5 cleanrooms can have only 3,520 particles 0.5 micron or larger per cubic meter of air, and only 29 particles 5 microns in size.

For ISO Class 2, four particles of 0.5 micron or larger per cubic meter are acceptable, whereas ISO Class 1 does not permit a single particle of this size.

The observatory's 20-meter (65.6-ft.) telescope is protected by a radome consisting of 620 fiberglass-reinforced plastic panels. The panels form a spherical dome with a diameter of 30 meters (98.4 ft.).

ONSALA SPACE OBSERVATORY

For 40 years, the Onsala Space Observatory has been at the forefront of international research, contributing to many scientific breakthroughs. The radio telescope is used to study comets, galaxies, quasars, and other cosmological phenomena.

The Onsala Space Observatory is Sweden's national radio astronomy facility. The radio telescope at Onsala enables researchers to observe star-forming areas, nebulae surrounding aging stars, gas clouds in the Milky Way and other galaxies, and cosmic background radiation—a remnant from the Big Bang. The observatory has been at the cutting edge of global research for 40 years. One of its strengths is its sophisticated, regularly upgraded technology. Its integration with Chalmers University of Technology is another key element in its success, as are its links to other organizations including Lantmäteriet (the Swedish mapping, cadastral, and land registration authority) and the Swedish Meteorological and Hydrological Institute (SMHI).

Sweden has contributed to major scientific advances with radio telescopes, atomic clocks, GPS, and gravimetry.

A GLOBAL REFERENCE SYSTEM

GeoVLBI (very-long baseline interferometry) technology, developed at Onsala and elsewhere, is used as a reference in space navigation. It has many other hi-tech applications, notably in geodynamics (tectonics, land uplift, and earthquake research) and studies of regional environmental effects and global climate change (sea level changes, atmospheric water vapor monitoring).

When Olof Rydbeck founded the Onsala Space Observatory in 1949, he was awarded a working grant by the Foundation. Since then, the observatory has been granted funding for equipment on many occasions, including nearly SEK 30 million for a telescope system for geodetic VLBI in 2011.

The telescope is part of a global reference system that is under construction. The system will continuously measure key parameters that describe the Earth's movement and shape, including tectonic plate movements. Studies of Planet Earth as a system are becoming increasingly timely. Measurement of the globe's large-scale behavior in a reference system is one of the cornerstones of an expanded future global observation program advocated by bodies including the United Nations.

The reference system is 10-fold more precise than previous frameworks—that has major implications for basic research. As a byproduct, the system will also continuously measure atmospheric water vapor levels (an important climate parameter) and provide basic data for precise global time synchronization and satellite navigation ∎

3

radio telescopes are located at the observatory.

The observatory also participates in international radio astronomy projects, including the European VLBI network of radio telescopes, the APEX and ALMA radio telescope projects in Chile, and construction of the SKA radio telescope array to be built in South Africa and Australia.

MISSION: TO MAKE THE INVISIBLE VISIBLE

One of the world's most cutting edge synchrotron radiation facilities is located outside Lund in southern Sweden. It could be described as a super-microscope that reveals details about nature's smallest building blocks. More than 2,000 visiting researchers a year conduct experiments at MAX IV.

It looks like a giant arena built on a plot of land in the Brunnshög district: the structure is similar in size to the Colosseum in Rome. But there won't be any athletes or gladiators performing here, only electrons.

The "arena" consists of a circular, ultra-high vacuum "storage ring" with a 528-meter (1732-ft.) circumference, linked to an accelerator. High-energy, light-emitting electrons circulate inside the ring at close to the speed of light.

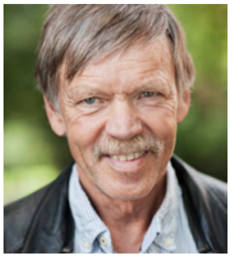
Scientists and companies from throughout Sweden and the rest of the world that conduct research based on synchrotron light will conduct their experiments here.

Most experiments will contribute to basic research on materials and molecules, but many will have applications in the development of new pharmaceuticals, batteries, and solar cells, as well as in the environmental and nano fields.

The grand opening of the facility was on June 21, 2016, the solar equinox.

"The facility generates more brilliant, photon-dense and thus finer, more focused and brighter light beams than any other facility in the world. So, it felt natural to hold the grand opening on the lightest day of the year," said Prof. Mikael Eriksson, the facility's chief designer.

The storage rings at MAX I, II, and III were shut down before the new facility was opened.



MIKAEL ERIKSSON

Professor of Accelerator Physics, Lund University, and the MAX Laboratory's chief designer.

The MAX lab is a Swedish national synchrotron X-ray facility. It is a collaborative venture involving Sweden's 12 largest research universities, hosted by Lund University.

Since its launch in the late 1980s, the MAX lab has received over SEK 1 billion in grants.

NEARLY EVERY SCIENTIFIC FIELD

One might think MAX IV is only for use by physicists, but that is definitely not the case.

"Researchers from most scientific disciplines will conduct experiments here. Physicists, chemists, biochemists, biologists, environmental scientists, archeologists, art historians, paleontologists, and more," said Christoph Quitmann, Director of the MAX IV Laboratory.

MAX IV is now the model for all such facilities being built in the world. What makes MAX IV so unique is that the beam formed in the storage ring becomes brighter and more precise than in similar facilities.

"It provides better resolution, which means we can study, view, and image even finer details than before. The next step is being able to see detailed molecular structures and processes in realistic, complex systems, such as working fuel cells, catalysts, or biological tissue," Prof. Quitmann said.

MAX IV is 528 meters (1,732 ft.) in diameter, as big as the Colosseum in Rome. Various technologies are used in the lab, including imaging, spectroscopy, and diffusion—often in combination.

HIGH STANDARDS YIELD NEW UNDERSTANDING

Stability and precision are two extremely important factors in the construction of a facility like MAX IV.

"The standards are high. Our RMS—which essentially tells us how large the vibrations may be—is 30 nanometers, and few facilities can beat that," said Prof. Eriksson.

The ring-shaped facility is interrupted at one point by a rectangular building. It houses a 250 meter (820 ft.) long linear accelerator. The particles are fed into it and then accelerated to close to the speed of light before being flung out into the storage ring.

"There, the particles' path is bent using powerful magnets that force them to slalom, which is when the synchrotron light arises. The light is then led out to a number of research stations through special beam lines that are connected to various points along the ring," Prof. Eriksson explained.

The accelerator's unusual length allows for plans to build a free-electron laser in a later expansion phase.

A MULTIBILLION-KRONOR INVESTMENT

There are plans for seven beam lines (specialized experimental stations for the intense synchrotron beams) in the first stage, but the hope is to have 25 by 2025.

The first seven beam lines were financed by the Knut and Alice Wallenberg Foundation and 12 universities. All of the beam lines are specialized for various purposes. There are hopes to include medical beam lines to image biological tissue in the near future.

The first accelerator financed with international funding will be the eighth to be installed. A research facility of this size is a multibillion-kronor operation. Each beam line alone costs around SEK 100 million. That's why funding from many sources is needed.

"This has been important. The facility is national, but our ambition is to make it more international. Firstly through an expansion toward the Scandinavian and Baltic countries. It's important to use it to its full capacity," said Prof. Eriksson.

Researchers and companies that publish their results in Open Access channels can use the facility free of charge.

"Those who choose to keep their results for themselves have to pay a fee. To gain access to the facility, an application must be submitted that is reviewed by a number of experts through a peer-review process. It's important for the experiments carried out to maintain the highest quality. We must also be able to prioritize the applications," he added.

The MAX IV facility actually includes two storage rings. The smaller, with a circumference of 96 meters (314 ft.), is still larger than the rings in the previous MAX labs ■

An estimated 2,000–2,500 scientists visit the MAX IV facility every year.

MAX

The name MAX is an acronym formed from "Microtron Accelerator for X-rays."

The MAX IV lab is a Swedish national laboratory dedicated to synchrotron X-ray research—intense radiation from infrared to X-ray wavelengths, which enables scientists to conduct extremely detailed research in fields such as materials science, biotechnology, nanotechnology, environmental science, and nuclear physics.

Construction of the facility began in 2010, and the lab opened in summer 2016.

The total area of the facility is approx. 50,000 sq. m (538,196 sq. ft.).

Lund University is MAX IV's host institution. The Swedish Research Council is the facility's main funder. Other major sources of funding are the Knut and Alice Wallenberg Foundation, VINNOVA, Region Skåne, and Sweden's 12 largest research universities.

Mikael Eriksson shows King Carl XVI Gustaf and Sweden's Prime Minister Stefan Löfven around the MAX IV facility as part of its inauguration.

The Foundation's chairman, Peter Wallenberg Jr, congratulates Christoph Quitmann, Director of MAX IV, at the inauguration.

250

METERS LONG

Particles are fed into a linear accelerator and then accelerated almost up to the speed of light before being flung out into a storage ring.

The particles—electrons, protons, and ions—are accelerated to high energy levels by means of alternating voltage produced by electrodes along the accelerator tube.

The first linear accelerator worked with direct voltage but could not achieve sufficiently high particle energy. At the suggestion of Swedish scientist Gustaf Ising, scientists tried alternating voltage instead.

In 1928, Norwegian engineer Rolf Widerøe constructed the first functioning particle accelerator.

A special type of superconducting circuit, called a SQUID, is designed and manufactured in Per Delsing's laboratory. The chip is mounted on a coil, then the experiment is run.

THE TWIN PARADOX ON A CHIP

By combining theoretical calculations with experiments on superconducting circuits, Per Delsing and his colleagues hope to understand how things fit together at the nano level. As part of their research, they plan to simulate objects that move very rapidly, almost at the speed of light, and demonstrate the twin paradox on a microchip.

Per Delsing is a whiz at controlling photons—tiny particles of light. His research team has generated photons directly out of a vacuum. As part of their project, they are now using photons to demonstrate the twin paradox in a new way. The paradox is a thought experiment stemming from Einstein's special theory of relativity, and has occupied the minds of physicists for more than 100 years.

Per Delsing, who happens to be a twin himself, explained: "The twin paradox says that if I go on a space journey in a high-speed rocket and then return, as an effect of acceleration I'll be younger than my twin brother. This effect has been measured in various ways. What we want to do now is demonstrate it on a microchip."

In other words, instead of traveling into space, his research team will move a cavity, i. e. "a box containing photons" a very short distance.

"But the cavity can be modified so quickly, so that it seems that it is moving close to the speed of light, which is difficult to reach in reality. So that's why we can achieve the effect, although this space journey only takes place on the chip," he said.

PER DELSING

Professor of Experimental Physics at Chalmers University of Technology.

Principal investigator of the project "Quantum states of photons and relativistic physics on a chip."

Co-investigators: Jonas Bylander, Göran Johansson, Vitaly Shumeiko; and David Haviland, KTH Royal Institute of Technology.

Project grant in 2014
Grant awarded:
SEK 50 million.

THE TRICK: A SUPERCONDUCTING CIRCUIT

The team is using a special type of superconducting electric circuit called a SQUID (Superconducting Quantum Interference Device), made in the hi-tech cleanroom at Chalmers University of Technology. When Prof. Delsing's team demonstrated how to create photons out of a vacuum in 2011, they used specially designed SQUIDs as ultra-high-speed mirrors to generate light particles.

In addition to the twin paradox, the project aims to study two other new physical phenomena on microchips: "photon condensation" and "frequency combs."

IT WORKS IN THEORY

A research team led by Göran Johansson, one of the co-investigators and Professor of Theoretical Physics at Chalmers, has published a scientific article showing that it is theoretically possible to demonstrate the twin paradox on a microchip.

Prof. Delsing emphasized the importance of theoretical foundations for empirical work. "Sometimes it's easier to test in theory first; sometimes it's better to start by experimenting," he explained.

The third research team involved in the project is led by David Haviland, Professor of Nanostructure Physics at KTH Royal Institute of Technology. He is developing methods for generating and analyzing signals with many tones at low frequencies (10–100 MHz) in "frequency combs."

"The nice thing is that we can combine our equipment with David's and create frequency combs in the microwave region," Prof. Delsing noted.

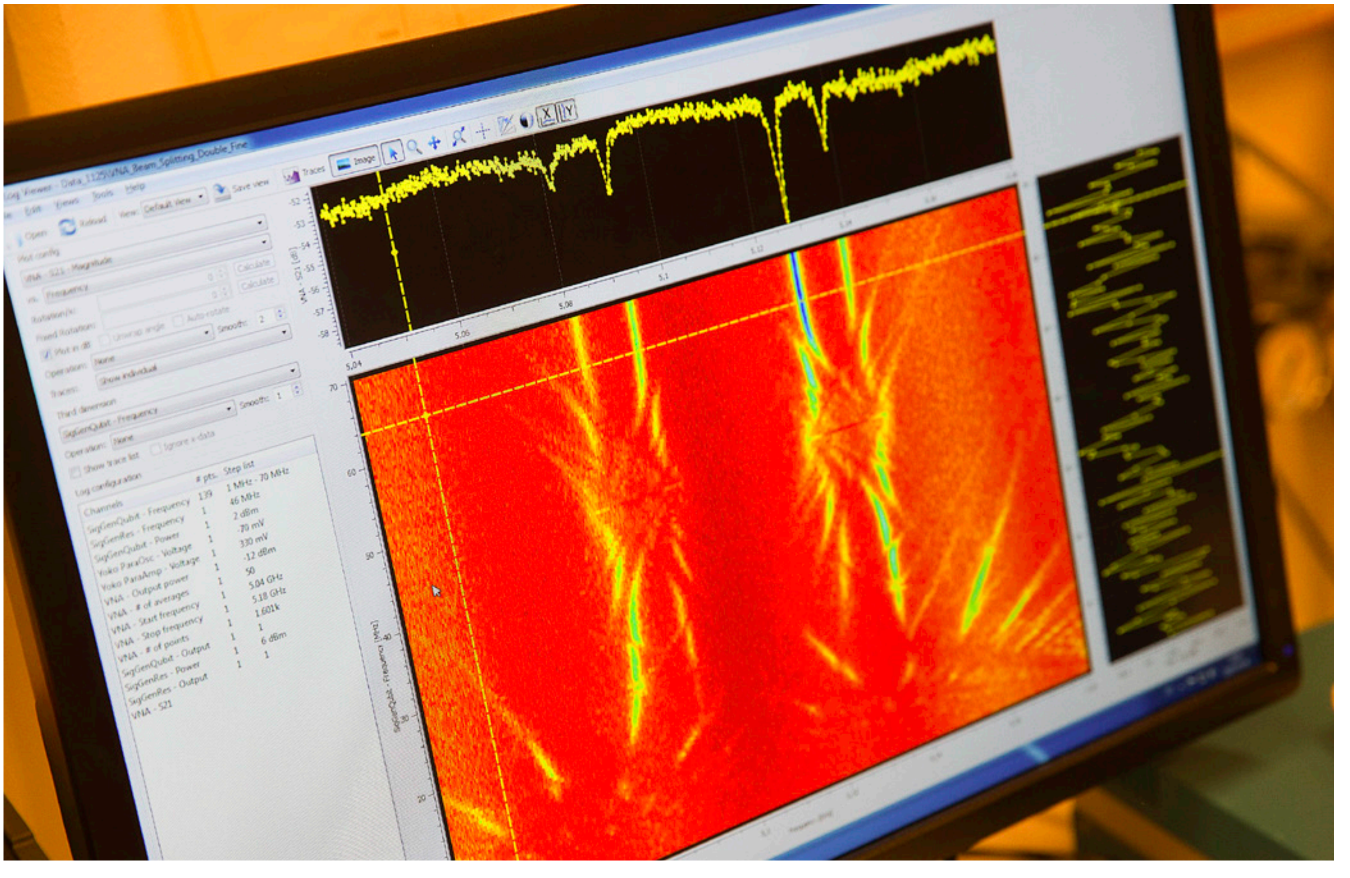
"These frequency combs could in turn be used to drive resonators the researchers use to create photons. A resonator is a component that oscillates at a given frequency; in this case, a transmission line with a SQUID at each end. There are some theories that say it might be possible to use frequency combs for processing quantum information," he added.

KEEPING QUIET AND CHILLED WITH A CRYOSTAT

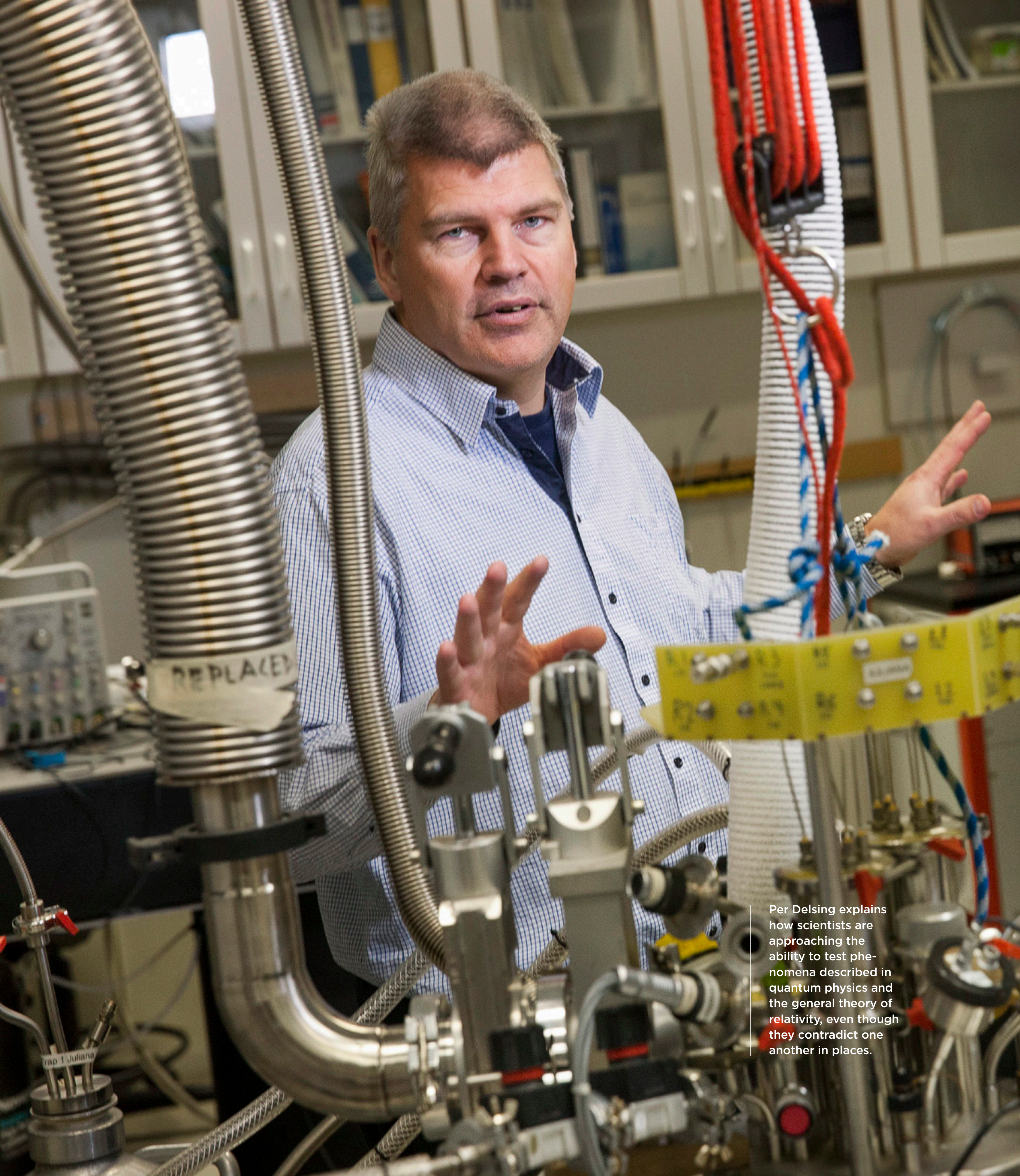
The Foundation's grant will primarily be used to recruit more researchers and buy a new cryostat. This equipment costs about SEK 3 million and is used to cool SQUIDs down close to absolute zero. This is necessary for two reasons, as Prof. Delsing explained during a guided tour of the lab.

"First of all, we need to eliminate all the noise generated at higher temperatures. And a cryostat also means our circuits will be superconducting," he said.

Prof. Delsing, who is also a Wallenberg Scholar, is often asked what his research can be used for. The answer is he does not know. He is conducting pure basic research, trying to understand how everything fits together ■



One part of Per Delsing's project involves developing methods for generating and analyzing signals with microwave "frequency combs."



Per Delsing explains how scientists are approaching the ability to test phenomena described in quantum physics and the general theory of relativity, even though they contradict one another in places.

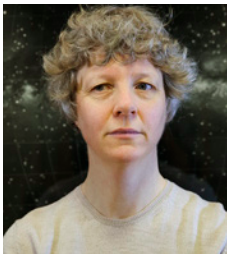
SHOWING THE STARS' PLACE IN SPACE

A recently launched satellite and better measurement equipment on Earth will give researchers massive amounts of new information. The history of the Milky Way is gradually being revealed.

Ever since the universe was young, stars have formed, existed, and died. The heaviest stars end as supernovas—huge explosions that cast material out into space. That material can form the basis of new stars.

"The stars we're looking at are either giant stars or dwarf stars. Primarily dwarf stars, since they don't change as much over time—we prefer extremely boring stars. The dwarf stars slowly consume their fuel, but their outer atmosphere remains the same for many billions of years," said Sofia Feltzing, Professor of Astronomy at Lund University.

A star's atmosphere becomes like a time capsule that shows the researchers exactly what elements dominated space when the star was formed. New elements are formed inside stars, and the elements are spread into space if the star ends in an explosion—so every new generation of stars contains a different composition of elements than their predecessors. So, it's possible to look back and see what the universe looked like several billion years ago, and compare the ages of different stars.



SOFIA FELTZING

Professor of Astronomy, Lund University.

Principal investigator of the project "The New Milky Way."

Co-investigators: Lennart Lindegren, Thomas Bensby; Paul Barklem, Andreas Korn, and Nikolai Piskunov, Uppsala University.

Project grant in 2013
Grant awarded:
SEK 34 million.

A NEW SATELLITE MAPPING A BILLION STARS

Prof. Feltzing enthusiastically explained how the new European space probe Gaia, launched in December 2013, will "change everything" for astronomers. Gaia will measure the distances to more than a billion heavenly bodies in the Milky Way (around 1 percent of the total number) and determine their positions. Today, researchers know the exact positions of around 100,000 stars, all of which are close to the sun.

"Gaia will measure distances and movements and some elemental content. The probe can always measure lateral movement; it can measure the movement in the line of sight for around the brightest 10 percent of stars," she explained.

When researchers know stars' precise locations, it becomes particularly interesting to analyze their composition. If two stars close to each other are different, it says something completely different than if two very remote stars are different. If two neighboring stars are different, one might have gotten there through another galaxy colliding with the Milky Way. Or one star might have moved quickly within the galaxy.

"Sometimes when stars move relatively rapidly, it can make our observations a little tricky," Prof. Feltzing noted.

MORE DATA THAN EVER BEFORE

The grant from the Knut and Alice Wallenberg Foundation will be used in three ways. First, it will

Stellar atmospheres are like time capsules. We can look back in time and see what the universe looked like several billion years ago.

The European Space Agency's Gaia probe will measure the distance from the Earth to over a billion objects in the Milky Way.

finance collaborative data analysis by researchers in Lund and Uppsala. The two groups already work together, but the new funding guarantees that they will be able to continue. Secondly, the funding will partially finance an international instrument called 4MOST, a spectrograph for analyzing the spectrum of starlight. This shows what elements stars' atmospheres contain. Thirdly, the researchers will continue to develop and improve methods for analyzing large numbers of spectra simultaneously.

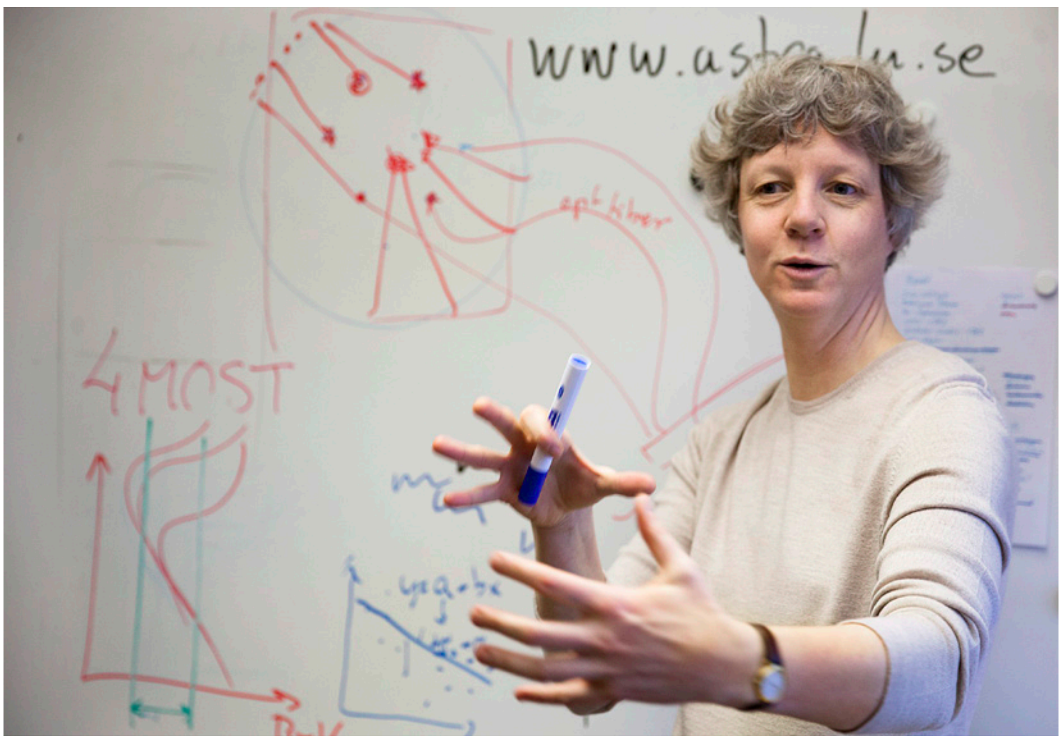
Together, Gaia and 4MOST will provide more precise, accurate, and abundant data than the researchers have ever had access to before. When Gaia determines the position of a star, it can then be studied using the spectrograph, by directing an optical fiber so it only collects light from that star. In order to do this for millions of stars, new analytical methods and advanced statistical calculations are necessary.

"4MOST and Gaia are not designed for a particular observation; rather, they are instruments that we can use to ask several questions. They provide massive amounts of data, so we have to school ourselves to identify and analyze informative datasets," Prof. Feltzing explained.

THE MILKY WAY SHOWS HOW GALAXIES ARE FORMED

The goals of the whole project are to better understand the Milky Way as a galaxy, and to find out more about how galaxies are formed and why they look as they do. Prof. Feltzing also hopes for new collaboration between different specializations in astronomy.

"Today, we astronomers have a theory describing how everything in the universe was created, which explains why the galaxies are very well distributed in space. But our theory is pretty bad at explaining how individual galaxies formed and developed," she said ∎



Sofia Feltzing explains that the project's overall aim is to improve our understanding of the Milky Way and to find out more about how galaxies are formed and why they look as they do.

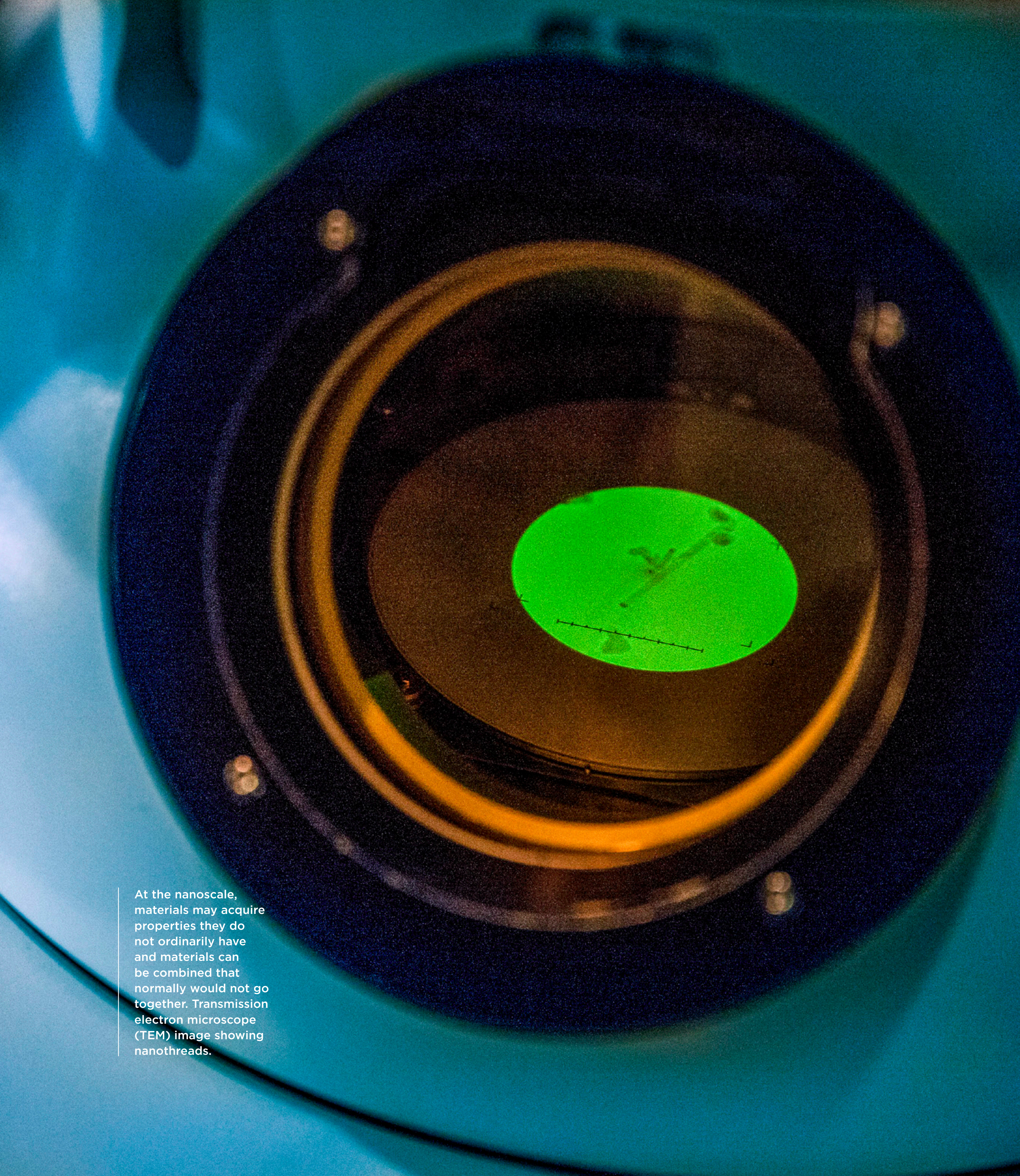
4

LIGHT-YEARS

is the distance from the Earth to the nearest star (other than the sun)—Alpha Centauri, which is actually a group of three stars that orbit each other.

The first person who successfully measured the distance to a star in the Milky Way was Friedrich Wilhelm Bessel, in 1838. That marked the beginning of our understanding of the Milky Way's size.

The Milky Way contains between 100 billion and 400 billion stars. From the Earth, we can see around 2,500 of them. Because the Milky Way loses some stars in supernovas and is continuously producing new ones, the number of stars is constantly changing. It takes 225–250 million years for our solar system to complete one loop around the galaxy. That time is referred to as the solar system's galactic year.



At the nanoscale, materials may acquire properties they do not ordinarily have and materials can be combined that normally would not go together. Transmission electron microscope (TEM) image showing nanothreads.

HOW DO NANOTHREADS GROW?

There is a need for more powerful, faster, and efficient electronic systems. Nanotechnology might be the key. In Lund, Kimberly Dick Thelander plans to design a microscope that shows exactly how nanothreads are formed. It will be a step toward forming new materials exactly the way we want.

All over the world, new electronics are being developed to have greater speed and ever-increasing functionalities while maintaining—or preferably reducing—their size and energy consumption. This requires materials with totally new properties.

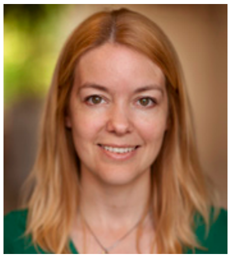
"Nanomaterials have interesting properties. I would never say that nanomaterials in themselves will revolutionize the future, but they are important contributors to progress," said Kimberly Dick Thelander.

Ten years ago, she left Canada for Lund to do a PhD at the Nanometer Consortium. She didn't plan to stay long, but she hasn't found any reason to move.

"My research went better than I expected, and Lund is a really good place for nano research," she said.

AT NANOSCALE, DIFFERENT RULES APPLY

A nanometer is one-billionth of a meter, and the terms "nanoscience" and "nanotechnology" refer to work done on this scale. At such tiny scales, materials behave completely differently, and the laws of classical physics no longer apply. Instead, "quantum physical effects" arise. For example, a particle might be able to pass through a barrier it shouldn't be able to penetrate.



KIMBERLY DICK THELANDER

Professor of Physics, Lund University.

Wallenberg Academy Fellow 2012

Main area of research: Nanothreads and semiconductor materials.

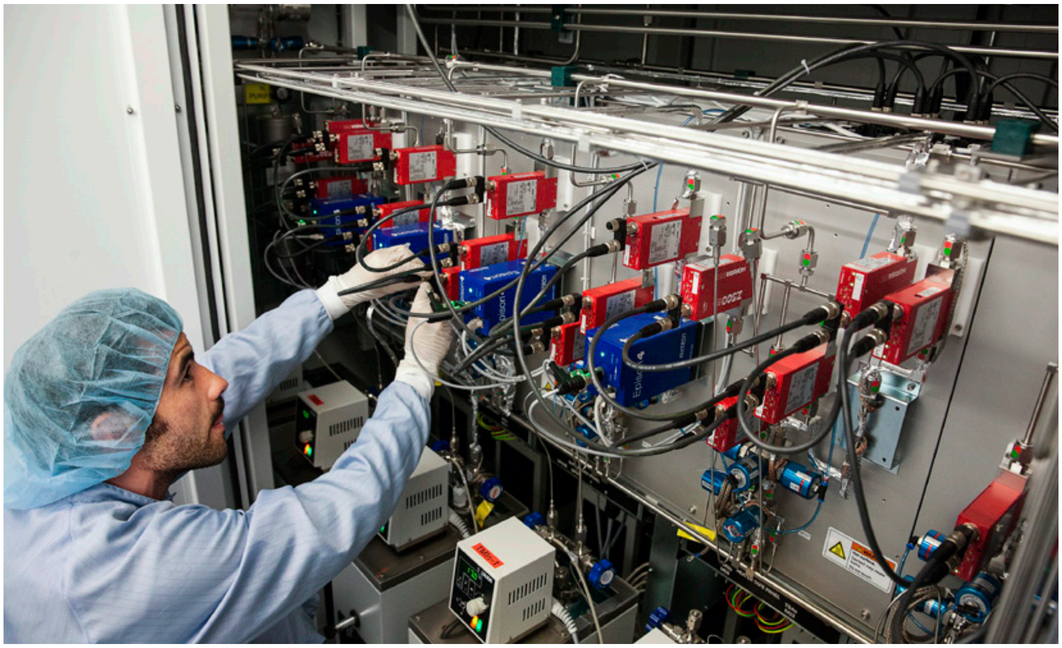
On the nanoscale, materials can be given properties they do not otherwise possess, and materials can be combined that would not ordinarily go together. Dr. Dick Thelander aims to make some material combinations of this type. But she is primarily interested in understanding more about materials. She plans to study a process called epitaxy, in which particles spontaneously produce nanothreads on a surface, building up one atomic layer at a time.

"I want to understand exactly how the threads are built up and how the atoms are organized in them. This can enable us to control them. I'm not involved in developing electronics, but I always keep potential applications for a material's properties in the back of my mind," she said.

STUDYING THREAD FORMATION IN REAL TIME

Nanostructures cannot be studied with ordinary microscopes. Scientists use electron microscopes, which can depict much smaller structures. As yet, nanomaterials have mainly been studied in their finished state. Dr. Dick Thelander plans to develop a new method, in which nanothreads are created inside the microscope, so the actual process can be studied in real time.

"There are a few electron microscopes in the world today where processes can be studied, but



The research team plans to develop a new method for creating nanothreads inside the microscope, so the actual process can be studied in real time. Here, a student works with a metal-organic vapor phase epitaxy system, which is used to grow nanothreads.

what we aim to do is significantly more complex," she explained.

To achieve their aims, the researchers must design a special microscope and control the process so that it happens fast enough to be observed. Dr. Dick Thelander played a short video of a nanothread building up. She pointed at the time code. The playback speed was accelerated to make the thread growth visible—in reality, only a few atoms were added per minute.

The nanothreads she plans to study form a semiconducting material. Semiconductors are crucial components in almost all electronic devices, and while most semiconductors today are made from silicon in traditional ways, some are made using "nanoproduction" techniques. Dr. Dick Thelander explained how important it is for her and her colleagues to be as close to the industrial process as possible, so their results will be relevant to manufacturers ■

"There aren't that many good avenues in Sweden right now for young scientists who want to set up their own team and conduct successful research. Being named a Wallenberg Academy Fellow has given me that opportunity." —Kimberly Dick Thelander

NANOTECHNOLOGY

Nanotechnology and nanoscience involve studying, manipulating, and assembling materials almost atom by atom, enabling design of materials with specific properties and functionalities.

Nanotechnology refers to technology in which the active elements are measured in nanometers—normally in the region of 1–100 nanometers. It has uses in electronics and materials engineering, as well as in chemical and biological applications, which has led to a brand-new scientific field: nanomedicine.

Research topics in nanomedicine range from new target-seeking pharmaceuticals to cheap home tests for illnesses like strep throat.

"It's the fundamental processes that interest me. Being able to see what happens in nature at the atomic level, being able to control things on that scale. I think there also needs to be space for this kind of basic research," says Kimberly Dick Thelander. A transmission electron microscope (TEM) is used to generate images of nanothreads grown in the lab. Dr. Dick Thelander pours liquid nitrogen into the equipment. The liquid nitrogen is used to retard growth to maintain a high vacuum inside the microscope.

DESIGNING NANOLAMINATES WITH UNIQUE PROPERTIES

Endless possibilities are predicted for nanomaterials, especially in future electronics. Johanna Rosén hopes to contribute to this development. As a Wallenberg Academy Fellow, she aims to develop magnetic nanolaminates with tailored properties.

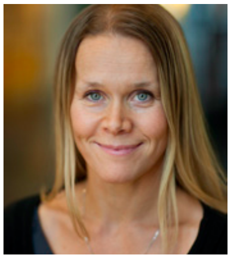
Johanna Rosén is a person who has always sought answers to the question "why?" Her greatest impetus has always been the joy of discovery, exploring things, breaking new ground, and trying out new things as she learns along the way.

"In a sense, I play at work. It's an awful lot of fun. I get to investigate things I find exciting—and get paid to do it. I don't know if everybody feels this way about their job, but I think it's a great perk," she said.

MATERIAL PHYSICS

When Dr. Rosén was an undergrad studying to be a high-school teacher, she discovered that math and physics were really fun and exciting. So, when the others in the teacher-training program went off to their practice-teaching placements, she stayed on campus and continued studying with the physicists, and she just continued in that vein.

"If you think physics is fun in itself, you can do just about anything. I could just as well have worked with polymers or black holes or whatever. I just happened to get into material physics because I met an enthusiastic, inspiring person—Jochen Schneider, who later became my PhD supervisor," she explained.



JOHANNA ROSÉN

Professor of Thin-Film Physics, Linköping University.

Wallenberg Academy Fellow 2012

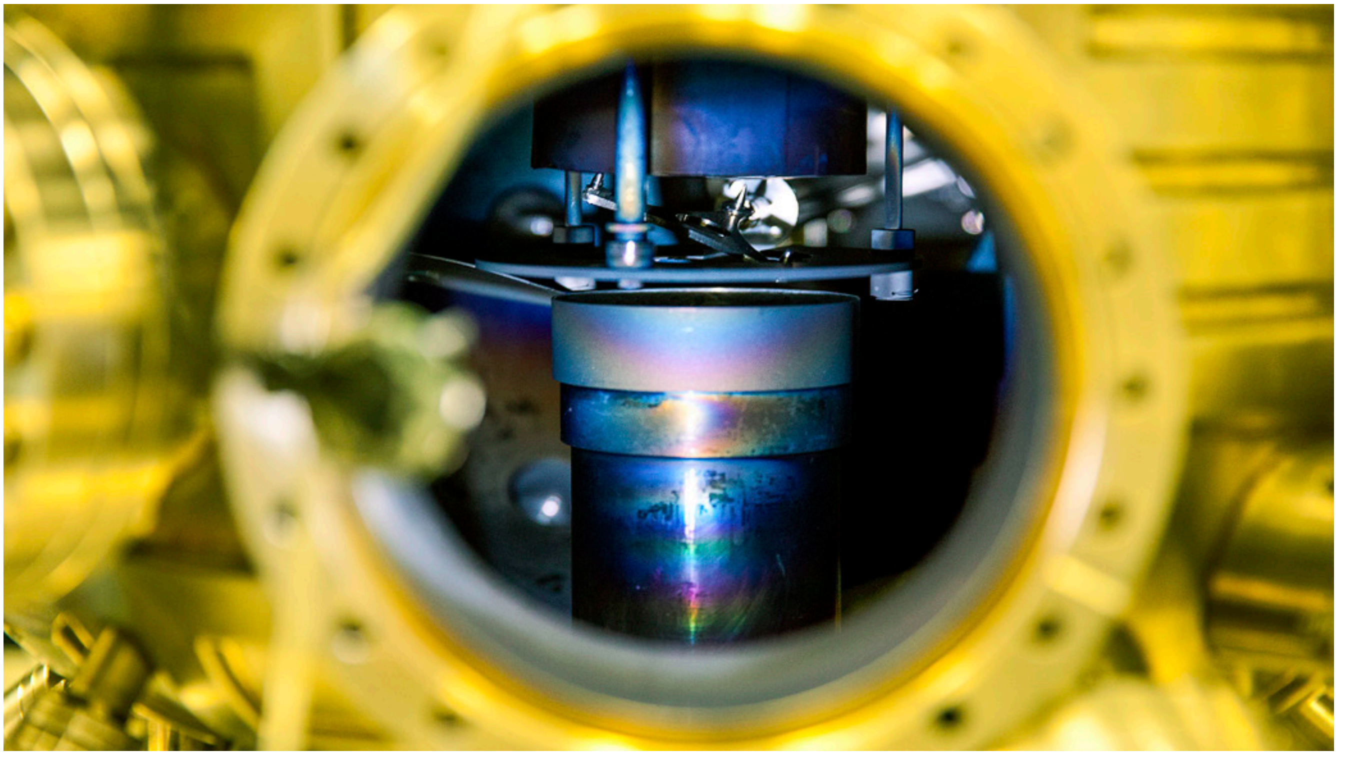
Main area of research: Material physics.

In basic terms, you could say that material physics is about trying to understand how the materials around us work, and developing new materials that work better. More precisely, Johanna Rosén is currently studying nanostructures in thin films. The objective is to develop magnetic nanolaminates, built up from layers of atoms, with tailor-made properties.

The main approach in her research is to build these nanolaminates by stacking different "MAX phases" on top of each other. A MAX phase generally consists of a layer of a metal from the middle of the periodic table (e.g. titanium), a layer of a metal from the right-hand side of the periodic table (e.g. aluminum), and a layer that usually consists of carbon or nitrogen.

"We start by making computer models by putting together atoms and building up the material on screen—you could call it a kind of atomic craft project. Then we run calculations on them: Are the MAX phases stable? What properties do they have? If we find a material that seems stable and has promising properties, we run down to the lab," she said.

The aim is to produce magnetic nanolaminates, built up one atomic layer at a time, with tailored properties. This image shows thin-film material.



Johanna Rosén and her colleagues have designed and built three vacuum chambers to enable them to produce MAX fibers and nanolaminates they modeled on the computer.

THREE VACUUM CHAMBERS

Dr. Rosén and her colleagues designed and built three vacuum systems in the lab, where they can generate the MAX phases and nanolaminates they have modeled on the computer. The process is based on two separate processes that force atoms and ions out of a material. One process, called arc evaporation, is fast, violent, and produces plasma containing many ions. The other, called sputtering, is slower, more controlled, and produces plasma consisting mainly of atoms and molecules.

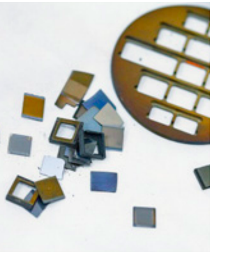
In both arc evaporation and sputtering, the plasma lands on a substrate (surface), where the new material is formed. Once the researchers have found some exciting new MAX phases, they can make superstructures by layering them on top of each other.

"We begin by looking at how the MAX phases work together. Can they be layered and fit together well? What kinds of properties does the layered material have? We have developed exciting new materials and are now trying to understand how they work so we can eventually tailor their properties," Dr. Rosén explained.

Her research group was the first in the world to synthesize magnetic MAX phases. They are also the first to try to use MAX phases to create magnetic nanolaminates. Many uncertainties and challenges remain, though.

If Dr. Rosén and her colleagues successfully design materials at the atomic level, there are many possible applications—particularly in electronics. For example, magnetic nanolaminates with tailored properties could be used to reduce energy consumption in data storage and data transfer. They could also lead to faster, smaller, and more stable hard drives.

"We'll have to see exactly what our materials will be suitable for," she said ∎



NM

"Nano" means "one-millionth" and comes from *nanos*, the Greek word for dwarf. A nanometer, abbreviated nm, is one-millionth of a meter, or one-thousandth of a millimeter. It is comparable to the size of a typical atom, which is just over 0.1 nm in diameter.

Nanotechnology and nanoscience involve studying, manipulating, and building materials on the atomic level, where objects have sizes in the order of 1–100 nanometers. The aim is to design materials with particular properties and functionalities.

"Recognition is important. It also means resources to implement your ideas, which in turn means the chance to hire talented people. With a highly respected Wallenberg Foundation grant, it becomes easier to attract and recruit good researchers."
—Johanna Rosén

In the spring of 2015, the Foundation launched Wallenberg Autonomous Systems and Software Program, a 10-year program to support autonomous systems and software development. In this photo, Piotr Rudol operates a helicopter drone.

AUTONOMOUS SYSTEMS: WASP AND WITAS

The term "autonomous systems" includes independent, self-guided equipment and systems combined with advanced software, complex data, and—in some cases—human interaction. This technology is expected to bring changes as comprehensive as those in the Industrial Revolution.

Some types of autonomous systems currently being developed are smart energy infrastructure, automated excavation equipment, intelligent traffic systems to minimize jams and accidents, and robots that match fixings to components in manufacturing systems. The technology could also enable rescue operations in inaccessible disaster areas.

Today's automatic systems can perform complex functions in structured environments, but future autonomous systems will also have to plan and execute complex actions with limited human involvement, in unsecured and unstructured environments—plus deal with unexpected events.

The Knut and Alice Wallenberg Foundation sees a need for Sweden, as a nation heavily engaged in research and industry, to build a platform that will help it become a global leader in autonomous systems and software development.

To that end, in the spring of 2015 the Foundation launched a 10-year grant program in the form of the Wallenberg Autonomous Systems and Software Program (WASP) Total investment will be SEK 1.8 billion, including SEK 1.3 billion contributed by the Foundation. The remaining SEK 500 million will come from the participating universities: Chalmers University of Technology, KTH Royal Institute of Technology, Linköping and Lund universities, as well as Swedish industry.

THE WITAS PROJECT

The WITAS (Wallenberg Information Technology and Autonomous Systems) project was launched in the late 1990s at Linköping University. That was the Foundation's first major automation project. The project ran for eight years and received grants of SEK 173 million.

The project's long-term goal was to design, specify, and make IT components for an intelligent autonomous aerial vehicle.

During the project, a helicopter was constructed that could maneuver in the air completely independently, without a pilot. Using cameras, infrared sensors, and other equipment, it could avoid obstacles, spot people on the ground, and send data collected to air traffic control.

For the system to work, it needed to analyze and interpret images from the helicopter's video cameras. The system also had to interpret the terrain; distinguish between buildings, vehicles

SOS

SYSTEM OF SYSTEMS refers to a system in which various technological solutions work together.

A system of systems (SoS) integrates existing systems that each have their own value so that they all work together toward a common goal.

This type of integration is often dominated by IT solutions. The SoS concept is an important contribution to the digitization of society, enabling automation of flows and therefore greater efficiency.

and living beings; anticipate events; and make independent decisions.

The researchers at Linköping developed the software themselves, but test helicopters were purchased from external suppliers. The largest model helicopter weighed around 95 kilograms (209 lbs.) and its rotor blades were 3 meters (9.8 ft.) long.

The most promising applications were in advanced traffic monitoring, where it could instantly detect accidents, follow stolen vehicles, and assist rescue crews—or in disasters, such as after earthquakes or chemical spills, to search for survivors in places where rescue crews could not enter.

WALLENBERG AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM

This research program, launched in spring 2015, is a major investment in basic research, advanced training for scientists, and recruitment in autonomous systems and software development.

The program is intended to increase skills and competence in numerous fields where vehicles, robots, and complex software-intensive intelligent systems are acquiring human-interactive autonomy. This is crucial know-how that will enable Swedish science to keep pace with developments toward an online society with increasing numbers of self-regulating systems.

One key element of the research program will be the construction of a platform for academic research and education that can interface with Swedish industry, based on strong knowledge transfer to industrial research and development teams. An example of this is a graduate school of science, to be run in conjunction with leading Swedish industries. Over 100 graduate students will be admitted, half of whom will be studying for industrial PhDs.

Infrastructure, such as demonstration platforms and national demonstration arenas, will also feature in the venture.

Despite the participation of industry, the program's main focus is on basic research. In addition to Sweden's four major information and communications technology institutions, the program includes research groups from other universities. The idea is to combine existing expertise in electronics, computer science, and data processing. There is also an international recruitment program.

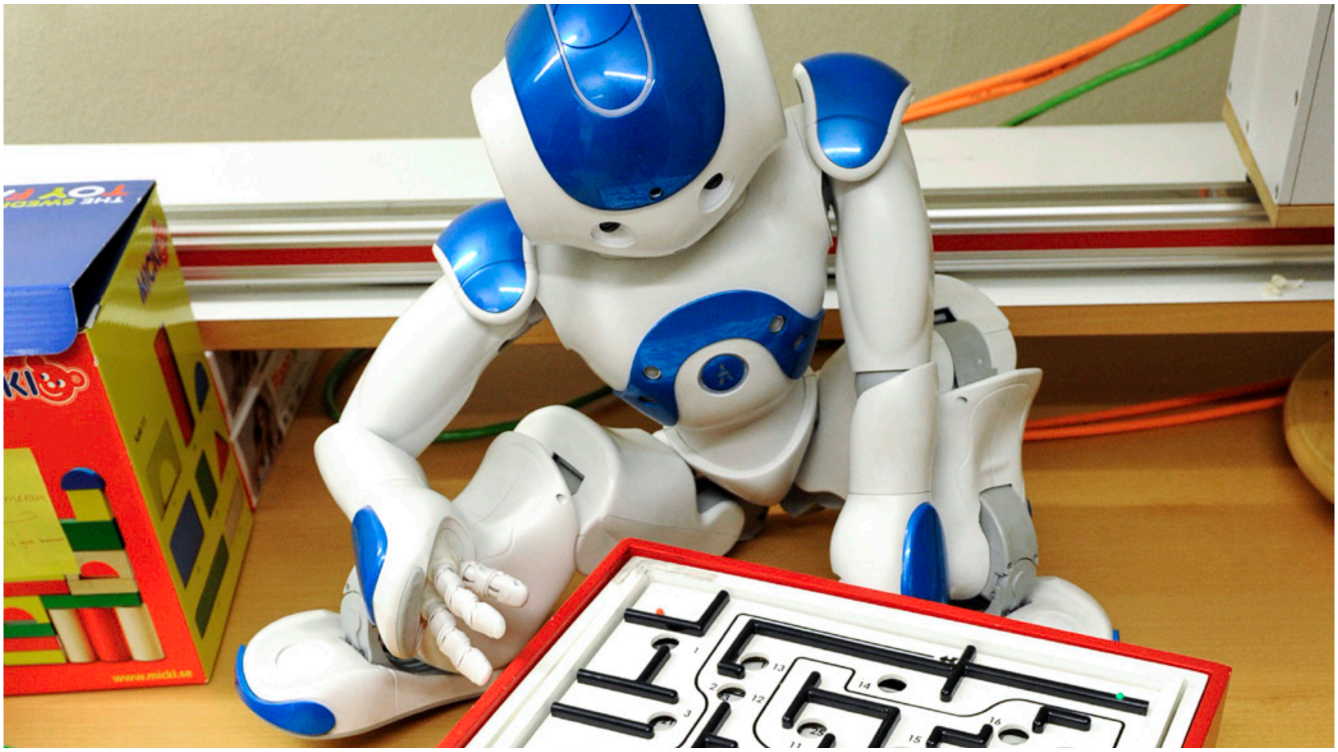
CHALLENGES

One key component is the development of digital cognitive systems, which can help decision-making in cases where the human brain can easily get bogged down with details and distractions.

The level of automation needs to be fluid, which presents a major challenge. Machines and humans will have to function both independently and in close cooperation, depending on the situation. Making the technology both scalable and secure is another challenge.

The program emphasizes software development and algorithms that will enable the identification and screening of information from massive amounts of data. Autonomous systems will need the ability to integrate data from the internet and their sensors with human input. Humans will have to delegate tasks to machines, machines to other machines, and machines back to humans. Expertise from researchers in the humanities and social sciences will play an important part in that regard ■

In the WITAS project, a helicopter was constructed that could maneuver in the air without a pilot. This photo shows Patrick Doherty with the unmanned helicopter.



A robot in Michael Felsberg's Computer Vision Laboratory at Linköping University.

SUPERCOMPUTERS

Enabling complex scientific calculations

Climate simulations, development of pharmaceuticals, and financial mathematics. These are just a few examples of research fields that depend on massive computing power. Over the years, the Foundation has invested over SEK 200 million in advanced computer systems in Sweden.

The first major grant was made in the 1980s. The Swedish Natural Sciences Research Council (NFR) argued that Sweden needed a supercomputer for research purposes. But the NFR had trouble sourcing sufficient funding. The Foundation offered a grant of SEK 1 million, followed by over SEK 1.6 million the next year, toward the purchase of the necessary encryption equipment.

The Foundation's Board of Directors quickly realized that the new computer would soon be inadequate, so from 1985 to 1987 they earmarked a total of SEK 30 million for a future supercomputer. That became the nest egg for Sweden's National Supercomputer Center (NSC) at Linköping University. The new supercomputer was ready for use in May 1989.

The Swedish National Infrastructure for Computing (SNIC) is a national supercomputing network based in Uppsala.

The network consists of six national computing facilities, from Umeå University in the north to Lund University in the south. Several of them have been partly or wholly built up with funding from the Foundation.

E-SCIENCE

Scientists' use of computers and their requirements for highly complex scientific calculations are increasing so rapidly and so intensively that there is talk of a new scientific path. Alongside theory and traditional experiments, scientists are increasingly working with computer simulations, an approach that is spreading to more and more fields, including the social sciences and humanities. This is often called "e-science," and it encompasses far more than just the use of supercomputers.

One example is the potential to generate new, much more detailed climate models. In order to understand how the climate might change in the next 500 or 1,000 years, a huge range of parameters have to be input and then processed and simulated in a model.

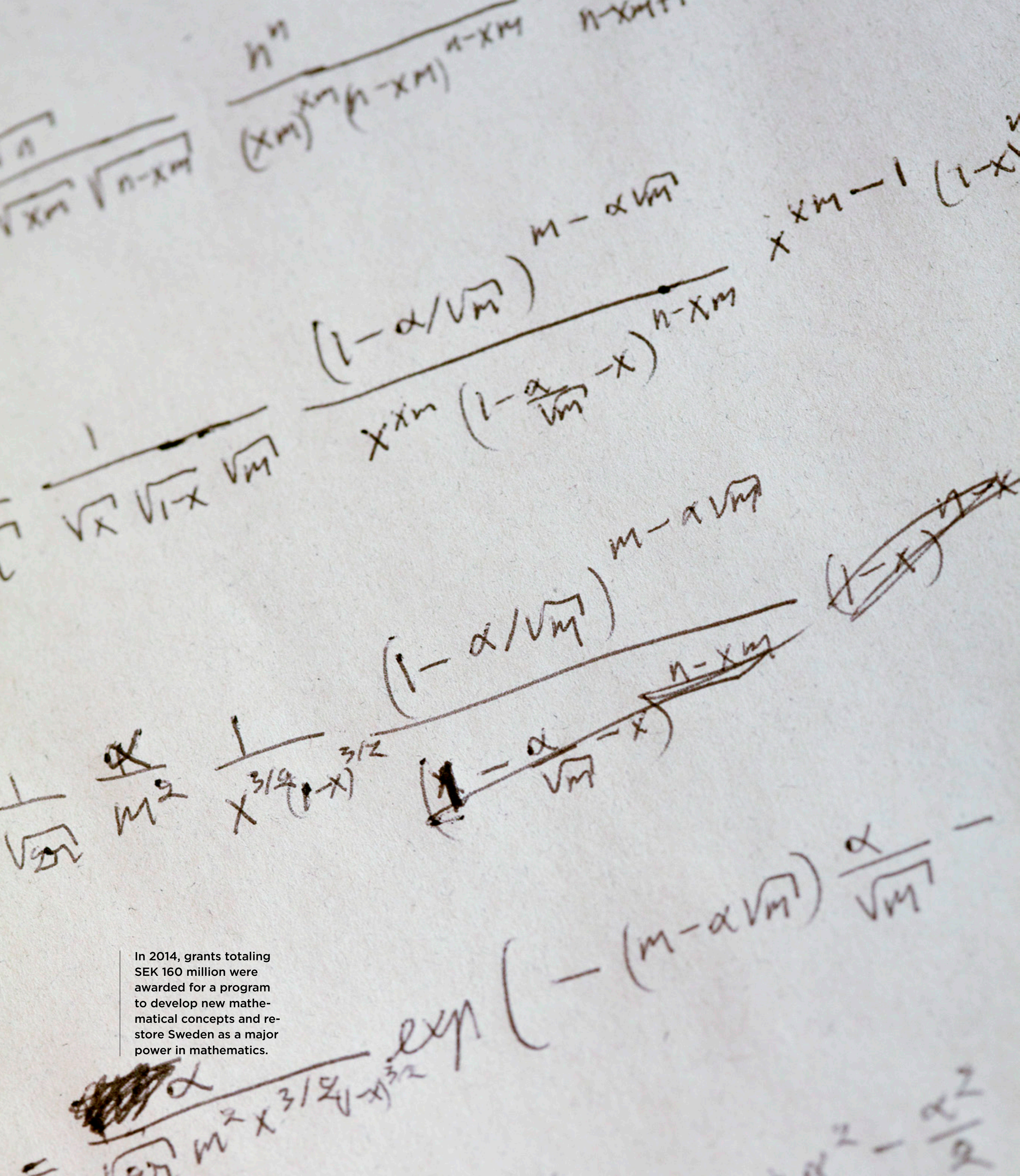
A possible application in the life sciences might be to sequence the genomes of a group of individuals, perhaps as the first stage toward producing new pharmaceuticals, or in astronomy to simulate collisions between galaxies and other huge-scale phenomena.

The drawback with supercomputers is that they quickly become obsolete. The rapid progress of technology means that typical useful lifespans are just three to four years. A laptop computer made in 2010 had the same performance capacity as a supercomputer built in 1995 ■

KNUT AND ALICE

In 1996, the Foundation awarded a SEK 16.3 million grant for a scalable parallel computing system within HPC2N—the High Performance Computing Center North—at Umeå University, a facility that would meet the need for large computing power at several institutions.
In 1997, an IBM parallel computer called "Knut" was installed for high-performance calculations and visualizations.
A SIG Onyx2 advanced visualization computer, given the name "Alice," was installed for use in virtual reality applications.

Supercomputers have a short lifespan. The rapid pace of progress means it doesn't take long for a faster, more powerful machine to come along. Image from SNIC in Uppsala.



In 2014, grants totaling SEK 160 million were awarded for a program to develop new mathematical concepts and restore Sweden as a major power in mathematics.

MAKING SWEDEN NUMBER ONE IN MATHEMATICS

Math is everywhere. Even though we might not always be aware of it, mathematics is present in every aspect of our lives in the form of applications. For example, a Google search is based on sophisticated mathematical algorithms, as is a GPS location device or a bank transfer via a secure data connection. All online gaming and betting sites are completely dependent on mathematics.

Math helps us understand and manage our economy and our society. New mathematics and statistics contribute to progress in chemistry and physics, and they are indispensable in understanding modern biology and climate science.

In many cases, solutions to mathematical problems are achieved long before we realize their potential uses. The mathematicians who first became interested in algorithms probably had no inkling they could lead to a reduction in the shortage of organ donors by creating mathematical models to match many more living donors with recipients.

The history of mathematics goes back at least 4,000 years, and some people believe it stretches back far more than that. Our earliest evidence of humans' use of mathematics is from ancient Egypt and Babylonia.

MATHEMATICS BRINGS EFFICIENCY TO MANY SCIENTIFIC FIELDS

Current mathematics is not sufficient to enable us to utilize the massive quantities of data produced today—we need to develop new mathematical tools. Then it will be easier to understand the relationships between genes and diseases, or how climate change affects life on Earth. There is a demand for such tools in ever more fields, and new methods are being created all the time—partly as a result of theoretical work in mathematics, and partly through practical applications.

Sweden has a long tradition as an international leader in mathematics, and many students engage in higher mathematics studies. Mathematicians with advanced degrees are also in great demand in business and academia. Even so, Swedish mathematical research has lost ground on the international scene in recent decades.

Over the years, the Knut and Alice Wallenberg Foundation has awarded major grants to mathematicians and mathematical projects. In 2014, it awarded grants totaling SEK 160 million with the aim of returning Sweden to the top of the international league and developing innovative mathematics. These grants include awards to postdocs leaving Swedish universities to go abroad, and for recruiting postdocs and visiting professors from abroad to institutions at Swedish universities.

In addition, a grant of SEK 40 million was awarded to Institut Mittag-Leffler at the Royal Swedish Academy of Sciences, one of the world's foremost institutes of mathematics. It is crucial for researchers from all over the world to exchange ideas if new theories and knowledge are to emerge. Eminent venues like Institut Mittag-Leffler are valuable forums for the development of new mathematical approaches.

Another previous grant worth mentioning is for "Strength and Unity in Mathematics," a fundamental mathematics project launched in 2006 at KTH Royal Institute of Technology. The Foundation awarded a grant of SEK 27 million for research and training future researchers in KTH's Department of Mathematics. In recent years, the Foundation has also funded a number of major projects in pure and applied mathematics ∎

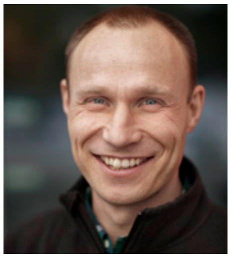
MATHEMATICS AND PHYSICS LINK ARMS

The major breakthroughs made in modern mathematics would not have been possible without the strides made in physics—and vice versa. Tobias Ekholm and Maxim Zabzine, a mathematician and physicist respectively, have realized the value of learning from each other. Now they are establishing an internationally attractive research environment.

Tobias Ekholm, Professor of Mathematics, and Maxim Zabzine, Professor of Theoretical Physics, know each other very well. They have been discussing questions of mutual interest at the interface between math and physics since around 2007. That was when Prof. Ekholm rejoined the Ångström Laboratory after a stint as a professor in the U.S. To his delight, he found a Russian with whom he struck up a rapport in the corridor. Prof. Zabzine, who hails from St. Petersburg, had arrived in Uppsala a year earlier.

"My PhD supervisor was Russian, as was my postdoc supervisor at Stanford. There's a kind of scientific culture I would call 'Russian,' a different way of approaching problems and exchanging ideas. So, it felt natural to talk with Maxim, and we aren't that far apart, scientifically speaking, especially not now," said Prof. Ekholm.

He is studying symplectic geometry and mathematical knots. Prof. Zabzine is conducting research into string theory in quantum physics. Their fields share much common ground—where mathematics and physics meet—that is also a major current frontline of research.



TOBIAS EKHOLM

Professor of Mathematics, Uppsala University.

Principal investigator of the project "Geometry and Physics."

Co-investigator: Maxim Zabzine.

Project grant in 2014
Grant awarded: SEK 35 million.

NEEDING EACH OTHER'S KNOWLEDGE

As Prof. Zabzine explained, the distinctions drawn between mathematics and physics at modern-day universities did not exist a century ago. "There has been a marked tendency toward specialization. But 30–40 or so years ago, things began to change, following dramatic developments in both physics and mathematics. Scientists in these fields suddenly realized they needed one another," he said.

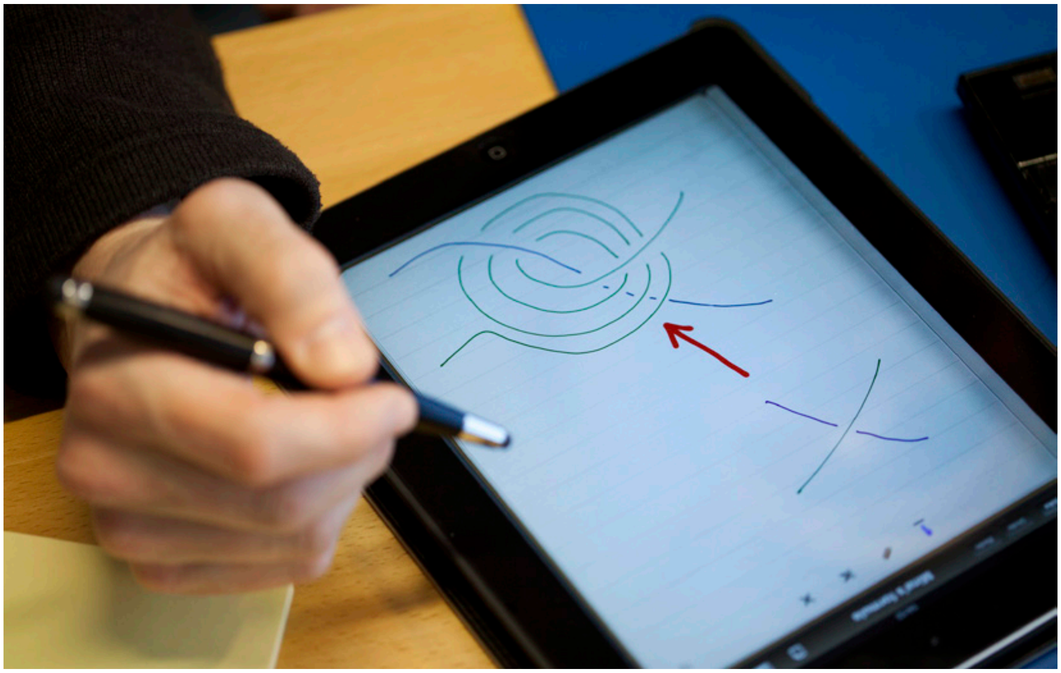
Prof. Ekholm pointed out that the main strides made in modern mathematics over the past decades are directly or indirectly related to mathematical physics. "Physics always has a clear objective, which is to explain how everything works. But mathematics sometimes needs input from somewhere, which is where physics comes in. And physicists need the tools that we mathematicians can provide," he noted.

Together, they want to create an internationally attractive research environment combining geometry with physics. The aim is to attract talented young researchers and create the "critical mass" required for major new breakthroughs.

"We need highly skilled mathematicians and physicists. They must be able to understand both languages," said Prof. Ekholm.

Mathematicians use knots to study multi-dimensional space and simplify complex structures. Knots can also be used in applied sciences.

Tobias Ekholm and Maxim Zabzine have discussed issues at the interface between math and physics for a number of years.



A blackboard and chalk are still many mathematicians' preferred tools, but Tobias Ekholm has grown attached to the drawing app on his tablet.

KNOTS AND STRINGS

There were many dramatic scientific advances in the 1970s, including the development of gauge theories, which became important to both physicists and mathematicians. Gauge theories are the theoretical basis for the "Standard Model," which describes the very smallest particles and their interactions.

The Standard Model describes different forces in quantum physics, but one force that does not fit into the model is gravity. Something will have to give if that problem is to be solved. One fruitful avenue has been to see particles as one-dimensional strings, rather than as points. This is how Prof. Zabzine describes his field of research.

Prof. Ekholm's area—symplectic geometry—is rooted in classical mechanics. Over the past two decades, the field has moved much closer to other theories of physics, specifically supersymmetrical versions of quantum field theory and string theory.

"You could say we're studying the same things from two different angles. While gauge theories were revolutionizing particle physics, geometricians were adopting a new approach to knot theory, among other things. These approaches derive directly from gauge theory and string theory in physics," he explained.

Mathematical knots resemble a tangle of strings in space. They are found in proteins and DNA, for example. "You could call knots the mathematical counterpart of fruit flies in biology. It's very easy to find relevant examples, and a great many of the enormously difficult mathematical problems there can be applied in a wide variety of areas," he added.

UNPREDICTABLE APPLICATIONS

As Prof. Zabzine pointed out, historically speaking, the most fundamental scientific breakthroughs have resulted in the best applications. But it's hard to know how and when they will bear fruit. Sometimes it takes a long time.

"When Einstein developed his general theory of relativity to describe gravity, he used both mathematics and physics, and he had no idea that his theory would be just as important 100 years later, and have applications such as GPS technology," he noted ■

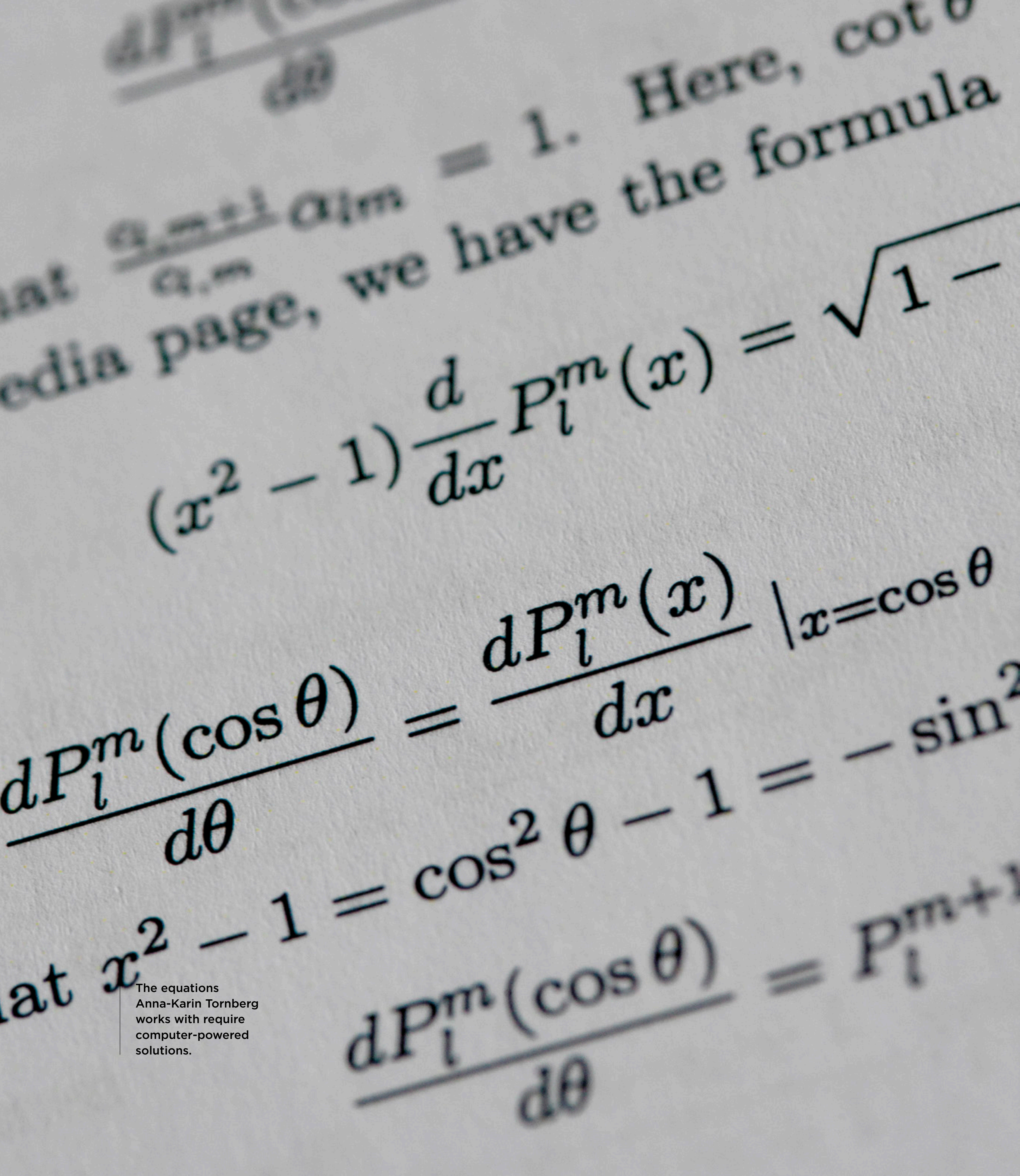
STRING THEORY

String theory is currently physicists' best theory for unifying all known natural forces.

According to string theory, fundamental objects are not dot-like particles but one-dimensional strings, and all known particles—such as quarks, electrons, and force particles—are described as a kind of vibrational state in the fundamental strings. The strings also give rise to elementary particles we have not yet observed. One such is the graviton, which is necessary for the quantum-mechanical description of gravity.

The graviton enables quantum physics to be combined with gravitational theory into a single theory. For string theory to work, strings must be able to vibrate in a multidimensional space. The theory stipulates 10 space-time dimensions—six more than the four we recognize today: length, width, depth, and time.

Because the six extra dimensions have never been observed, scientists assume they have been rolled up incredibly small. The tiny dimensions must be symmetrical in a particular way, forming a "Calabi-Yau space." Naturally, their incomprehensibly tiny dimensions (compared to our universe) make them even harder to study.



The equations Anna-Karin Tornberg works with require computer-powered solutions.

COMPUTER SIMULATION OF MICRO-FLUIDICS

As systems for discovering and testing new pharmaceutical substances are miniaturized, a detailed understanding of the movement of fluids is required. Anna-Karin Tornberg is developing robust algorithms capable of simulating the movements of nano-sized droplets.

Researchers in fluid dynamics—the science of how fluids move—study everything from flows in huge dams to tiny droplets in microscopic analytical equipment. Prof. Tornberg utilizes advanced computer calculations to simulate various flow-related problems.

"I'm particularly interested in systems where a fluid contains droplets, particles, or elastic fibers. That creates more interaction, generating fascinating physical phenomena as well as problems that are harder to solve mathematically," she said.

She explained that a great deal of the world around us can be described with equations, which makes mathematics and fluid mechanics fascinating. "But the equations are extremely complex—too difficult to solve with a pencil and paper. Instead, we have to find approximative solutions and let computers do the work," she noted.

NANO-LEVEL APPLICATION

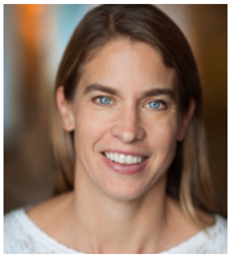
Prof. Tornberg explained that fluid phenomena are all around us in the natural world, and they are used in many technical applications. In recent years, there have been increasing applications in biology and biotechnology.

Motivated by development of "microfluidic systems" within the KTH Royal Institute of Technology's Department of Nano-biotechnology and SciLifeLab, they are looking for efficient methods of simulating droplets with a diameter of less than 30 thousandths of a millimeter. In these systems, tiny water droplets are suspended in oil and serve as sample containers, enabling scientists to analyze extremely small amounts of various substances.

"The next step in this technology development involves using this miniaturized analyzing technique in settings like the pharmaceutical industry, to screen new preparations faster and more efficiently. But to get there, a greater understanding of the fluidic mechanism is needed," Prof. Tornberg said.

The challenge is to achieve the right mix of surface tension, fluid density, and droplet deformation in the fluid mechanic calculations. The idea is that the water droplets will act like test chambers, isolated from each other. To prevent them from merging together, they are covered in surfactants. Even so, tiny molecules can leak from one droplet to another, ruining an experiment.

"By developing a mathematical model and using it as the basis for a computer simulation algorithm, we hope to simulate these systems—and ultimately find a way to counteract leakage," she explained.



ANNA-KARIN TORNBERG

Professor of Numerical Analysis, KTH Royal Institute of Technology.

Main research field: New methods for simulating droplets in microscopic fluid systems.

Program for Mathematics 2014

AN ITALIAN POSTDOC

Thanks to the Knut and Alice Wallenberg Foundation and the Royal Swedish Academy of Sciences' investment in mathematics, Prof. Tornberg was able to offer a two-year postdoc position to Chiara Sorgentone, an Italian researcher. Dr. Sorgentone uses calculus to develop, program, and test new algorithms that will be able to accurately simulate droplets in three dimensions.

Prof. Tornberg also received a grant to host a visiting scientist, Prof. Michael Siegel from the New Jersey Institute of Technology, who spent several months as part of the research team in the fall of 2015. Prof. Tornberg believes this is an excellent way to promote research in mathematics and build an international network. "It enriches the research environment," she said. "His coming here was a great asset—not just for me, but for my whole team and the rest of the math department too."

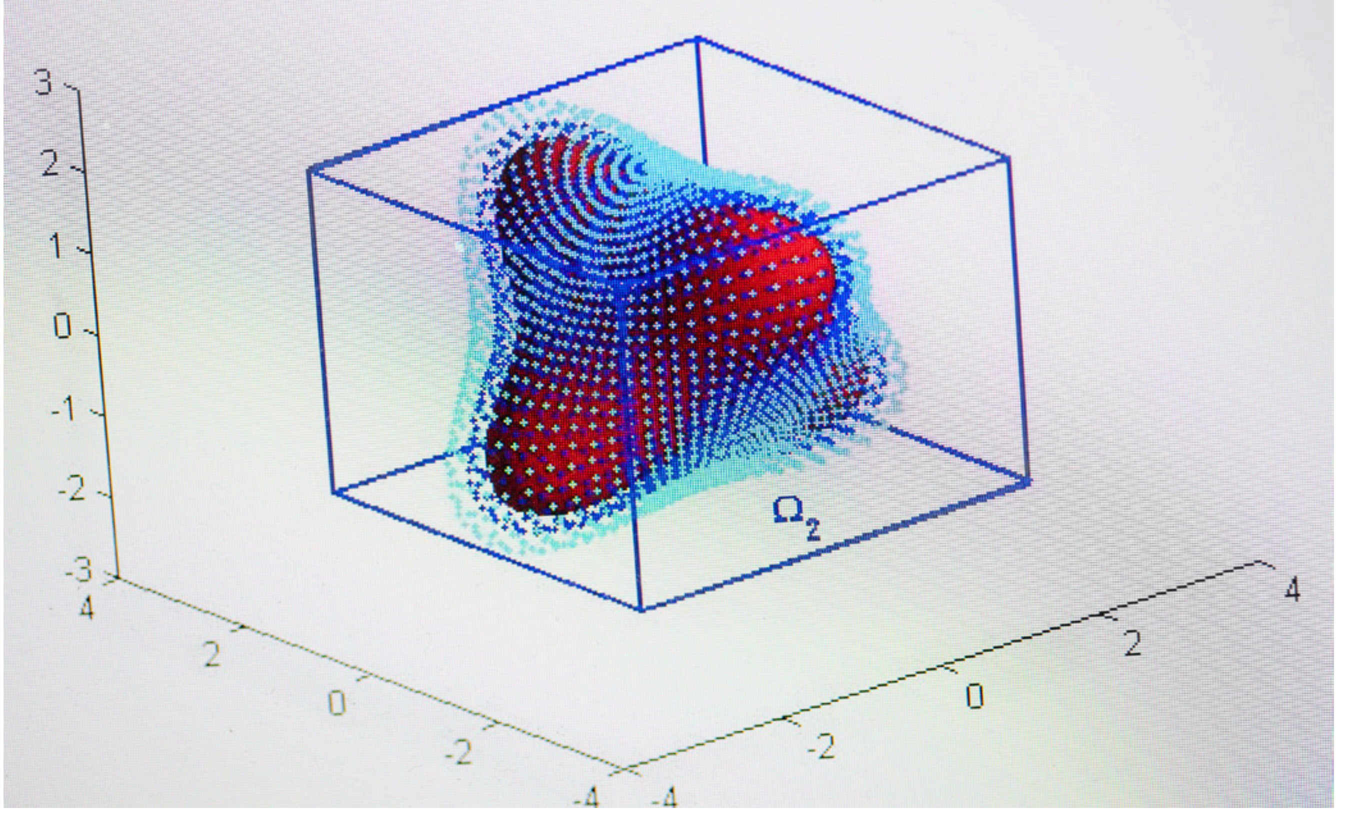
Prof. Tornberg has also successfully conducted research abroad and makes good use of her network of contacts, especially in the U.S. She was an exchange student at the University of Texas and spent five years working at the Courant Institute of Mathematical Sciences in New York. That was what awakened her interest in numerical analysis of tricky questions involving fluid mechanics. Microfluidics is a rapidly growing research field, she said.

"It's important to me to have an application that drives my research. Another advantage of mathematics is that it's general, so research and methods can be adapted to other areas of application," she added ∎

ALGORITHMS

The term "algorithm" describes a step-by-step way to solve a problem or perform a task. The dictionary definition is "A process or set of rules to be followed in calculations or other problem-solving operations."

An algorithm is not a solution; it only describes how to get to one. To reach the goal, you have to run the algorithm. Algorithms are available for many types of problems and are constantly improved upon for better accuracy and wider applicability.



Microfluids are a rapidly growing area of research. Prof. Tornberg's project involves generating simulation models.

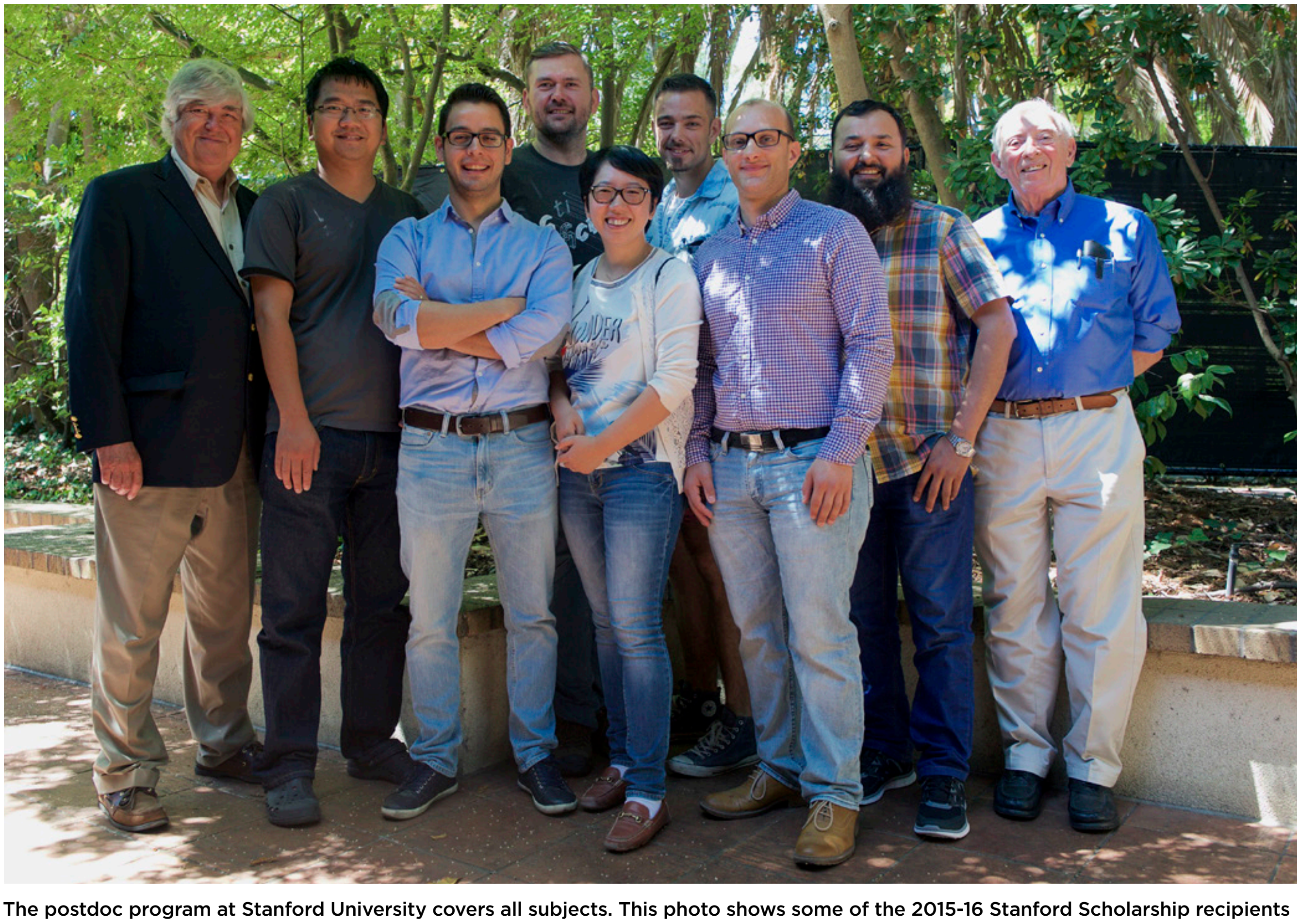
Anna-Karin Tornberg says it is crucial to have funding opportunities for research in mathematics: “Mathematics is the foundation for so many other fields, and it’s impossible to know beforehand what math will be required for the challenges of the future.”

The Wallenberg Foundations are present at Stanford University, especially for collaborations with Swedish researchers.

Jacob and Marcus Wallenberg outside Wallenberg Hall, which houses classrooms and a lecture theater with hi-tech equipment for tomorrow's teaching and research. The Swedish contact center is also located here.

EDUCATION

The Foundation's bylaws stipulate that its main purpose is to promote scientific research and education or study with content beneficial to Sweden. So far, this jubilee volume has focused mainly on the Foundation's research grants. But a significant portion of its activities have been oriented toward education and study.



The postdoc program at Stanford University covers all subjects. This photo shows some of the 2015-16 Stanford Scholarship recipients outside the Stanford Faculty Club. From left to right: Chaofan Zhang, Onur Parlak, Laurynas Riliskis, Lin Li, Karl-Magnus Persson, Andrew Marais, Hafiz Sohail. The Scholars are flanked by mentors Robert Sinclair and Arthur Bienenstock.

EDUCATIONAL INITIATIVES TO REDUCE SOCIAL EXCLUSION

The Foundation, along with the Marianne and Marcus Wallenberg Foundation and the Marcus and Amalia Wallenberg Foundation, announced in 2016 they were funding a 10-year program entitled “Education for Increased Integration.”

The initiative was prompted by the identification of a number of clear challenges for Sweden’s future. One of the most critical, for both the short and long term, is in education. Far too many people in Sweden are excluded from society, and even more are at risk—in many cases because of a lack of education or language skills, or because their education did not adequately prepare them for the Swedish job market.

The Wallenberg Foundations are working with several organizations to fund various educational initiatives. In 2016, the Royal Swedish Academy of Sciences launched a series of science summer schools for teens in low-income areas and for schoolchildren who had recently immigrated to Sweden, while the Swedish Academy was involved in intensive Swedish as a Foreign Language courses for newly arrived schoolchildren.

Funding is being provided to enable expansion of the Royal Swedish Academy of Engineering Sciences’ “Leap to Work” pilot project. Leap to Work is an internship program for newly arrived academics with degrees in technical, scientific, and economic subjects.

There is also funding for Sophiahemmet University, a school of nursing, to provide training for newly arrived medical doctors, dentists, and pharmacists. KTH Royal Institute of Technology launched a program aimed at recent immigrants to train and prepare software developers and programmers for the Swedish job market.

The Royal Swedish Academy of Engineering Sciences and the Royal Swedish Academy of Sciences received funding to develop and expand their “Science and Technology for All” program so it can be adapted to the needs of newly arrived schoolchildren.

In addition to these initiatives, the Wallenberg Foundations are providing support for a number of projects focusing on schoolchildren in low-income areas and new immigrants. One aim, for example, is to increase access to the Universeum science center in Gothenburg and the National Museum of Science and Technology in Stockholm for these groups. There is also after-school tutoring for schoolchildren in deprived areas, primarily through Stockholm University and the University of Gothenburg. The Wallenberg Foundations are also providing support for integration projects and other initiatives to hire more teachers in deprived areas.

Karan Partovi teaching at Vinstagårdsskolan in Vällingby, Sweden. He is training to be a teacher with Teach for Sweden, a program that helps place additional teachers in deprived areas.

> “The grants of the Wallenberg Foundations also include integration projects and initiatives to improve school staffing in deprived areas.”

COLLABORATION IN EDUCATIONAL RESEARCH

The Wallenberg Foundations have had a permanent link with Stanford University since 1994. The motivation for establishing this link was to generate collaborative work between Stanford and Swedish universities in teaching and research. This link was later expanded into the Wallenberg Research Link (WRL), a contact center with offices in Wallenberg Hall. WRL serves as a point of contact at Stanford for the Foundations and universities, as well as a network for Swedes—especially students and postdocs—at Stanford.

From 1995 to 2015, the Wallenberg Foundations funded a number of joint projects involving Stanford and Swedish universities. These include:

- The Sweden Silicon Valley Link, online courses focusing on the "virtual classroom": collaboration between KTH Royal Institute of Technology and Stanford.
- The Wallenberg Global Learning Network (WGLN), setting up "learning labs" at Uppsala University, Karolinska Institutet, KTH Royal Institute of Technology, and Stanford (Wallenberg Hall). This was later expanded into a joint project on preschool to high-school teaching and education for all Swedish universities. The program included over 50 projects.
- Programs in digital humanities, teaching, and brain function with research teams from Stanford and Swedish universities.
- Wallenberg Hall, with classrooms and a lecture theater equipped with new technology and a research lab.
- Postdoc programs.

SWEDISH LEARNING LAB

At the time the WGLN was set up at Stanford, there were calls to create a similar learning lab in Sweden so the initiative would constitute a genuine partnership with equal nodes in both countries. In response, a Swedish learning lab ("SWELL") including Uppsala University as the main Swedish node along with KTH Royal Institute of Technology and Karolinska Institutet, was set up with funding from the Foundation.

The KTH Royal Institute of Technology library, part of the Swedish Learning Lab project.

Students in the Peter Wallenberg Theater, Wallenberg Hall, Stanford University.

"Back in 1994, the Wallenberg Foundations set up a permanent base at Stanford University. The idea behind it was to facilitate teaching and research collaborations between Swedish universities and Stanford."

EDUCATION RESEARCH PROJECTS

A NEW PROGRAM TO TRAIN ENGINEERS

The CDIO (Conceive, Design, Implement, Operate) initiative was a program to train future engineers organized by MIT in Cambridge, Massachusetts; Chalmers University of Technology; Linköping University; and KTH Royal Institute of Technology. It focused on developing and assessing new teaching methods for engineering and was modeled on real-world needs for graduating engineers. At KTH Royal Institute of Technology, new courses were developed to emphasize skills in practical engineering, conception, design, and implementation early in students' education. Linköping concentrated its efforts on new introductory courses and new concepts in electronic engineering, with input from SAAB and Ericsson for new project management courses. Chalmers University of Technology developed new methods for assessing the new CDIO concept, while MIT integrated all the subject areas to create "innovative learning." Theoretical and practical courses with a problem-solving focus formed the core of the program. The new concept was first introduced in aeronautical engineering courses.

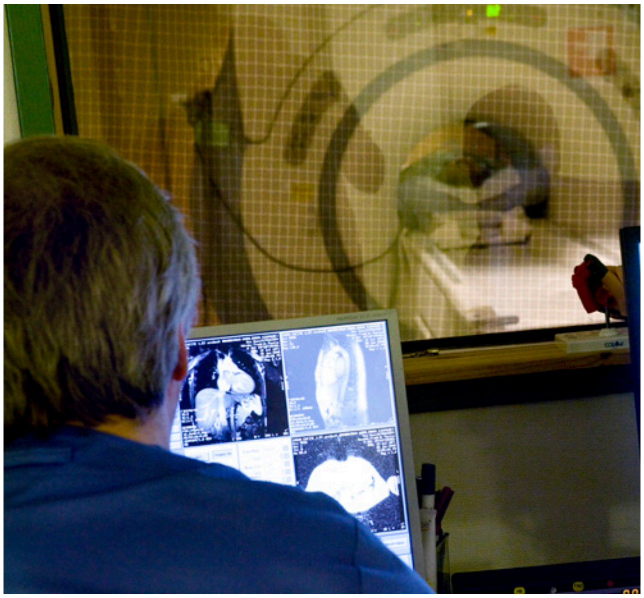
LEARNING AND MEMORY

The objectives of this program were to support and generate high-quality, international-standard research projects in the field of children's learning and memory. This was prompted by the realization that there was an increasing need to improve learning at all levels in the Swedish education system. Research in psychology, cognitive science, and neuroscience had improved our understanding of children's learning, their motivations, conceptualization, and memory. Internet-based information and other interactive teaching and learning programs had also gained importance as educational tools.

This program included projects in:
- Emotions and motivation.
- Formation and development of concepts.
- Interactive learning processes.

The program ran for five years and was funded by the Knut and Alice Wallenberg Foundation, Riksbankens Jubileumsfond, and the Swedish Research Council's Committee for Educational Sciences.

The CDIO project.



Juha Kere and Torkel Klingberg of Karolinska Institutet taking part in the "Learning and Memory" project.

GRANTS TO EDUCATIONAL INSTITUTIONS

Stockholm School of Economics, new building.

STOCKHOLM SCHOOL OF ECONOMICS

As Sweden's international connections expanded in the late 19th century, the need for university-level education in economics became increasingly apparent. The initiator and driving force for the founding of the Stockholm School of Economics was Knut Wallenberg. He realized the importance of outstanding teaching and research in economics and commerce. In 1903 he contributed an initial donation of SEK 100,000 of his own money. The Stockholm School of Economics Association was established in 1906, and on October 1, 1909, one of the world's first schools of economics opened its doors.

Classes were initially held on the premises of the Brunkeberg Hotel in central Stockholm with three professors teaching 110 students. When the Royal Swedish Telegraph Agency acquired the property 17 years later, the school was forced to find new premises. At the Chairman's suggestion, the Foundation's Board of Directors resolved to grant the Stockholm School of Economics Association SEK 1 million toward the construction of a new building on an empty lot the City of Stockholm offered on Sveavägen, north of the center. Knut Wallenberg had a particular fondness for the Stockholm School of Economics, evidenced by several grants over the years. This was underscored in the minutes of a Foundation Board meeting in 1925: "Upon the establishment of the Knut and Alice Wallenberg Foundation, Mr. K. A. Wallenberg declared null and void a previously drafted will in which he had bequeathed certain sums to the Stockholm School of Economics and the town of Saltsjöbaden for their respective development and improvement. In so doing, Mr. Wallenberg by no means intended to deprive these establishments of the support he had intended to bequeath them; rather, he desired that the Board of Directors of the Knut and Alice Wallenberg Foundation should always regard it as one of their duties to support and promote the said establishments." Prior to the school's 100-year anniversary, the Foundation awarded it SEK 180 million for new equipment and facilities, including a new, modern library.

SIGTUNA BOARDING SCHOOL

In 1925, the Foundation contributed to the establishment of Sigtunaskolan, a boarding school. Later grants were provided for school buildings and scholarships.
Knut Wallenberg found the school's ethos appealing: "to find a form of schooling within the present-day educational framework that has the greatest possible regard for each pupil's education and training in becoming a good person and a useful member of society."

OTHER GRANTS PROVIDED TO EDUCATIONAL INSTITUTIONS THROUGH THE FOUNDATION'S HISTORY

Höglandsskolan Ålsten primary school, Carlssons School, Maria Elementar, Enskilda Gymnasiet, École Française Stockholm, Biskops-Arnö Folk High School, Olofskolan, Carl Malmsten, Nyckelviksskolan, Friends of Handicraft, the Royal Swedish Naval Academy, nursing training, Tornedalen Folk High School in Övertorneå, Sámi Folk High School in Jokkmokk.

Grants have also been given for sports facilities and student unions at Swedish universities.

GRANTS TO SCIENCE CENTERS

- National Museum of Science and Technology, Stockholm
- Universeum, Gothenburg
- Visualization Center C, Norrköping
- Technichus, Härnösand
- The House of Emigrants, Växjö and Karlstad.

GRANTS AND SUPPORT FOR YOUNG RESEARCHERS

1921—THE FIRST SCHOLARSHIP PROGRAM

The Foundation awarded its first educational scholarships in 1921 and has continued giving grants ever since—partly through its own scholarship programs and partly through grants to research programs in teaching and learning. These include:

- 5 scholarships of SEK 10,000 each to the Swedish Society for Medical Research to promote the Society's activities.
- 5 scholarships each to the Royal Swedish Academy of Agriculture and the Royal Swedish Academy of Engineering Sciences.
- 2 scholarships to the Royal College of Forestry to enable studies and investigations within that institution's sphere of activity that could lead to improvements in methods or innovations for the benefit of commercial endeavors of particular significance to Sweden.
- 3 scholarships of SEK 30,000 each to the Publicists' Club for the professional improvement through studies abroad of journalists who cover economic and financial matters in the Swedish press.

THE JUBILEE DONATION—TRAVEL GRANTS THAT HAVE OPENED UP THE WORLD FOR 50 YEARS

Attending scientific conferences is an important part of scientists' professional lives. They report on their own research findings, learn about new discoveries, and make valuable contacts with colleagues from other countries.

The "Jubilee Donation" came about in 1967 to mark the Foundation's 50th anniversary. Even then, science was becoming more internationalized, and the Foundation wished to help promote contacts between scientists from Sweden and abroad. The Jubilee Donation was primarily intended to give younger scientists opportunities to travel to international conferences and symposiums.

The Jubilee Donation has continued through the years, and the Foundation has contributed a total of over SEK 220 million in travel grants under this initiative.

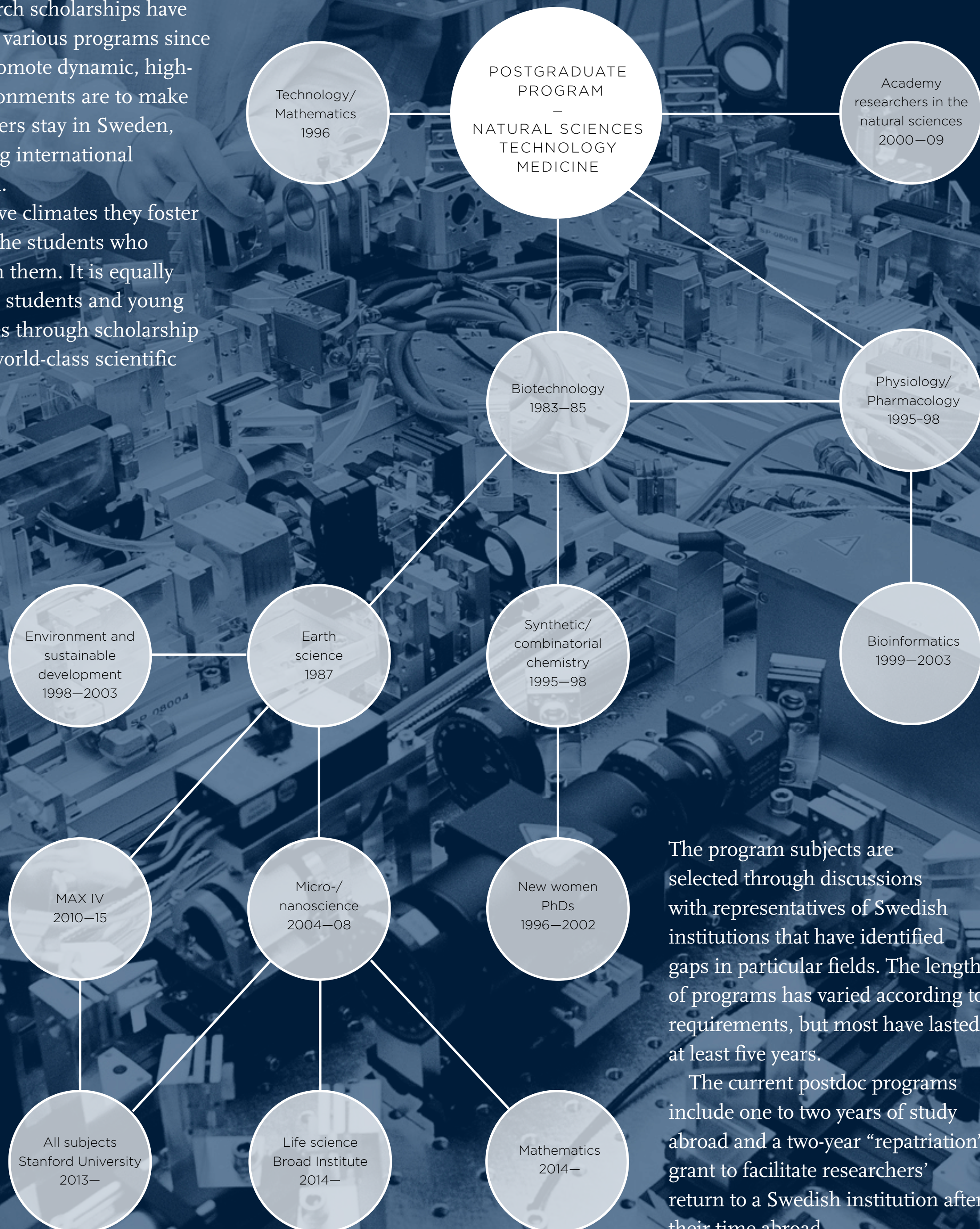
The Jubilee Donation provides opportunities for young researchers to attend conferences and symposiums.

POSTGRADUATE STUDIES IN THE NATURAL SCIENCES

SCHOLARSHIP PROGRAM FOR POSTGRADUATE STUDIES

More than 1,500 research scholarships have been awarded through various programs since 1921. Other ways to promote dynamic, high-quality learning environments are to make sure the best researchers stay in Sweden, and attract outstanding international researchers to Sweden.

The dynamic, creative climates they foster are also inspiring for the students who come into contact with them. It is equally important to give grad students and young scientists opportunities through scholarship programs to work in world-class scientific settings abroad.



The program subjects are selected through discussions with representatives of Swedish institutions that have identified gaps in particular fields. The length of programs has varied according to requirements, but most have lasted at least five years.

The current postdoc programs include one to two years of study abroad and a two-year "repatriation" grant to facilitate researchers' return to a Swedish institution after their time abroad.

POSTGRADUATE STUDIES IN THE SOCIAL SCIENCES AND HUMANITIES

Scholarships for grad students were awarded for 11 years, and nearly 200 students had an opportunity to study modern languages—an area in great need of qualified academics.

Law scholarships were granted for advanced study abroad for junior lawyers who were employed, or planned to work, in the public sector. Almost 300 scholarships were awarded during the 12 years of that program.

In conjunction with the Swedish Academy and the Royal Swedish Academy of Letters, History and Antiquities, the Academy Scholar program gave 41 researchers the opportunity to conduct their research for a five-year period.

The Stellenbosch Institute for Advanced Study (STIAS), located at the Wallenberg Research Centre on the Stellenbosch University campus, includes researchers from both theoretical and experimental disciplines. STIAS is designed to be a meeting place for young African researchers and those from Sweden and other parts of the world.

For much of his life, Peter Wallenberg had close ties to Africa. His wish was that STIAS would become a center where African and Swedish researchers could seek out new knowledge and find future discoveries and solutions to foster progress on the African continent.

1917

THE KNUT AND ALICE WALLENBERG FOUNDATION ESTABLISHED

Quaere et invenies = Seek and you shall find. Knut Wallenberg's motto at his installation in the Royal Order of the Seraphim in 1916 (Knight and Commander of His Majesty's Order).

20

MILLION KRONOR ENDOWMENT IN 1917

IS EQUIVALENT TO

593

MILLION KRONOR AT TODAY'S CURRENCY VALUE

23.6

BILLION KRONOR IN GRANTS SINCE 1917

AT TODAY'S CURRENCY VALUE, THAT'S

29.4

BILLION KRONOR

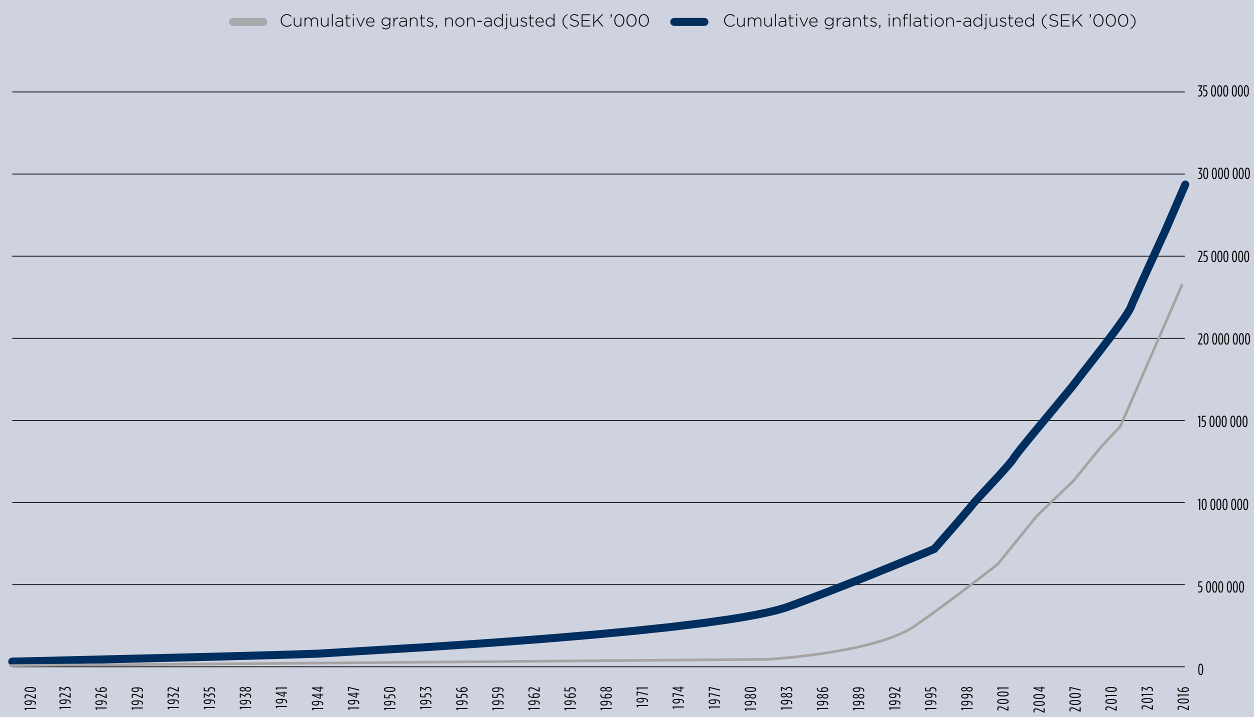
1920

FIRST GRANT TO A WOMAN

Kerstin Hesselgren, for the project "Hemgården: experimental activities among youths."

MORE THAN 6,000 GRANTS AWARDED OVER 100 YEARS

CUMULATIVE GRANTS AWARDED 1918–2016



1 of

THE
LARGEST
PRIVATE
RESEARCH
FUNDERS
IN EUROPE

1.7 BILLION	90 BILLION
GRANTS 2016	ASSETS 2016

Peter Wallenberg sitting at his desk at Atlas Copco.

THE FOUNDATION —ITS PAST, PRESENT, AND FUTURE

Sweden has many foundations set up by families. Many were established in response to more stringent wealth taxes after the World War II. But the origins of the Knut and Alice Wallenberg Foundation lie elsewhere.

Knut Wallenberg was the second son of André Oscar Wallenberg, the founder of Stockholms Enskilda Bank. Knut, who had rescued the family's bank following a crisis in the 1870s, amassed a sizable personal fortune but had no heirs. Rather than divide up the money among his many nieces and nephews, he wanted to ensure the family's continued influence over the bank while putting his money toward various projects "for the benefit of the nation," increasingly in science and education.

For the first two decades after the initial endowment in 1917, the aging Knut continued to manage the Foundation's grant awards largely on his own, with support from his younger half-brother Oscar. In addition to the Foundation's grants, the Investor and Providentia industrial holding companies were managed under the bank's auspices. The bank had been transformed, from ownership by private "lots" to a listing on the stock exchange. Nevertheless, many external shareholders were happy that the family was in charge of the bank.

After the large-scale merger in the early 1970s that formed the S-E Bank, the family and the bank began to drift apart. The old order continued to fade under the brothers Jacob and Marcus Wallenberg, and Peter Wallenberg brought new ideas. The 1980s stock-market boom after half a century of slumber reinforced its change of direction.

Peter Wallenberg had joined the Foundation's Board of Directors as a deputy member in 1971. The following year, at the age of 46, he succeeded his late brother Marc Jr as a regular member.

Thanks to its independence, the Foundation could award grants for initiatives in new fields such as computing, when funding was granted for the first mainframe computer in the mid-1960s. That would be followed by many similar individual grants, as well as a large sum for the Swedish National Supercomputing Center. Peter Wallenberg was fond of saying that "the Foundation computerized Sweden's universities."

The merger of Stockholms Enskilda Bank and Skandinaviska Banken brought an urgent need for a new principal for the Foundation's activities, which had been handled within the family's bank up to that point. The Principals' Council was formed to expand links with universities and academics—an arrangement intended partly to ward off governmental intrusion in commercial enterprises and partly to facilitate coordination between the Foundation's activities and Swedish scientific research and education.

PETER WALLENBERG

Peter Wallenberg was the great-nephew of Knut Wallenberg, the Foundation's founder. He was eager to continue his great-uncle's work.

"We aim to be an all-around source of support and contribute to important research in Sweden. Without our funding, many research projects might never have gotten off the ground, and more Swedish scientists would have had to seek opportunities abroad."

Peter Wallenberg was called "Pirre" by those closest to him, while colleagues usually addressed him as "PW." His son Peter Jr is often called "Poker."

BROTHERS JACOB AND MARCUS

Peter Wallenberg, who served as the Foundation's Chairman for 33 years, was interviewed on several occasions in 2013–14 during preparation of this commemorative book. He recalled how things were before he took over the Chairman's gavel.

"There was no doubt who had supreme command at the Foundation's meetings. When the old brothers Marcus and Jacob were there, whoever was speaking would usually be interrupted by one of them. The meetings were steered by their thought processes," he said.

Jacob kept a firm grip on the gavel right up to his death. He only became chairman after the death of Nils Vult von Steyern in 1966, who in turn had taken over when the founder Knut Wallenberg's younger half-brother Axel resigned in 1961.

"But Jacob had 39 years on the Board under his belt by the time he became Chairman. There was nothing he didn't know about what had gone before. A common refrain in his remarks went something like this: 'Well, I guess we'll say no, then! If they really want it, they'll be back.' The attention of my father 'Dodde,' on the other hand, was always divided. The phone would ring and he'd have to run and take the call, while Jacob would continue the meeting as if nothing had happened," Peter recalled.

The industrial crises of the 1970s brought a period of stagnation for the Foundation. As a consequence, dividends from the revenue-generating holdings shrank. In real terms, the amount of grants awarded declined. The total amounted to around SEK 20 million in the form of 40–50 grants per year. Both Investor and Providentia, which delivered dividends to the Foundation as well as the new bank, were struggling with high costs in their companies resulting from wage inflation in Sweden and a slump in exports.

A more active period began when Marcus Wallenberg took over the chairmanship of both holding companies in 1978. Restructurings were initiated, including sales of the Diligentia property-management company to Trygg-Hansa, and Kema Nobel to Bofors. The Foundation had its own stake in Diligentia.

When Marcus Wallenberg died in the fall of 1982, he had also been Chairman of the Foundation for a couple of years. It was then that Peter Wallenberg took over the chairman's post, where he remained for 33 years.

JACOB WALLENBERG AND MARCUS WALLENBERG

Jacob Wallenberg worked at the Foundation from 1927 to 1980, serving as its Vice Chairman 1961–66 and later Chairman 1966–80.

Jacob's brother Marcus was elected to the Board of Directors in 1938 and later succeeded him as Vice Chairman and then Chairman. Marcus' son Peter followed in his father's footsteps, becoming Chairman in 1982.

Marcus Wallenberg with his brother Jacob in the SEB boardroom.

Peter Wallenberg Jr in conversation with his father Peter Wallenberg in 2006.

THE HEART OF THE WALLENBERG LEGACY

In 1989, the Foundation's assets showed more than an elevenfold increase in book value compared with a decade before, and the grants had increased nearly fivefold in the same period. But the ever-increasing presence of Wallenberg grants in Swedish research was hardly mentioned outside the Foundation.

"I didn't want to beat the drum about the internal work of the Foundation," Peter Wallenberg said. "Not because it was some shady operation, but because to me, the Foundation had come to stand out as the heart of the Wallenberg legacy. It wasn't just the aim of the whole enterprise across generations, it was also the most vulnerable part of the sphere. I had seen the ways politicians maneuvered to grab power—not least the various efforts by the Swedish Trade Union Confederation, together with the employee funds that received money from taxes on corporate profits. All it would take was a few strokes of the political pen to dramatically change the conditions we operated in. Best to try to ward off critical attacks in the media by never going out and beating your chest. And above all, we would never get involved in science policy."

There was no doubt Peter Wallenberg was proud of what his family had achieved.

He often returned to that unwieldy expression, "beneficial to Sweden," which his great-uncle Knut had used in the bylaws.

"I understood that the Foundation's assets were not for the use of scientists in other parts of the world, and not for the companies in the Wallenberg sphere, either. They had been earned for the long-term development of the Swedish nation," he explained. "I increasingly came to admire Knut's vision, how he started by giving money to construct the actual buildings for research and education. Then it came time to fill the buildings with modern equipment. Then came the museums. Following this, my own contribution to the long-term progress 'for the nation's benefit' Knut initiated was to focus on world-class Swedish research. It was when I found Göran Sandberg, then president of Umeå University—a northern Swede with his feet on the ground—that the pieces fell into place. I'm especially proud of the contributions we've made together."

GRANT POLICY

"I increasingly came to admire Knut's vision, how he started by giving money to construct the actual buildings for research and education. Then it came time to fill the buildings with modern equipment. Then came the museums. Following this, my own contribution to the long-term progress 'for the nation's benefit' that Knut had initiated was to focus on world-class Swedish research," Peter Wallenberg said.

Efforts to focus on world-class research were launched by Executive Director Jan S. Nilsson, who took the view that Swedish research and Swedish scientists should be involved in dynamic international research environments in places including the U.S. Then the "Academy Researcher" program for young scientists with high potential was launched in conjunction with the Royal Swedish Academy of Sciences and ran for 10 years.

Prof. Erna Möller continued these efforts during her term as Executive Director, launching the Wallenberg Scholars program, which gives senior researchers the opportunity to conduct unfettered research for five years. Grants for equipment were concentrated on projects with great scientific merit that already had personnel and operational support from other sources, and on equipment for national scientific facilities.

A LONG-TERM CYCLE

Shortly before Peter Wallenberg's passing in 2015, his son Peter Wallenberg Jr took over the Foundation's chairmanship.

"Previously, we hadn't focused on communicating the inner workings of our Foundations and their investments in Swedish science. Up to now, we've paid more attention to the work we do as active shareholders in the companies we have holdings in. That's generated significant increases in assets and returns, but we haven't talked as much about what the Foundation has used that money for," Peter Jr said.

"The purpose of active ownership and dividends is simply to be able to distribute as much as possible to Swedish research and education," he continued. "It's a cycle. The money we distribute goes to various research projects, and the money we retain in the Foundations is invested in new companies in long-term, active investments, which then enables even greater research grants in the future. The measure of our success is quite simply the standing of Swedish science in comparison with the rest of the world."

For the first time in the Wallenberg Foundations' 100-year history, they are now at the center of the Wallenberg family's story. Since succeeding his father as Chairman, Peter Wallenberg Jr has had primary responsibility for the grant program, while his brother Jacob and cousin Marcus are in charge of shareholder management of Investor and FAM, respectively. The three cousins share offices in the Foundations' headquarters.

"Together with a few other family members on the boards, we represent the proud fifth generation, endeavoring to implement the founders' vision. My father shouldered this responsibility on his own. Having more of us to share the various roles gives us greater ability to get things done. Add to that the sixth generation, who have just been voted in as deputy members in nine of the other Wallenberg Foundations," he said.

Peter Wallenberg Jr explained how he himself had begun working at the Foundation and why he wants to make the Wallenberg Foundations more visible than his father originally wanted.

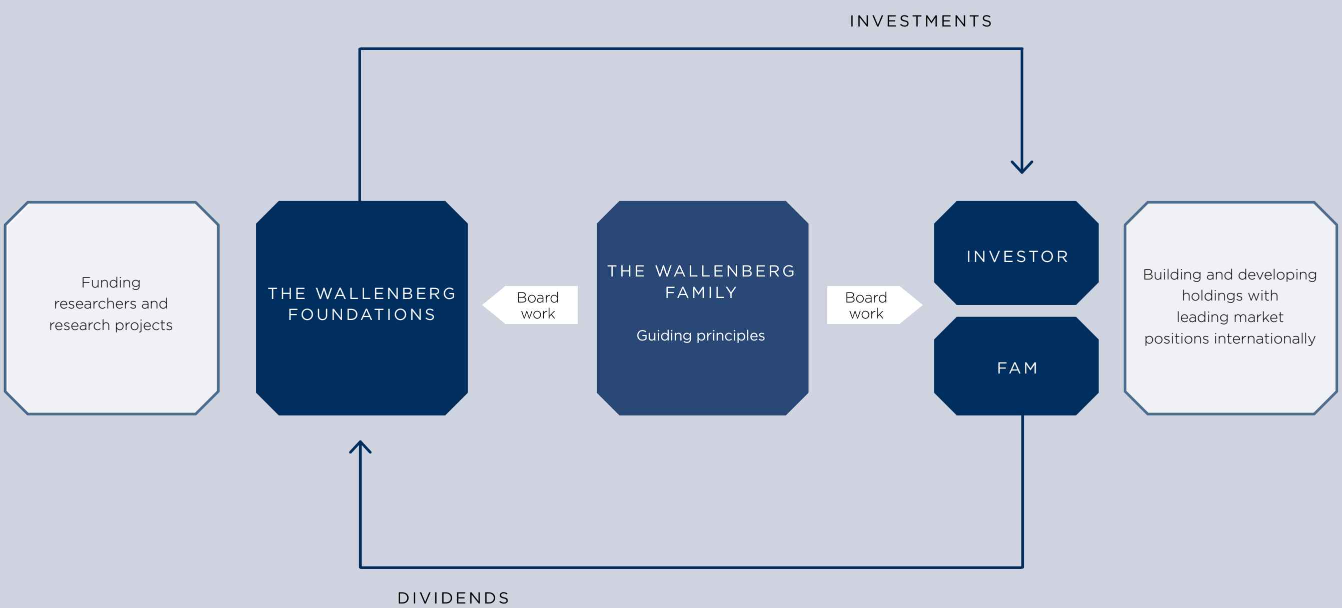
"The three of us in charge of the Foundations today got started early. Both my father Peter and grandfather Marcus regarded it as good training. Grants were awarded more informally back then, and it wasn't easy to follow the discussions. But we gradually learned more and more," he recalled.

THE WALLENBERG CYCLE

The companies in which the Wallenberg Foundations, Investor, and FAM own stakes form the backbone of the Wallenberg family's business interests. Long-term work with these international corporations—and their successes—enable the Foundations to award around SEK 2 billion in grants to Swedish research and education each year.

The wholly owned holding company FAM AB, which manages some of the assets, is also part of the cycle. Most of the assets are managed by Investor, an industrial holding company partly owned by the Wallenberg Foundations and listed on the stock market.

During 2016 alone, the Wallenberg Foundations awarded grants totaling SEK 2.1 billion.



Chairman of the Board Peter Wallenberg discussing with Executive Director Erna Möller in 2007.

INCREASING GRANTS PROMPTS REORGANIZATION

"Because of the rapid growth of capital and the funds distributed in the 1990s, we started to talk about how to move the Foundations along—my father was already a driving force there. Johan Stålhand became the CEO of the new holding company, while Ingrid Sundström was the lynchpin. Even the attitude toward shareholding changed," Peter Wallenberg Jr recalled.

"Those of us in the fifth generation wanted to come up with a more mature, structured ownership concept, because we were dealing with increasingly large assets. The Foundations were taking on an ever greater role in Swedish research, so we had to rethink things. One of the things we did was to bring in Ulla Litzén and Pia Rudengren to build up a more professional management organization," he added. "At that time, I was in charge of the Grand Hôtel in Stockholm, but the family assigned me to take a closer look at the ways we worked. We set up WCap, a company that became the present-day FAM AB. In the process, I resigned as the Grand Hôtel's CEO. The biggest change was in our role as shareholder: we focused on keeping our capital structure in good order and being a more active shareholder."

When Prof. Erna Möller, who had previously been a researcher at Karolinska Institutet, was due to retire as Executive Director, the search for her successor began.

"We were looking for someone who would fit into the new organization, with contacts and experience from Swedish academia, ideally a scientist. After several years of searching, we were delighted to recruit Göran Sandberg. He was the president of Umeå University, and had spent much of his previous scientific career abroad."

Peter Wallenberg Sr ("PW") stood out as an odd combination of an internationalist and an old-fashioned patriot—something the Irishman Peter Sutherland, his friend and right-hand man on the Board of Directors, liked to point out. Göran Sandberg gives a similar impression.

"PW had different political views from me, but he had sharp intuition and took the long view when he made up his mind. Everything the Foundation funded had to be the best Sweden could produce. Accepting a project that was judged to be substandard just because it would benefit the Wallenberg sphere—that could never happen. The old fellow gave anybody a rap on the knuckles if they even hinted in that direction."

EXECUTIVE DIRECTOR

Until 1980, the Foundation's regular operations were led by a secretary/managing director. In 1980, the Board of Directors decided that instead of a managing director, it would be better to have a senior scientist attached to the Foundation as an Executive Director on the Board.

Prof. Gunnar Hoppe, former President of Stockholm University, was appointed Executive Director in 1981.

He was succeeded by Prof. Jan S. Nilsson, President of the University of Gothenburg.

From 2002 to 2009, Prof. Erna Möller was Executive Director of the Foundation. She is Professor Emerita of Clinical Immunology at Karolinska Institutet.

Since 2010, Göran Sandberg, Professor of Plant Physiology, has served as the Foundation's Executive Director.

INDIVIDUAL GRANTS TO OUTSTANDING SCIENTISTS

The concept behind the Wallenberg Scholars program, which awards grants to individual senior researchers, was developed by Erna Möller during her term as Executive Director, in close collaboration with the Foundation's Chairman and Vice Chairman.

EVALUATING EXCELLENCE

In 2016, the Knut and Alice Wallenberg Foundation was one of the largest private funders of scientific research in Europe, after the Wellcome Trust, based in the UK.

"The Wellcome Trust gives out three times as much money as we do, but in relative terms the Wallenberg Foundations mean more to Sweden than the Wellcome Trust does to the UK," Peter Wallenberg explained. "After PW, our legacy is clear. We don't even attempt to influence the Swedish government's investment policy—that's for politicians to decide. We focus on distributing our funds in the best way possible."

Scientific research is inherently international. International links are vital for stimulating the exchange of ideas and methods, to say nothing of the valuable networks that lead to further progress.

"Regardless of whether it's Swedish scientists returning from abroad or new people coming here, they help make Swedish science more international," Göran Sandberg said. "I had total support on this point from my previous Chairman as well. He recognized the value of what he used to refer to as networking and 'cross-fertilization.'"

Göran Sandberg can testify to Peter Wallenberg Sr's deep commitment to the Foundation.

"PW had done his research on Knut and his intentions. He was always talking about 'the Foundation,' by which he meant the Knut and Alice Wallenberg Foundation. In PW's world, Knut was the one who had shown the way. I'm absolutely convinced PW read all the documents that were written. So there were no shortcuts in discussions," he said.

Another matter Peter Wallenberg was very particular about was evaluation and assessment. The Foundation uses a comprehensive evaluation process to make sure it prioritizes research that is deemed to be of the highest international standard.

"Sweden has limited resources and spreads them thinly. We're eager to help coordinate and concentrate investments."
— Peter Wallenberg Jr

"The evaluation process is a cornerstone of the Foundation's support for Swedish research excellence. Peter Wallenberg was very eager to make sure applications were reviewed by eminent, independent experts of international standing. We set up a Scientific Committee with senior Swedish researchers, many of whom have sat on Nobel committees, and established a comprehensive peer review process," Sandberg explained. "Today, we have 370 international reviewers who help us read proposals. The basic principle is very simple. Applying for a Wallenberg grant is not about convincing 'Poker,' me, or anybody else about how great you are; it's about submitting an application so good that six to eight reviewers will say it's of the highest international quality. That's why the scientific world attaches high status to our grants."

After a while, though, a few issues arose with the peer review system. Even leading scientists are conservative. They like to promote research they understand and can often reject research and possible breakthroughs that are so revolutionary nobody yet realizes their significance. So there was a clear risk that research supported by the Wallenberg Foundations might miss out on crucial new discoveries in the future.

"We talked about this—many times. You like to think the scientific community is open and receptive to new ideas, but it's conservative," Sandberg said. "To counteract that conservatism, we introduced two programs for individual grants: Wallenberg Scholars and Wallenberg Academy Fellows. We evaluate applications for them—in collaboration with the royal Swedish scientific academies—using the same principles, but the difference is that once we've selected the researchers, they can do what they want with the money. It's a unique form of grant. We don't require any monitoring or reports, but of course we have control of the budget. We've gained a reputation for giving researchers total freedom."

It was also important to Peter Wallenberg to follow the discourse in Swedish science and understand what scientists want. The Foundation's Scientific Committee, established in 1972 (the year after Peter Wallenberg Sr was elected to the Board of Directors), fulfills an important function in this regard. The Committee is made up of representatives of Sweden's major research universities and its five royal academies of science.

Peter Wallenberg and Göran Sandberg at the Foundation's Board meeting in 2013.

RESEARCH AND EDUCATION

Göran Sandberg addressed the distinction between research and education: "The primary role of universities is to educate highly competent people, who go on to achieve great things in business and the public sector. We tend to see universities as innovation generators, but then we forget that it's these skilled people who are the most important product. The Foundation's contribution is to make sure the best scientists stay in Sweden so we get that dynamic, creative environment that at least some students can benefit from."

But then he cautioned, "It's naïve to think Swedish corporations are solely dependent on scientists from Swedish universities. I do think, though, they are dependent on the quality of the engineers, mathematicians, and other academics Swedish universities produce—not least so they can continue to have a significant presence in Sweden for the foreseeable future."

One social challenge he anticipates is the increasing polarization of the education system. While there have never been as many people with degrees as there are today, there are also people who can barely read and write.

"We're still producing a lot of highly competent people," he said. "But it's a challenge to include everybody, and integrate all the newcomers. If you look at where our pool of creativity is, it started when Sweden expanded the system so kids from outside the big cities could get an education. Then the number of women at universities increased so that they're now in the majority. Where will we find young creative people in the future? I hope part of the answer is in the suburbs and among new immigrants to Sweden."

Sandberg added: "It's a huge challenge, but also an enormous opportunity. If Sweden didn't have this influx of talent today, over time we'd have great difficulties finding enough skilled employees. We're not short of talent, but many of the people coming here have tremendous drive and creativity."

To support this aim and counteract social exclusion among new arrivals in Sweden, the three largest Wallenberg Foundations initiated a 10-year program entitled "Education to Improve Integration" in 2016. The funding includes grants for summer schools, academic internships, and intensive classes in Swedish as a Foreign Language. The program is being run in conjunction with the Royal Swedish Academy of Sciences, the Royal Swedish Academy of Engineering Sciences, the Swedish Academy, and other nonprofit organizations.

Over the years, the bulk of the Foundation's grants have gone toward research in the natural sciences and medicine.

"Today, we're probably too technocratic and rely too heavily on the natural sciences and medicine, but I only need to point out society's sudden need for researchers who previously specialized in subjects like Islamic culture, who have now become a huge asset," Sandberg noted. "More of the Foundation's money has to go toward the humanities—it's important for ethics and society to keep up with technological progress."

EXCELLENT RESEARCH

Peter Wallenberg emphasized that support should go to the very best research.

"We want to support excellent research in Sweden with outstanding scientific potential according to national and international standards," Peter Wallenberg stated on several occasions.

"Swedish research is successful, but we cannot rest on our laurels. If we are going to compete internationally, we have to limit our scope and invest more in cutting-edge research and closer collaboration," said Göran Sandberg.

"We want to contribute to important research in Sweden. Without our funding, many research projects might never have gotten off the ground, and more Swedish scientists would have had to seek opportunities abroad."
—Peter Wallenberg, Chairman of the Foundation 1982—2015

"The Foundation will strive to be a research funder that makes a difference in the scientific world, now and in the future."
—Peter Wallenberg Jr, current Chairman of the Foundation

RESEARCH AND PUBLIC POLICY

The Foundation has played an active role in shaping Sweden's university and research communities ever since its earliest days.

"Whether we like it or not, the Foundation has become an integral part of Swedish research policy due to our status as one of Europe's largest private research and education funders—and in a relatively small country like Sweden. We've gone from merely communicating with universities to involvement in dialogue with policymakers in Sweden and at the EU level. After all, Sweden is an international player in research too," Göran Sandberg reasoned.

"We like to collaborate with public-sector funding bodies if we can make an impact on Swedish research and education. We've done a few joint projects like that. It happens through dialogue," Peter Wallenberg Jr added. "The circumstances determine the requirements. In some cases, policymakers realize they can't achieve the whole project themselves, and because we've always recognized the importance of cooperation among policymakers, academia, and industry, we've been able to provide grants to programs like SciLifeLab and Wallenberg Autonomous Systems and Software Program (WASP)."

THE NEXT 100 YEARS

In its first century, the Foundation has provided the scientific community with nearly SEK 24 billion in grants.

The Investment Committee does an important job: taking responsibility for ensuring that the Foundation's assets continue to grow and generate the returns needed to continue awarding grants at a consistently high level.

"Our duty to make sure the Foundation's assets are managed and built up to achieve consistent growth entails a great deal of responsibility, especially in view of the changes the Foundation has undergone throughout these 100 years," summarized Michael Treschow, Chairman of the Investment Committee.

The current investment policy, which mainly covers support for projects of a high scientific standard and grants to outstanding individuals, will be refined. In the longer term, the Foundation will build up its own "virtual faculty" through its Wallenberg Scholars and Wallenberg Academy Fellows programs, including Sweden's best scientists at all stages of their careers.

As Peter Wallenberg Jr summarized: "The Foundation will strive to be a research funder that makes a difference in the scientific world, now and in the future." ∎

Executive Director Göran Sandberg and current Chairman Peter Wallenberg Jr in the Foundation's offices.

Knut Wallenberg.

Alice Wallenberg.

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